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Wood Energy and Rural Planning: An Analysis of Land Use Policies in the Siting and Regulation of Forest-Based Bioenergy Technologies

Sarah Mittlefehldt ^{1,*}, Erin Bunting ², Joseph Welsh ², Emily Silver ³, Mya Curth ⁴, Mari McClure ¹ and Bradley Neumann ⁵

¹ Department of Earth, Environmental & Geographical Sciences, Northern Michigan University, Marquette, MI 49855, USA

² Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI 48824, USA; ebunting@msu.edu (E.B.); jjw0023@msu.edu (J.W.)

³ Department of Forestry, Michigan State University, East Lansing, MI 48824, USA; esilver@msu.edu

⁴ School for Environment and Sustainability, University of Michigan, Ann Arbor, MI 48109, USA; mcurth@umich.edu

⁵ Michigan State University Extension, Marquette County Extension Office, Negaunee, MI 49866, USA; neuman36@msu.edu

* Correspondence: smittlef@nmu.edu

Abstract: Land use regulations have played a critical role in the siting and operation of renewable energy technologies. While there is a growing literature on the siting of wind and solar technologies, less is known about the relationship between local codes and planning decisions and the development of wood-based bioenergy technologies, particularly in rural places. This research examines the relationship between local land use policies and the siting and operation of different types of wood-based bioenergy technologies in northern Michigan, USA. Land use codes including zoning laws and ordinances related to wood-burning devices from 506 cities, townships, and villages within 36 counties in northern Michigan were combined with US Census data in a GIS database. ArcGIS was used to examine geographical differences between communities and socioeconomic factors related to different regulatory approaches. We found that areas with greater population densities and higher income and education levels tended to have more nuanced land use codes related to all scales of wood-burning, including residential wood heating, commercial-scale heating, and power generation. This paper emphasizes the importance of local decision-making and land use policies in shaping the development of wood-based energy technologies, and suggests the need for greater attention to rural community dynamics in planning the shift to a lower-carbon economy.

Keywords: wood bioenergy; rural development; siting; land use planning; zoning



Citation: Mittlefehldt, S.; Bunting, E.; Welsh, J.; Silver, E.; Curth, M.; McClure, M.; Neumann, B. Wood Energy and Rural Planning: An Analysis of Land Use Policies in the Siting and Regulation of Forest-Based Bioenergy Technologies. *Land* **2024**, *13*, 1569. <https://doi.org/10.3390/land13101569>

Academic Editor: Brian D. Fath

Received: 7 August 2024

Revised: 10 September 2024

Accepted: 23 September 2024

Published: 27 September 2024



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1. Introduction

The proliferation of renewable energy technologies has been constrained and facilitated by a variety of policy decisions, including tax structures, incentive availability, and land use regulations (e.g., zoning). Several scholars have documented how land use codes can shape the development of wind and solar projects; less is known about the relationship between local regulation and bioenergy technologies [1–3]. Although most people associate technologies such as wind turbines and solar panels with renewable energy, biomass remains one of the largest sources of renewable energy in the United States [4]. Of all the different types of biomass energy, one of the oldest sources—wood—contributes 23% of the United States' total renewable energy [5]. Woody material can be transformed into energy through biochemical processes that result in liquid biofuels or thermochemical processes that result in other forms of biofuel, but more often, wood is burned to produce heat or electricity. Many rural, forested regions in the U.S. consider energy markets to be a valuable

outlet for low-value or small-diameter woody material generated during harvesting and primary manufacturing processes. In places with significant thermal demands such as northern climates or higher-elevation communities, combined heat and power (CHP) facilities use wood to produce both heat and electricity at rates that are more efficient than power-generation alone. This paper focuses on regulations pertaining to wood-burning technologies used to produce heat, electrical power, or a combination of heat and power in communities throughout northern Michigan.

