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Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe



Attitudes and perceptions of wood energy technologies in the Great Lakes region, USA

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ARTICLE INFO

Keywords: Wood energy Public perceptions Social acceptability Bioenergy

ABSTRACT

This paper explores social acceptance of different wood-based energy applications in the Great Lakes region in the Upper Midwest, USA. Specifically, the paper examines attitudes and perceptions towards residential wood burning, commercial-scale wood boilers for heat, combined heat and power (CHP) facilities, and industrial power generation in Michigan. In 2021, we conducted a state-wide survey (n = 207) and 30 semi-structured interviews with individuals representing different stakeholder perspectives, including regulatory agencies, biomass industry leaders, non-governmental organizations and scientists who have shaped biomass debates, forest products workers, and Michigan residents. Results suggest that the depth of an individual's knowledge about different types of wood energy applications generally led to more positive attitudes, particularly for smaller-scale uses of wood for heat. Despite perceived environmental, economic, and human health risks of using wood for different energy applications, across all stakeholder groups, 70% of respondents perceived environmental benefits, 61% perceived economic benefits, and 57% perceived health benefits. Changing economic and environmental conditions in different parts of the state contributed to people's attitudes toward different forms of wood energy and their perceptions of associated risks and benefits. A key recommendation of this study is that policy-makers and energy developers seek to understand the complex factors that influence social acceptance when planning for the adoption of new types of wood-based bioenergy technologies.

1. Introduction

As the world transitions to a clean energy economy, biofuels will play an increasingly important role in both regional and global energy portfolios [1]. Compared with European counterparts, the US has been relatively slow to adopt advanced wood-burning combustion technologies [2]. Biomass provides about 10–14% of the world's energy but only 4-5% in the US [3,4]. Northern Europe shares many similarities with forested regions of the northern US, and research demonstrates a similar potential for the diffusion of forest biorefineries in both regions [5]. However, wood-based energy technologies in Nordic countries are more developed and adoption of these technologies is more widespread [6]. This study examines the socioecological dimensions of wood-based bioenergy systems in the northern Great Lakes region of the US, where different kinds of wood-based energy systems may become more common in areas with high or volatile energy prices and seasonally cold

weather. Specifically, we examined how people's level of knowledge about different types of wood-burning energy technologies influenced perceptions of associated risks and benefits, and influenced social acceptability of wood energy.

According to Upham et al., the idea of social acceptance has become one of the most important social science concepts in energy research because of its implications for technological adoption [7]. Social acceptance of new technologies tends to contribute to more secure investment while public resistance can create unfavorable political conditions and contributes to uncertainty. Social uncertainty, or lack of social acceptance, has historically deterred investment and contributed to unstable markets [8]. One of the biggest drivers of social acceptance of a particular energy technology is how people perceive associated risks and benefits [9,10]. This research aims to contribute to the theoretical development of the concept of social acceptability by examining perceptions of risks and benefits associated with wood-based bioenergy

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technologies while also providing practical knowledge about attitudes and perceptions towards wood energy in Michigan.

A growing body of scholarship has begun to examine the social acceptability of different types of biofuels, including ethanol [11,12] and advanced lignocellulosic feedstocks such as switchgrass [13]. Like these other forms of biofuel, development of different types of wood-based energy applications has been constrained by social and political challenges that are specific to particular landscapes and communities. Yet much of the literature on the social dimensions of woody biomass energy has focused on challenges associated with physical supply. According to prior research, social acceptability tends to be defined by landowners' willingness to harvest wood for fuel and therefore landowner perceptions influence availability of supply [14,15a,b, 16a,b,17a,b]. Other stakeholder perceptions (non-landowners) have affected supply for wood energy applications in other ways as well. Leaders within the forest products industry have expressed concern about the value of wood for energy as compared with other forest products and uses, and how demand for low-grade forest residues might interfere with traditional forest product markets such as pulp and paper [18a,b].

This study combines quantitative survey data and information from qualitative semi-structured interviews to examine how knowledge about different types of wood-burning energy technologies has shaped people's perceptions of risks and benefits. Conflicting perceptions about different kinds of risks associated with wood energy have proven to be a barrier to its development since engineers began developing advanced wood-burning energy technologies in the 1970s and 1980s. Our aim with this research is to illustrate how public acceptance of different forms of wood energy is affected by people's understandings of these technologies. We hypothesize that people's ideas about risks and benefits associated with wood energy are complex and shaped by particular economic, geographical, political and cultural factors.