Like other energy sources, using wood to create heat and power has advantages and disadvantages. In many rural parts of the US, wood is relatively abundant and can play an important role in climate change mitigation [6]. Compared with fuel oil, coal, natural gas or propane, burning wood for energy can produce less carbon dioxide. For example, in Europe, where woody biomass makes up 60% of renewable energy, investment in wood energy significantly reduced carbon emissions for all 27 EU countries between 1990 and 2017 [7]. In forested rural areas with limited economic opportunities, woody material left over after harvesting or milling can provide additional employment opportunities and other economic benefits [8]. On the other hand, depending on how biomass supplies are harvested and procured, wood fuels can have significant impacts on land and water resources [9]. Furthermore, the combustion of wood produces smoke, which contains fine particulates (PM_{2.5}), carbon monoxide, nitrogen oxides, and carcinogenic compounds like polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) [10]. In densely populated areas, these pollutants can cause nuisances to neighbors and public health problems on a larger scale [11]. This research focuses primarily on how local regulatory frameworks address the consequences of wood combustion.

Many state and federal policies have been enacted to regulate environmental and public health concerns associated with wood-burning energy technologies. For example, the US Environmental Protection Agency (EPA) requires that all residential woodstoves manufactured after 15 May 2020 must limit the amount of smoke emitted to 2.0 g per hour (g/h) [12]. Federal laws such as the Clean Air Act require National Emission Standards for Hazardous Air Pollutants that apply to biomass-fueled boilers and power stations [13]. At the state level, many jurisdictions such as Michigan have legislation to regulate the operation of commercial-scale wood boiler systems [14]. State and federal policies have played an important role in the promotion of advanced wood-burning energy technologies in other ways as well. For example, in response to the energy crises of the 1970s, the US Congress passed the Public Utility Regulatory Policies Act of 1978 (PURPA). PURPA required utilities to buy electricity from qualifying facilities that used renewable fuels that included woody biomass. More recently, many states have enacted renewable portfolio standards (RPSs) that allow states to measure and track progress toward increasing renewable power within their jurisdictions. State governments in the US began adopting regulations on residential outdoor wood boilers in the mid-2000s, and local governments have adopted local ordinances related to the technology [15]. While existing scholarship has looked at the role of federal and state policy on wood-based bioenergy development, less is known about the relationship between local land use regulations and the development of wood-based bioenergy technologies [16–21].

This paper examines the relationship between local land use regulations and the siting and operation of technologies that use wood for heat and power. Just like state and federal regulations, local regulatory frameworks can be used to promote wood energy and to limit the unintended consequences of combustion. For example, some of the oldest municipal codes were developed to address problems associated with smoke [22]. Local land use regulations are important because they establish specific parameters on where and how wood-burning technologies can be used. Local ordinances can range from outright prohibition of particular types of wood-burning technologies in certain zoning districts, to setbacks from neighboring properties, to regulations on smokestack height and other technical requirements. This research examines the relationship between zoning and other local land use codes and the development of wood-burning energy technologies in northern

Michigan at three different scales: residential heating, commercial heating, and industrial power generation (or combined heat and power). Although each of these scales employs different forms of wood feedstocks—cordwood is typically used for residential applications, while woodchips, mill wastes, and forest residuals are often used for CHP plants and power-only facilities—all of these wood technologies rely on combustion and therefore produce emissions. The purpose of this paper is to examine how local jurisdictions attempt to manage the negative externalities associated with wood-burning, and to characterize different factors associated with different approaches to regulation. Using local ordinances for 506 jurisdictions within 36 forested counties in northern Michigan, we sought to answer the following questions:

1. What relationships exist between local regulatory frameworks (as defined by land use codes) and the siting and operation of different types of wood-based bioenergy technologies in northern Michigan?
2. How are socioeconomic factors associated with land use policies related to bioenergy development? Specifically, how does population density, income, poverty level, education, age, and racial diversity vary between places that prohibit or heavily regulate wood-burning energy technologies and communities that have little to no regulations?

By combining the analysis of land use policy documents with spatial data, this research uses new methodological approaches to inform rural planning and renewable energy development.

Study Area

The study area focused on the state of Michigan, because according to the EIA, Michigan has one of the highest rates of residential wood heating in the US and is also one of the top states for producing biomass power [23]. In 2019, Michigan was the third largest producer of biomass power behind California and New Hampshire [24]. Although Michigan uses other forms of biomass throughout the state, including agricultural crops and residues and municipal solid waste (MSW), this study focuses on local regulations related to wood-burning energy applications in the thirty-six northernmost counties.

As shown on the inset map in Figure 1, the northern half of the state is predominantly forested. Most wood-based bioenergy technologies in Michigan are in this area, which is primarily rural and includes the greatest number of homes that rely on wood as a primary heating source as compared with the more urbanized southern part of the state.

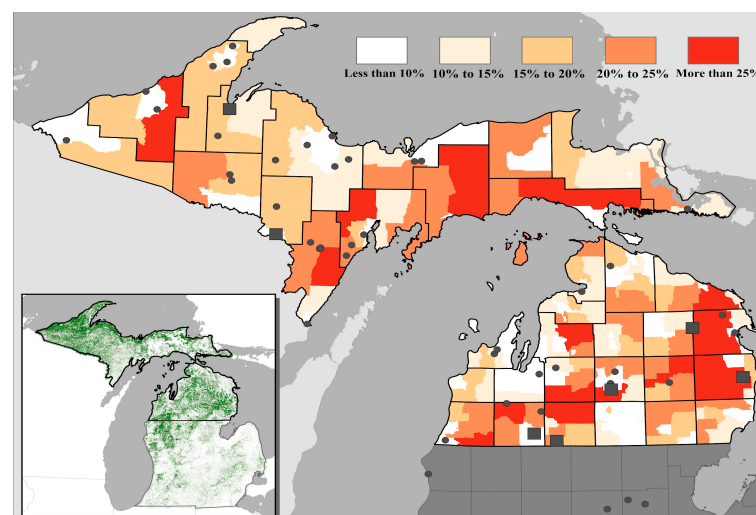


Figure 1. Figure shows the study area with the percentage of homes (by census tract) that use wood as their primary heat source (Source: American Community Survey 5-year estimates, 2020) [25]. The map also shows locations of regulated commercial-scale wood-fired boilers (dots) and biomass power stations or combined heat and power plants (squares). The inset map shows the outline of the study area and the concentration of forest cover in the Upper Peninsula and northern Lower Peninsula. Shaded green areas represent forest cover (Source: NOAA, 2016) [26].

The thirty-six counties in northern Michigan contain a total of 506 different jurisdictions including cities, villages, and townships: 189 in Michigan's Upper Peninsula and 317 jurisdictions in the northern Lower Peninsula. By focusing on the northern forested part of the state, this study area allowed for a finer-grained analysis of dynamics in communities that use different forms of wood energy. For each of the 506 jurisdictions, we searched for zoning codes and any local ordinances related to wood-burning energy technologies such as general ordinances on burning and building codes related to wood heaters. According to Michigan's Zoning Enabling Act of 2006, zoning can take place at the county level or within townships, cities, or villages. The Act also allows for jurisdictions to be "unzoned" or to not have zoning. According to a state-wide zoning database developed by Dr. Sarah Mills, 87% of all Michigan townships have zoning, 99% of cities have zoning, and 82% of villages have zoning [27]. Our study area reflected these general state-wide trends.

Although most states in the US require that wood-burning devices meet federal EPA standards and some states such as Washington have more stringent rules on wood-burners, Michigan's Natural Resources and Environmental Protection Act states that federal emission standards for wood heaters adopted after 2014 will not be enforced in Michigan [28]. This gives more decision-making authority to local and state authorities to regulate wood-burning energy technologies. We focused on zoning ordinances because these local land use laws are intended to promote the public health, safety, and welfare of a community by establishing regulations on the use of private property. Zoning ordinances separate incompatible land uses by creating residential, commercial, industrial, and other types of districts and then regulating different types of land uses within those districts. For land uses that may or may not be compatible with other permitted uses in a particular zoning district, some ordinances allow landowners to apply for a special land use permit.