2. Methods

2.1. Michigan case study

The energy crises of the 1970s inspired a wave of innovation in wood-burning energy technologies in Michigan. Because of the state's history as a hub for logging, manufacturing, and wood products industries, Michigan was well-positioned to host the development of new wood-based bioenergy technologies. Companies such as Messersmith Manufacturing, Inc. in Bark River, MI began manufacturing new kinds of wood boilers that could be used at larger scales. Others such as Morbark, LLC in Winn, MI began creating new kinds of chipping technology that facilitated the processing of forest residues for new energy applications. These new applications included more efficient EPA-rated residential woodstoves and pellet stoves, outdoor wood boilers, commercial-scale boiler systems, and woody biomass power stations.

The adoption of these wood-burning energy technologies across the state of Michigan in the 1980s and 1990s resulted in a wide range of responses depending on specific economic, political and environmental characteristics of communities where those technologies were introduced. This paper builds upon work in the region that illustrates how the development of wood-based energy technologies has sparked a range of ideas about different approaches to forest management, perceptions of the state's forest history, and the future of Michigan's forests [15a,b,16a,b,17a,b]. Specifically, Eaton notes that one of the barriers to biomass development in Michigan is collective "sociotechnical imaginaries" that remember the consequences of the cut-over era of the 1800s when the northern part of the state was nearly completely clearcut. He writes "These evoked memories were often treated as a harbinger of what may come if too many bioenergy plants were sited. ([15a,b] 246)."

Like Eaton's [15a,b] work, prior research on perceptions of wood-based power production in Wisconsin suggests that people draw on lived experiences, remembered histories, and community discourse

about forests in their advocacy or opposition to bioenergy projects [18a, b]. This research builds upon these findings to examine the role that knowledge and geographic factors play in shaping perceptions of risks and benefits associated with different scales of wood-based bioenergy technologies.

2.2. Data collection

To capture the complexity of people's attitudes and perceptions and to balance out methodological limitations of qualitative and quantitative approaches, this study employed a mixed methods approach. We used a triangulation design, where qualitative and quantitative data collection, analysis, and results were merged to compare, interrelate, and validate results [19]. This approach has become standard practice in research on social acceptance of energy technologies [7]. Our qualitative interview and quantitative survey data were collected in parallel, with questions chosen to validate and interrelate responses between the two instruments.

To examine the spatial distribution of responses, we designed and administered a statewide mixed-mode survey that was linked to a GIS database. The survey included an interactive mapping component and thus participants had to be willing to take the survey online. The survey included questions about respondents' perceptions of environmental, economic, and health risks and benefits associated with residential and commercial heating applications, as well as industrial-scale power generation. The survey also recorded demographic information about respondents and the location of their primary residence in relation to commercial-scale wood energy facilities throughout the state of Michigan. Participants were given a series of distance ranges from Michigan's seven biomass power station locations (shown on a map) ranging from 1 to more than 50 miles. We also collected a response for which county a person was from. Individual locations were summarized by county to maintain anonymity of survey respondents.

Because we wanted to compare responses of those who lived near existing biomass energy facilities to those further away, we sent the survey out to general state-wide groups and then focused on the seven counties that had biomass power stations. Focal counties with biomass power plants included Alcona, Baraga, Crawford, Genesee, Missaukee, Montmorency, and Wexford. In addition to hosting a biomass power station, these seven focal counties also had relatively high levels of residential wood heating and several commercial-scale boiler systems. The survey link was first sent out through researchers' state-wide networks and through Michigan-based social media sites representing a wide range of interests and perspectives. We sent postcards to 500 randomly sampled points in the state, with QR codes and survey links. The primary author purchased property tax parcel data for the entire state of Michigan which includes name and address of all property owners. A simple random sample was performed in ArcGIS, dropping points that were then associated with parcels. We then supplemented this random sample by purposively sampling via Michigan State University Extension agents in focal counties with biomass plants, and posted to all civic group social media pages we could find in those seven counties. We also sent online focused recruitment e-mails to people in counties that had a wood-burning power station, so we could compare those with proximity to wood-based electricity generation and those further away, based on the hypothesis that proximity to larger facilities may have led to familiarity and/or knowledge.

In addition to the survey, we conducted 30 semi-structured interviews with people who represented different interests. Interview questions were designed to complement the survey and asked participants in-depth questions about their experiences, knowledge, and perceptions of risks and benefits associated with different kinds of wood energy technologies. We chose a broad range of people to interview in an effort to account for multiple perspectives and ideas about biomass energy. Interviewees came from each of the following sectors: 1. state, federal, or tribal regulatory agencies; 2. the forest products industry

(loggers, truckers, foresters, or plant operators); 3. non-governmental organizations; 4. residents of places that hosted a range of wood energy applications; 5. scientists or academics from different disciplines related to wood energy. We borrowed the format and reporting system for interview data from Hughes et al. [20]. To protect the identities of research interviews, their comments were coded by group and will be reported by three letter code and a number (Table 1).