There are a few ways in which zoning can affect the development of wood-burning energy technologies. Many zoning ordinances in Michigan include a nuisance clause that requires land uses to not be detrimental to the health, safety, or welfare of people or property, and limits the excessive production of smoke, fumes, odors, or other dangers. It is often up to local planning and zoning authorities to determine whether a proposed use may be detrimental or not and what is considered "excessive production", though when challenged, Michigan courts look poorly on vague or subjective standards [29]. In industrial or manufacturing districts, production processes often result in undesirable byproducts such as noise, smoke, or fumes. Local land use codes attempt to mitigate these kinds of issues by highlighting state and federal standards. For example, for manufacturing districts in Keweenaw County, Michigan, the code states that any use "shall be operated in such a manner as to comply with the applicable performance standards [30]". This example is consistent with how most local communities regulate manufacturing or industrial districts—by relying on performance standards established by other state and federal authorities or independent non-governmental organizations such as the National Fire Protection Association (NFPA).

Several rural, sparsely populated communities in northern Michigan do not have zoning. These jurisdictions typically do not have staff to create, manage, and enforce a zoning code. A study by Locke and Rissman found that socioeconomic characteristics of communities in Michigan tended to be a predictor for whether or not those communities had adopted zoning [31]. Rural communities in Michigan that do not have zoning sometimes have other ordinances on burning or related nuisances. Although this study focused on zoning codes, we searched other related codes such as municipal and township ordinances, county building codes, and other local ordinances well. Descriptions of this process are found in the methods section below.

2. Materials and Methods

2.1. Data Sources and Coding System

To examine the relationship between local ordinances and the siting and operation of different types of wood-based bioenergy technologies, we obtained codes by searching local government websites, using the Municode database, and calling, faxing, emailing and

mailing local government offices across northern Michigan. For all 506 jurisdictions located in the 36-county study area, we searched for all local regulations related to wood-burning including zoning laws and other ordinances. We examined land use codes and other ordinances in each of the 506 jurisdictions in northern Michigan by searching for the terms “woodstove”, “wood smoke”, “boiler”, and “furnace.” Ordinances that included language related to wood-burning technologies were then coded by their levels of regulatory nuance. Regulatory nuance was determined in the following way: if there was no mention of anything related to wood energy, it was categorized as 0. If the code included general regulations related to “smoke” but those regulations were not necessarily specific to smoke generated from wood-heating technologies, it was 1. If the ordinance included nuanced regulations that contained details specifically related to wood energy technologies, it was 2. Jurisdictions that explicitly prohibited wood-burning devices were 3. While higher levels of detail in a code do not always equate to greater complexity, we use the term “regulatory complexity” throughout this paper to explain the amount of nuance contained in each code. Communities that typically included multiple standards with specific and detailed information about how and where different wood-burners could be used exhibited greater regulatory complexity than communities that had no regulation on wood burners or communities that had only had one or two standards.

Of those areas that contained regulations related to wood-burning energy technologies, most specifically addressed outdoor wood boilers (OWB). We developed a separate coding scheme to examine the different ways in which jurisdictions regulated OWBs. According to the Michigan State University Extension office, there are several ways in which local governments can control smoke emitted from outdoor wood boilers. These include creating setbacks to distance OWB from dwellings and property lines, regulating smoke stack height, restricting the types of zoning districts OWB are allowed in, requiring compliance with independent safety standards, construction codes and other regulations, and regulating what materials can be burned. Michigan’s Department of Environmental Quality (now Michigan’s Department of Environment, Great Lakes and Energy) created a model ordinance for outdoor burning that includes regulations on OWB [30]. Table 1 combines information from Michigan State University Extension and the Department of Environmental Quality to show some of the different types of standards that local jurisdictions can adopt to regulate outdoor wood boilers. We coded areas that had OWB regulations in the following way: if a jurisdiction included one of the standards in Table 1, it was 1, two standards it was 2, three standards it was 3, etc. If the jurisdiction had five (or more if it included other standards not on this list, such as seasonal limits on use), it was categorized as 5. These different levels reflect different degrees of detail or complexity of a given ordinance. If a jurisdiction prohibited OWB outright, it was 6.

Table 1. Standards for regulating outdoor wood boilers and furnaces. Adapted from Dean Solomon, Michigan State University Extension, 2013 and Michigan Department of Environmental Quality, 2011 [32,33].