Before each interview was conducted, participants provided verbal consent to participate in the study. We began conducting the interviews in summer 2019. At that time, some interviews were conducted in person; others were conducted online using Zoom recording software. During the global pandemic of 2020–2021, all interviews were conducted via Zoom. All transcripts and recordings of interviews are secured on researchers' password-protected computers. The involvement of human subjects in this study was initially approved by the Institutional Review Board of [removed for peer review], project number HS19-1045 in May 2019, with modifications approved in February 2020.

2.3. Data analysis

Survey data was cleaned and analyzed in the R Statistical Software Program (CRAN, 2022). We ran chi-square tests to compare categorical variables, with a significance threshold of p < 0.05. We grouped our focal counties (n = 7) with adjacent counties (n = 15) to examine potential differences in survey response based on proximity to biomass power stations. This grouping ensured that respondents would be within 100 miles of a potential facility if classified as 'proximal' and less than 100 miles if classified as 'distant.' We also created a knowledge index variable by summing the responses to Likert-scale knowledge questions for five sub-item questions: "Please describe your level of knowledge about the following: 1) How agricultural and forest products are used to produce energy, 2) wood-based electricity generation, 3) wood-based heat production, 4) combined heat and power, 5) wood pellet stoves, furnaces, and grills. For each sub-item, a "1" indicated they didn't know anything and a "5" indicated they knew a great deal. We summed the responses for all five sub-items, classifying respondents into five levels from most to least knowledge. For our qualitative data, we recorded and transcribed the semi-structured interviews, then coded the transcripts to examine themes and patterns. Coding was checked among the group of co-authors, three of which are social scientists, for consistency and reliability of thematic groupings and supporting quotes.

Interviews were transcribed and analyzed by focusing on particular themes. The interview protocol (located in the Annex) contained four categories of questions: 1. questions asking demographic and geographical information about the interviewees; 2. questions about perceptions of the risks and benefits associated with different scales of wood energy; 3. questions about decision-making processes involved in specific biomass projects; 4. questions about broader issues related to biomass development. Because this study focused on perceptions of risks

Table 1 Interviewees by stakeholder group.

Category	Explanation	Number of interviewees	Abbreviation
Agencies	Employees of federal, state, or tribal government agencies	9	GOV
Industry	Employees of forest products industries, including loggers, mill and plant operators, etc.	7	IND
NGO	Employee of environmental, health, or land use NGO	5	NGO
Residents	Individuals who live varying distances away from biomass energy	5	RES
Scientists	Academics who research or teach subjects related to wood energy	4	SCI

and benefits related to wood-based bioenergy, we focused the analysis of interviews on responses to the second set of questions. Specifically, we coded interview data on three main themes: perceptions of environmental risks and benefits, perceptions of economic risks and benefits, and perceptions of health risks and benefits. The interview data allowed us to examine perceptions of these risks and benefits for different scales of wood energy applications in greater detail than survey results alone would have provided.

3. Results

3.1. Survey and interview respondents

To assess the responses to the survey and ideas from the interviews, it is important to understand the general characteristics of research participants. The majority of the 207 survey respondents and 30 interviewees lived in rural or suburban parts of the state. Eighty-one percent of the survey respondents considered wood to be a renewable resource, and 88% agreed or strongly agreed that having renewable energy nationwide was important. Because our survey was distributed through researchers' professional networks in academia and through the state wood energy team, respondents generally had more knowledge about different forms of woody biomass than one might expect from the average citizen. Specifically, 69% of respondents reported that they knew a moderate to a great deal about the use of agricultural and forest products to produce energy (Table 2). Fifty-three percent felt similarly confident about their knowledge of the use of wood for electricity production, 82% about thermal applications, 53% about Combined Heat and Power (CHP) systems, and 75% about domestic applications such as wood pellet stoves, furnaces, and grills. This finding suggests that people are more familiar with traditional wood heaters like woodstoves in the home and less familiar with the use of wood for non-residential applications, especially those that involve power generation.

3.2. Role of knowledge in shaping attitudes and perceptions of wood energy applications

Survey results and transcriptions of interviews suggests that while the majority of stakeholders support wood energy at the residential scale, for community or commercial heating, or for industrial power generation, they were most supportive of smaller-scale applications and for using wood primarily for thermal applications. When asked how they felt about different scales and applications of wood energy, 68% or respondents indicated that they would feel very or somewhat positive about their neighbors installing a wood stove or wood boiler to heat their home, 62% would be very or somewhat positive about a local school, hospital, sawmill, or other institution installing a wood boiler to heat their facilities, and 53% would be very or somewhat positive about a wood-fired electrical power station in their area. These responses were statistically significant when compared to our knowledge index (Table 2); the more knowledge a respondent had, the more positively they felt about the use of these technologies. Those who responded to the open-ended questions in the survey noted that the most controversy surrounding biomass energy was when power plants added tires and creosote rail ties to the fuel mix.

The results of the survey were consistent with interview data, which also indicated that the more knowledge a respondent had about a particular type of wood-energy technology, the more likely they were to have a positive attitude toward that technology, particularly towards smaller-scale thermal applications. The knowledge index ranged from 0 to 25 based on the items included, with a mean knowledge of 15.5, a median of 16. 15% of respondents had a knowledge index less than 10, 40% between 11 and 20, and 45% greater than 21. The higher the index, the more overall knowledge the respondent had. The index was statistically significantly related to attitudes toward mid-scale wood-burning energy technologies (e.g., school, mill or hospital) and large-scale

Table 2Descriptive statistics for knowledge, concern, and attitude questions Question/Item.

Question/Item	Response Level - % of sample					
	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat Disagree	Disagree
Having renewable energy nationwide is important to me	64	25	6	2	<1	<1
Having renewable energy in my community or region is important to me	61	26	8	2	<1	<1
Using renewable energy in my home or for my energy needs is important to me	57	24	11	5	0	2
Renewable energy is good for the environment	62	24	8	5	<1	<1
Renewable energy is good for the economy	53	24	10	9	2	1
	I don't know	I know a	I know a moderate	I know a lot	I know a great	
	anything	little	amount		deal	
Level of knowledge: How agricultural and forest products are used to produce energy	4	27	34	25	11	
Level of knowledge: Wood-based electricity	17	31	31	12	10	
Level of knowledge: Wood-based heat production	15	16	28	28	27	
Level of knowledge: Combined heat and power	17	31	30	15	8	
Level of knowledge: Wood pellet stoves, furnaces, and grills	34	22	27	28	20	
	No concern	Neutral	A little concern	Some concern	Great concern	
Level of concern: environmental risks for wood-based energy generation	15	7	16	34	28	
Level of concern: economic risks for wood-based energy generation	19	30	16	27	7	
Level of concern: health risks for wood-based energy	16	14	19	33	19	
	No benefit	A little benefit	Neutral	Some benefit	Great benefit	
Benefits of wood-based energy to society: environmental	4	11	16	42	27	
Benefits of wood-based energy to society: economic	5	7	27	44	17	
Benefits of wood-based energy to society: health	6	11	26	39	19	

technologies like power stations (Table 3). For example, the more knowledge a person had about residential wood heating systems, commercial wood boilers, and woody biomass power generation, the more positive their attitudes were about those technologies. Those relationships were all statistically significant (Table 3).

Table 3Statistical comparisons of knowledge index with attitudes.

Attitude	Chi- squared statistic	Degrees of freedom	P-value (<0.05)
Benefits to society: economic	43.04	16	<0.01*
Benefits to society: health	26.296	16	0.05
How would you feel if your neighbor installed wood-burning energy technologies	31.043	16	0.01329
How would you feel if a school, hospital, sawmill, or other organization near you installed a wood-burning boiler?	31.285	16	0.01237
How would you feel if a new wood- burning electrical power station were built near you?	39.102	16	0.001051
Having renewable energy nationwide is important to me	16.691	20	0.673
Having renewable energy in my community is important to me	18.151	20	0.5775
Having renewable energy in my home is important to me	17.627	16	0.3462
Renewable energy is good for the environment	16.031	20	0.7147
Renewable energy is good for the economy	12.638	20	0.8924
Concern about wood-based energy: environmental	20.071	16	0.217
Concern about wood-based energy: economic	12.506	16	0.7085
Concern about wood-based energy: health	11.967	16	0.7462
Benefits to society: environmental	22.866	16	0.1174

^{*}Bold items indicate statistical significance at the p < 0.05 threshold.