Standard Category	Definition	Example(s)
Setbacks and location restrictions	Distance between OWB and dwellings or other buildings, property lines, etc.	Require setback up to 500–1000’ for large units
		Prohibited in front yards
Smoke stack height	How tall the smoke stack can be; taller stacks will send particulates further from structures and people	5’ taller than any structure within 500’
		Minimum of 15’
Zoning district restrictions	Only allowing OWB in particular zoning districts	Allow in agricultural or forestry districts
		Allow in low-density districts with additional restrictions
		If there are no feasible solutions to address safety and smoke, prohibit in higher-density districts
Additional technical requirements	Required compliance with independent safety standards or other regulatory agencies	Use standards such as NFPA, UL, CAN/CSA, ANSI, or others
		Functioning spark arrestor required
Materials	Limit what can be burned to only clean wood, cordwood, wood pellets	Prohibit the burning of garbage, treated wood, plastic, lawn clippings, etc.

In addition to analyzing local ordinances related to residential wood heating applications, we examined specific regulations pertaining to commercial and industrial-scale wood-burning energy technologies for heat or power generation. We obtained data from Michigan's Department of Licensing and Regulatory Affairs (LARA) on all regulated boilers in the state that burned wood. According to the state statute, LARA tracks larger non-residential boilers in Michigan and boilers that heat apartment complexes or other facilities that house more than six families [14]. Each regulated boiler has information about its size, location, fuel type, and other characteristics. Boilers that use the fuel type "other solid" burn wood or some form of cellulosic material, including forest or mill residues, wood chips, paper waste, or pellets. In the southern part of the state, cellulosic material might also include agricultural wastes such as corn stover. But according to the boiler inspector for the northern part of the state, "other solid" is wood and wood-derived material in the northern-most counties [34]. Within the project area, 48 boilers were used to produce heat for commercial purposes while seven used wood to produce electricity or a combination of heat and power at an industrial scale (Figure 1). We combined information about the location of these different types of wood-burning devices with local regulations related to woodsmoke and outdoor burners in a geographic information system (GIS) database. We then used ArcGIS to examine spatial patterns between the locations of different types of wood-burning technologies and characteristics of communities with different approaches to regulation.

2.2. Calculation of Socioeconomic Factors

To answer our second research question related to socioeconomic and demographic trends within the study area, we developed a database of census data from the American Community Survey and the US Census Bureau. These data sources contained information on population, race, ethnicity, diversity, education levels, and household income. These data were collected at the census tract level and then decomposed to match the local land use jurisdictions. Additionally, we used the Shannon–Wiener Index to calculate a measure of racial diversity based on demographic data. The Shannon–Wiener Diversity Index measures the diversity of different variables within a larger dataset—often defined as a population or community. For each race listed within a census tract, we obtained the population of the race and determined the percentage of the race compared with the total population of that tract. We then calculated the natural logarithm of the percentage, multiplied the natural logarithm value and the population count (of the single race). Then, to obtain the overall racial diversity index value for each tract, we calculated the inverse sum of all individual race values [35]. This method for calculating diversity of a particular population was used to understand the relationship between varying levels of racial diversity in communities within the study area and the location of different wood-burning technologies.

To analyze the socioeconomic profile of communities with different approaches to regulating wood energy, we used a Random Forest (RF) algorithm. Random Forest is a learning technique, like decision trees, that was developed by Breiman to model response of variables based on a set of covariates [36,37]. RF generates hundreds of trees (forests), which are aggregated to develop a classification of the response data. The RF response, in this case modeling characteristics of communities with different levels of regulatory complexity, was determined by evaluating the response of all the trees. When building the trees, RF tested subsets of the predictor variables for each decision branch or node. Roughly 2/3 of the reference data were sampled, with replacement, to build each tree. The remaining 1/3 of the response data were withheld from tree construction. This whole process is called "out-of-bag error" and was used to get a running unbiased estimate of the error associated with each tree as it was added to the forest. The RF analysis was used to understand the variable importance in terms of the response variable. In this case, we used RF to model the type of wood burning technology against characteristics of communities with different levels of regulatory complexity. The RF classification was completed in R (package "ModelMap"). The explanatory covariates were developed from data from the US Census and the American Community Survey.