3.3. Perceptions of environmental risks and benefits

Although the survey and interviews indicated general support for wood energy, stakeholders perceived the risks and benefits associated with burning wood in different ways (Table 2). Understanding how these different perceptions of risks and benefits have influenced broader debates about bioenergy is critical for ensuring public acceptance of wood-burning technologies. In terms of responses to the survey, environmental risks such as threats to forest health appeared to be the biggest area of perceived risk as opposed to economic or health risks. Specifically, 62% of respondents reported some or great concern about the environmental risks involved in the production of woody biomass energy systems (Table 2). One retired extension agent noted: "There's no way that our forests could totally displace the heating and cooling requirement of all the buildings in the state of Michigan. Our forest isn't large enough; it doesn't grow fast enough, there are some biological and some ecological limits" (SCI1). Like other interviewees, they noted the importance or evaluating projects on a smaller geographical basis because of the great ecological variability across the state.

Both survey and interview results indicated that one of the biggest environmental issues associated with wood energy was whether woody biomass an appropriate way to mitigate climate change. One younger forest scientist argued that carbon emissions produced by wood-burning technologies could be offset by the amount of new growth Michigan forests produce each year. They estimated the state's forests grew 8.7 or 8.99 million cords each year and "as long as we're keeping up on regrowing what we've clear-cutthat number really does offset the amount of emissions" (SCI4). Another respondent noted that compared to the state's historical dependence on coal, wood was was a far cleaner source of energy and much better for human health (GOV6). Others were less confident about the ability of Michigan's forests to meet the state's clean energy needs without causing long-term ecological damage and loss of biodiversity.

Survey and interview responses echoed long-standing academic debates about whether or not woody biomass is a carbon neutral form of energy. While many in or related to the forest products industry felt that wood could be considered a carbon neutral energy source with proper forest management, some environmentalists did not view wood energy as a long-term solution to reducing fossil fuel combustion and moving to a clean energy economy. In other cases, however, ideas about the carbon neutrality of wood did not fall along clear lines. One environmental advocate noted that "biomass is renewable energy, but it doesn't mean that there's zero greenhouse gas emissions" NGO2. Others noted that "trees do a lot of things: trees fix nitrogen, they absorb carbon dioxide, they self-replicate, produce sugars and food, change colors with the season ... To knock them down and burn them to produce electricity because you want to avoid producing greenhouse gases makes no sense" (RES2). The idea that wind and solar energy were better, cleaner forms of renewable energy was expressed by several survey and interview respondents, particularly those who lived in more urban areas.

Results from the survey and interviews revealed a range of attitudes towards wood energy among different professionals working in the environmental arena. Though the survey indicated general support for wood as a form of renewable energy, in addition to concerns about carbon neutrality and the possibility of forest degradation, some expressed concern about air quality and wildlife habitat. One experienced forester recalled being at community meetings were people opposed wood energy simply "because they don't like the idea of cutting trees" (SCI1). This research suggests that the variety of concerns raised by different types of environmental professionals may have contributed to greater public confusion about wood as a form of clean and renewable energy source. This, in turn, may have contributed to decreased social acceptability of wood-burning energy technologies, especially compared with wind and solar.

3.4. Perceptions of economic risks and benefits

While only 36% of survey respondents reported some or great concern about the general economic risks involved in the production of woody biomass energy systems, those with greater knowledge about different kinds of wood energy applications discussed economic issues that arose at different scales of wood-burning technologies (Table 2). Several noted the relative efficiency of Combined Heat and Power (CHP) plants compared with facilities that produce electricity only. One interview noted that arguing when generating power only, two-thirds of the energy in that fuel source was wasted. Others noted that as a power source, wood could simply not compete with wind and solar energy because the prices of those other renewable technologies had come down dramatically in the past few decades, while due to changes in the forest products industry, the price of wood and wood-based fuels had increased (GOV6).

Those involved with the forest products industry also expressed some concern about the relative value of forests for timber, pulp, and other traditional uses compared with the value of wood as an energy source. Though wood energy systems generally rely on residuals from harvesting and mill operations, some expressed concern that when boilers require higher-quality woodchips, that could compete with markets for pulp or cross-laminated timber.

One of the most common economic benefits that both survey and interview participants noted was opportunities for rural development. One former biomass plant operator noted that "Wood is local for the most part, period. Which is good especially in rural areas like we live in" (IND5). They went on to add that though some communities in Michigan faced resistance to biomass power generation, areas like his that had a long history of timber harvesting and an extraction-based economy welcomed wood energy. "I have never been a NIMBY, obviously. Not in My Back Yard. Because I've always had a power plant in my backyard. Because I work at the power plant" (IND5). Other who were familiar with that power plant and the surrounding area noted that there was a cluster of wood product industries in the area, and argued that wood energy projects in the vicinity could help enhance existing markets and contribute to better forest management decisions (SCI1, IND4).