3. Results

We were able to locate local ordinances for 503 of the total 506 jurisdictions within our project area. Of the 503 places where we found data, 70 (14%) had no zoning or other ordinances related to burning wood. Eleven (2%) places had some kind of ordinance pertaining to smoke or wood-burning nuisance factors outside of a comprehensive zoning code. The vast majority of jurisdictions (422) had some kind of zoning law or zoning plus other ordinances that were related to smoke, wood boilers, or outdoor furnaces (84%, Figure 2).

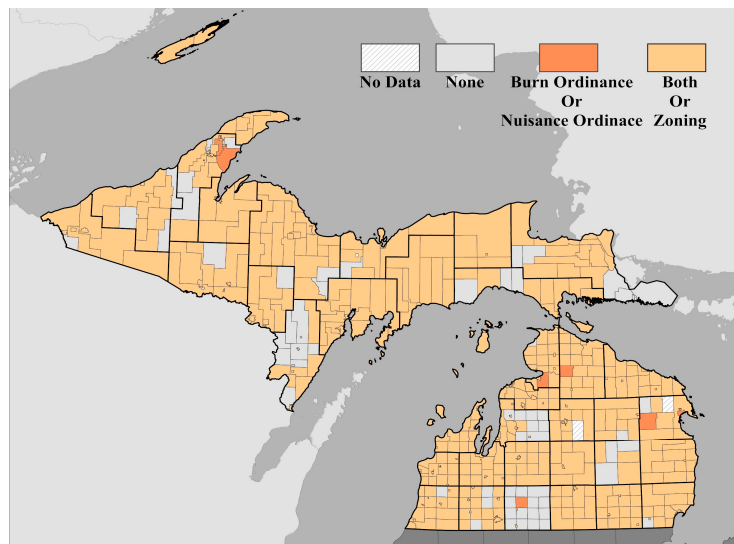


Figure 2. Study area map showing land use ordinances by legal boundaries. “Both or Zoning” means that the jurisdiction had either a zoning ordinance or both a zoning ordinance and other codes related to smoke or other nuisances related to wood-burning.

Policies related to wood energy varied among the 433 jurisdictions that had local land use regulations (either zoning or other local ordinances). Not surprisingly, the sixteen jurisdictions that had the highest levels of regulatory complexity were those with the greatest population densities; these were quasi-urban centers located within an otherwise rural landscape. Seventy-six locations had regulations directly related to wood energy, most commonly pertaining to outdoor wood boilers. Most places that had some form of local land use regulations contained general language about smoke or related nuisance factors (Figure 3).

3.1. Residential Wood Heating

Although state and federal governments pass consumer protection laws and set standards for regulating home heating devices such as the EPA’s efficiency standards on residential woodstoves, according to Michigan’s 2015 Natural Resources and Environmental Protection Act, local jurisdictions hold significant decision-making authority on how those guidelines are interpreted and adopted into local land use regulations. For example, Long Lake Township in Grand Traverse County established a thorough ordinance on outdoor furnaces and cited technical reports and guidelines provided by state regulatory authorities as justification for the local code [38]. Similarly, while the federal EPA has the authority to require wood stove manufacturers to increase efficiency standards, local land use regulations can determine whether private landowners can use older, less efficient technologies. In this way, local codes can reinforce and help to codify objectives identified by federal agencies and national organizations. For example, AuSable Charter Township in Iosco County requires that all outdoor wood boilers meet all current EPA standards as well as the National Fire Protection Association’s standards for chimneys, fireplaces, vents, and solid fuel-burning appliances [39].

Of 503 jurisdictions within the project area, 94 had specific rules about residential wood heating (19%) and 408 places had no specific regulations related to residential wood

heating technologies (Figure 4). Of those areas with local regulations, 100% were focused on outdoor wood boilers or furnaces. This is consistent with existing research that suggests that outdoor wood boilers, particularly those manufactured before 2015, have created the most nuisance issues related to residential wood heat [40]. Of the 94 jurisdictions that had regulations on residential wood boilers, 12 prohibited them outright, 52 had adopted at least four or five of the recommended standards for OWBs, and 30 adopted three or fewer standards.