Other perceptions of local economic benefits to rural communities

focused on employment opportunities. One resident from a county with a biomass power plant noted that their whole community was "designed to support the lumbering and timbering industry as well as that whole supply chain that [those industries] would feed." They went on to state that being from a rural forested part of Michigan was "no different than if you were in West Virginia and the economy centered around coal, or even in areas where a nuclear plant is the center of the power source that has its own supply source that has it's own supply chain" (RES3). These kinds of statements are consistent with what other researchers have found about social acceptability of energy projects in rural communities. Many residents focus on the importance of jobs created by such development and the rippling effect that increased employment has on rural communities.

Perceptions about the economic benefits of employment in rural communities was a common theme in both survey results and interview statements. Although most of this discourse focused on larger-scale projects and power generation, many also noted that residential use of wood also had similar economic benefits related to local employment. For example, one resident stated that "from a residential standpoint, again, it is locally sourced. You're not paying for somebody to import a fuel for you. It adds to your local economy if you're paying for someone else to cut the wood and bring it to you. Your dollars are moving around your local economy" (IND5).

3.5. Perceptions of cultural and political factors

In addition to a range of ideas about risks and benefits associated with wood-burning energy technologies, survey respondents and interviewees held a variety of ideas about cultural and political factors that influenced the adoption of woody biomass-based technologies. Several research participants highlighted the different cultural identities and political orientations in different parts of the state. One northern resident argued that 90% of Michigan's population and economic activity was located in the twenty southern-most counties in the state, and as a result, most state legislation was driven by the needs and interests of southern Michigan. He noted that "The North is looked at as a recreation playground" and that potential negative attitudes toward wood energy and resource extractive industries were not necessarily as wide-spread in the northern parts of the state as they may be in southern communities. Those who "grew up with a wood extraction economy ... [are] more open-minded towards some sort of economic development, especially if it can lead to lower heating costs" (SCI1). Other northern residents echoed this sentiment, with one commenting that:

"We've got a lot of people retiring up here. We have a lot of people coming from downstate that work[ed] at a factory or work[ed] for GM or whatever. They move to their little piece of heaven in the North and they want it to be quiet and rural and no industry. Which may have been more pressure to not have that kind of stuff [biomass energy] up here. But most people who live up here understand that everyone has to make a living (IND5)."

On a broader level, another resident from Crawford County, one of northern counties with a biomass power plant, noted that many of the larger forest product manufacturing companies in the area had adopted mission statements that focused on sustainability. They noted that "the culture of sustainability of the larger manufacturers" was a driving force for why people in the community were particularly receptive to different types of wood energy technologies (SCI4). Another Crawford County resident recalled that their grandfather planted trees in the area as a member of the Civilian Conservation Corps during the Great Depression. Community members' historical connection logging industries often made them more receptive to wood-based energy technologies. Several individuals from northern communities talked about the idea of independence as being especially important, and using wood to produce heat and power locally fit neatly into a cultural identity that was linked to self-reliance and rugged individualism.

3.6. Perceptions of power versus thermal applications

Although the survey and interview data indicated general support for different scales and applications of wood energy, there were some key differences in perceptions about using wood for producing electrical power versus using wood to heat buildings. Most people had more intimate knowledge of traditional forms of wood heating-residential woodstoves, outdoor boilers, pellet stoves and barbeques-than they did about modern technologies that used wood to produce electrical power. For example, when asked about the seven biomass power facilities throughout the state, most survey respondents were not aware of the plant closest to their home residence. One interviewee, a forestry instructor at a local community college, stated that "none of the students I've ever had have ever thought about biomass as more than just a woodstove ... no one really has a good definition of what it is around here" (SCI4). The one plant where survey respondents reported being aware of the local biomass power facility was in the Upper Peninsula of Michigan. The L'Anse Warden Plant was the only location with any respondents having a very negative attitude toward the plant. Even in this case, our survey reported more positive attitudes toward the plant than negative. In each of the seven case study communities, respondents were overwhelmingly neutral about the biomass power plants. The only exception was the Grayling Generating Station, where no negative responses were reported, and the majority of responses were very positive. This was consistent with interviews of individuals who lived in the Grayling area. The former plant manager of the station noted that they were "welcomed with open arms in Grayling when we built that plantIt was a real good fit for the community" (IND5).

While people's attitudes toward electrical power generation seemed to vary by location and by an individual's level of knowledge about biomass power, there was generally more support for thermal applications across locations and among stakeholder groups. Several foresters and those with greater knowledge of different types of biomass energy systems often noted that thermal energy was a more efficient way to use wood for energy than burning woodchips to create electricity. Rural residents noted that while heating their homes with wood was cost effective, it was not necessarily "time effective" (RES1). Yet this laborintensive fuel source worked well for lower income families who valued the independence that came from heating their homes with local forest resources. Several research participants spoke about the health benefits of the physical work of cutting, hauling, and using wood as a heat source, as well as the sense of accomplishment that comes with providing your own heat. One resident from Michigan's Upper Peninsula recognized that heating public buildings with wood often presented more logistical challenges then heating with natural gas. For example, the town of Calumet, MI heated their school buildings with wood and the driveway that led to the boiler system was the same driveway that buses used to drop off children. In this case, the school had to arrange deliveries of woodchips during non-school hours. These kinds of logistical challenges involved in commercial wood heating systems-and the additional costs involved in transporting and storing wood fuels-contributed to some decision-makers' hesitancy to switch to wood. In general, however, survey respondents and interviewees felt generally positive toward the use of wood for thermal applications at both residential and commercial scales.

3.7. Role of geographic proximity to large-scale biomass power facilities

To compare attitudes toward wood energy technologies of those who lived near a large-scale biomass power plant to those who lived further away, we grouped survey responses based upon respondents' home location. The survey contained an interactive map of Michigan's seven biomass power stations and respondents were asked to identify the plant closest to their home. Note that respondents identified the closest plant to their home; they did not necessarily live within the same jurisdiction as the plant. Approximately 20% of respondents lived closest to the

L'Anse Warden Biomass Plant, 18% near Cadillac Renewable Energy, 7% near Hillman Power Company, <1% near Viking Energy/Lincoln, 8% near Grayling Generating Station, 11% near Viking Energy of McBain, and 31% near Genesee Power Station (Fig. 1). Over half of respondents did not know the facility existed prior to the survey displaying the facilities on the map, nor did they know how energy from the nearest facility was used.

Of all survey questions, none were statistically significantly different when grouped by counties with biomass power stations versus those without. This suggests that living near a large-scale biomass facility does not necessarily mean your knowledge of and perceptions about these facilities are different from those who live farther away. To examine attitudes towards specific biomass power plants, we asked residents who lived near the seven power plants questions about their perceptions of those facilities. Of the 207 survey respondents, 16% lived in or adjacent to a county with a wood-fired power plant (Fig. 1). Perceptions of facilities were general neutral or positive, except for L'Anse Warden Biomass plant; 20% of those who lived closest to L'Anse Warden had a very or somewhat negative perception of the facility. About one third of respondents who lived near L'Anse Warden, Cadillac, and Genesee commented that there was conflict or controversy around the location of the facilities when they were first constructed, but the remaining respondents either didn't know or said there was no current conflict. Respondents thought that access to wood and affordable land were the top reasons for why facilities were sited where they are. When asked about change in community sentiment and wood-based energy since the facilities were first built, only L'Anse Warden and Viking Energy had 50% and 10% (respectively) of respondents who answered more negative, while those living near other facilities felt it was either more positive or no change.

4. Discussion

In general, we found that the more people know about different types of wood-burning energy technologies, the more likely they were to see the benefits of wood as a renewable fuel source. This finding is consistent with surveys of forest landowners regarding harvesting their woods for bioenergy production [14,15a,b,16a,b,17a,b]. However, our results suggest that the more complex wood-burning energy technologies become, such as combined heat and power (CHP) facilities and industrial-scale power plants, the more education is needed for communities to understand the benefits and risks of those technologies. The results of the survey and interviews suggest that perceptions about wood energy in Michigan are multifaceted. Despite perceived risks to forests, human health, and economic stability, research participants also perceived environmental, economic, and public health benefits of using wood for different energy applications. Specifically, 70% reported some or great environmental benefits from using wood as a replacement for fossil fuels. Sixty-one percent reported some or great economic benefits from using wood as an energy source, and 57% reported some or great health benefits from using wood as an energy source. Survey and interview respondents simultaneously perceived wood to have several benefits, but also many risks. Ideas about different types of wood-burning technologies did not fall along clean and distinct lines between environmental versus pro-logging interests. Instead we found that people's level of knowledge and their situation within rural or urban communities tended to influence their attitudes and perceptions about wood energy.