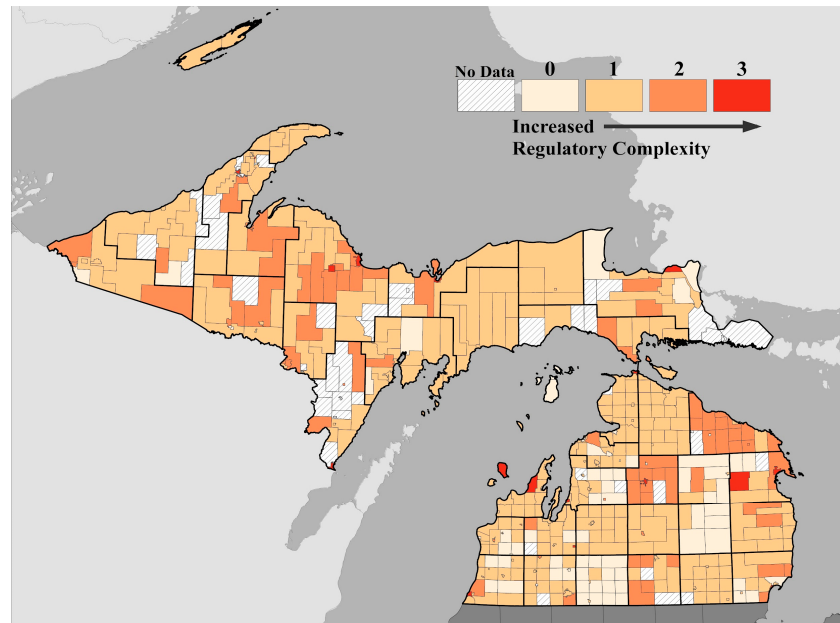


Figure 3. Map depicts degrees of regulatory complexity related to burning and wood energy technologies. Values range from having no standards (value = 0) to having rules against excessive smoke or burning in general (value = 1) to having detailed and specific standards regarding the use of wood-burning for energy (value = 2). Jurisdictions that prohibited wood-burning energy technologies had value = 3.

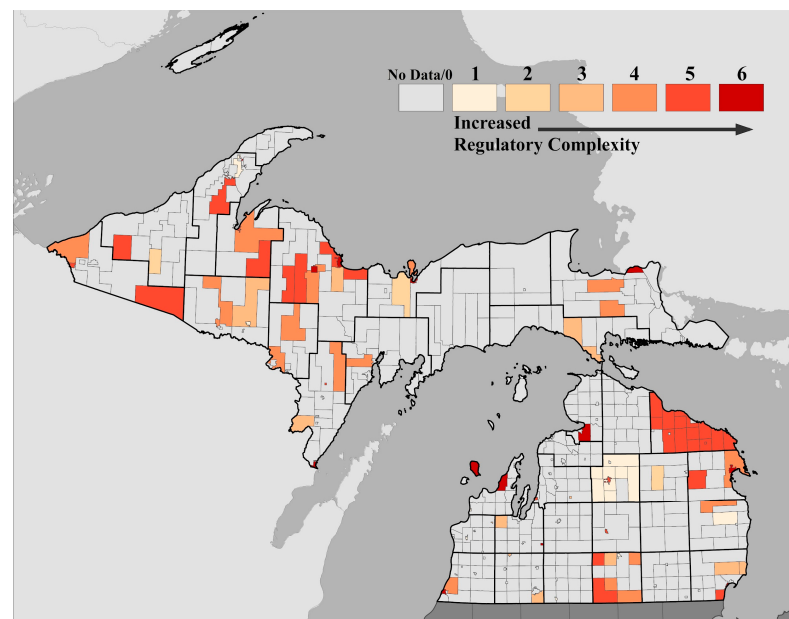


Figure 4. Map shows jurisdictions with specific regulations on outdoor wood boilers and depicts different levels of regulation ranging from no restrictions (value = 0) to five or more standards (value = 5) to being prohibited (value = 6).