One of the limitations of this research involves potential bias of survey and interview data. Survey and interview responses were recruited through the authors' professional networks, such as the Michigan Wood Energy Team, Michigan State Extension, and forestry professionals throughout the state. These professional networks may have produced some bias in the research results. Also, it is possible that because many of these people work in natural resource science and management fields, they may have been more educated about different

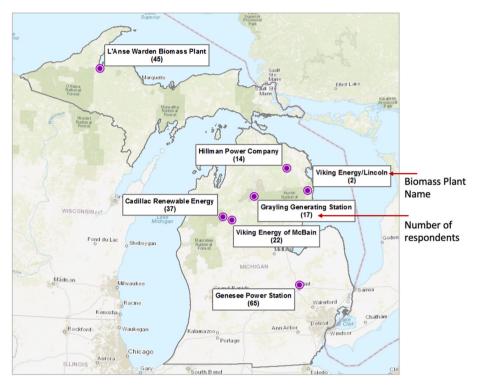


Fig. 1. Location of large-scale commercial bioenergy facilities with their name and the number of survey respondents from the county in which each facility is located.

forms of wood energy than the general public. To solicit broader participation in the survey and interviews, we relied on social media sites such as Facebook groups. These kinds of sites can also produce different forms of bias, though recruiting research participants in this way has been recognized as a viable research strategy [21].

Surveying a population within the state that had familiarity with different types of woody biomass applications was useful for helping to understanding the different kinds of risks and benefits associated with those different applications, and how ideas about risks and benefits varied by location and scale of technology. Interviews with people with a range of backgrounds reinforced survey results and revealed that people's knowledge about wood-burning technologies seemed to be shaped by a range of cultural values and different ideas about the costs and benefits of wood energy. Understanding how those values and ideas play out in specific community contexts is essential to cultivating social acceptance of wood-burning energy technologies.

5. Conclusions

While the idea of social acceptance has gained traction in the literature on renewable energy adoption, communities rarely have a singular hegemonic response to a particular proposed energy technology. This research illustrates variation within communities and shows that ideas about wood energy did not easily fit into a rigid binary of social acceptance or non-acceptance. Examining specific perceptions and attitudes toward different types of wood-burning energy technologies reveals that individuals can support wood heat or power while also seeing risks associated with those technologies.

This research highlights the important role of education in shaping social acceptance of wood-burning energy technologies. Individuals who had more knowledge about different wood energy applications, often gained through direct experience working with woodstoves, boilers, or power plants, tended to be more willing to accept the risks associated with wood energy, and were more likely to see the benefits of those applications. Although most research participants viewed wood as a renewable energy source that was preferable to fossil fuels, support for

wood energy was greatest in more rural parts of the state in forested communities with a history of logging and forest products manufacturing. This suggests that education may be beneficial to promote greater social acceptance of wood-burning energy technologies among people from more urban areas. Like other forms of renewable energy, however, determining whether a particular wood-burning energy technology is a good fit for a given location is typically very place-specific. Geographic factors such physical resource availability as well as cultural and political context need to be considered when deciding what types of energy technologies should be developed.

By showing how education and awareness have shaped attitudes and perceptions of wood energy in Michigan, this work aims to help policy-makers make more informed decisions regarding future technologies. Wood energy has received far less attention than other renewables such as wind and solar, and as a result, there are a lot of misunderstandings and confusion about risks and benefits associated with different types of wood energy. This research aims to elucidate a range of attitudes toward different applications of wood energy in one Great Lakes state, and explores some of the underlying factors that shape those perceptions. Understanding the factors that shape people's ideas about different kinds of wood-burning energy technologies can help ensure that the transition to a sustainable bioenergy future is not only economically and environmentally viable, but it is also socially and culturally appropriate.

Specifically, this research suggests the following three recommendations. First, when planning for the adoption of new wood-based bioenergy technologies, policy makers and developers need to understand the complex set of factors that shape individuals' and communities' attitudes towards those technologies. Second, the development of novel bioenergy technologies will require widespread public support in order to secure investment. Social acceptance is critical and may depend on more education about different forms of wood-based bioenergy and associated risks and benefits. Finally, this study focused on attitudes and perceptions of wood energy technologies that rely on combustion to produce heat and electricity. More research is needed on different aspects of social acceptability as it relates to other forms of wood-based bioenergy, such as liquid biofuels produced from cellulosic materials

such as forest residues and other woody material. Development of these types of applications may become increasingly important as the world seeks lower-carbon fuel sources for aviation and marine transportation.

Data availability

The data that has been used is confidential.

Acknowledgements

This research was funded by the National Science Foundation's Science and Technology Studies Program, grant number 1922030. We'd like to thank Erin Budzyn; Michigan State University Extension Agents for assistance with survey recruitment and implementation efforts. We'd also like to thank the [removed for peer review] who helped distribute the survey on our behalf.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.biombioe.2023.106897.

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