To examine the relationship between areas that rely primarily on wood for residential heating and different levels of regulation, we created a table that included Census data from tracts where more than 25% of occupied housing units used wood as a primary source of heat (Figure 1). These areas covered 120 different jurisdictions, all of which were rural counties, townships and villages except for the City of Stephenson in Menominee County. The general level of regulatory detail for these areas was less than one, meaning that of our scale from 0–3, most places either were “0” with no regulation, a “1” an area that had basic rules regulating excessive smoke or related nuisance factors, or the area did not have data available. Of the 120 areas where at least 25% or more of households relied on wood heating, 20 had specific regulations on outdoor wood boilers. Those areas had at least four standards and none of them prohibited outdoor furnaces. Eleven of those areas included all five standards from model ordinances suggested by the state, including all jurisdictions within Presque Isle County where 33% of households rely on wood as a primary heat source.

Another important way in which local governance shapes residential wood energy use lies in enforcement of rules and regulations. In most rural or semi-rural communities, enforcement of local land use codes relies on nuisance violations. In other words, the enforcement of regulations on outdoor wood boilers or woodsmoke typically happens when neighbors complain. From conversations with local planners and zoning administrators, it appears that many jurisdictions with regulations on OWB were developed in response to neighbor concerns and local policy-makers trying to be proactive in protecting health, safety, and welfare.

3.2. Commercial Wood Heating

Rural land use regulations also play an important role in shaping the location of commercial boilers, power plants, and combined heat and power facilities. One of the primary ways in which zoning affects these larger-scale technologies is by establishing the legal geography of where certain technologies can or cannot be located. Sawmills and industrial power stations are typically prohibited from residential zoning districts. Commercial or industrial districts that may allow these technologies often include restrictions on potentially hazardous uses. For example, according to the Kalkaska County Zoning Ordinance, land uses within commercial or industrial districts cannot “be hazardous to adjacent property”, nor can they include uses or equipment that could be detrimental to the health, safety, or welfare of people or property, or engage in “excessive production of . . . noise, smoke, odor, fumes, etc.” The code also requires that the Planning Commission, Zoning Board of Appeals, and the County Board of Commissioners consider “prevention of nuisances” when making decisions about permitted uses in these areas [41].

Many jurisdictions include language about smoke as part of a general provision against nuisances. For example, Greenland Township in Ontonagon County contains a statement for industrial areas against “Deleterious Effects” that includes air pollution, smoke, noise, odor, explosion, or “hazard of fire” [42]. These types of local nuisance laws can be general or specific to wood-burning technologies. For example, the City of Iron River in Iron County has a local ordinance on burning that addresses multiple types of wood-burning devices including commercial incinerators such as a boiler at a sawmill that uses mill residues to produce heat and wood-fired furnaces for residential use [43].

Like residential heating applications, we found that wood boilers used for commercial purposes tended to be well-distributed across northern Michigan. When we plotted the location of all commercial wood boilers regulated by the State of Michigan, we found no significant clusters in 36 northern counties. A preliminary cluster/hotspot analysis was completed within ArcGIS Pro and verified the lack of concentration of such technologies across the state. For a variety of economic and physical constraints, wood burning energy technologies tended to be diffuse.

To compare local regulatory approaches related to different technologies, we examined land use policies for jurisdictions that housed the 48 commercial-scale wood boilers and seven biomass power or CHP plants in the project area. We were curious to see if areas

that had detailed regulations for residential wood-burning applications also had specific regulations for larger-scale wood-burning technologies, and to see if there were any patterns between the regulation of different scales of technology. We found that 23% had regulations specific to residential wood heating. This was slightly higher than average for the total project area (19%). Of those places with regulations on outdoor furnaces, 64% had at least four or more standards. Of the seven places that housed biomass power plants in the project area, three had regulations on residential wood heaters (43%), though only two jurisdictions with power plants had four or more standards on residential wood heating. Though the sample size was too small to determine statistical significance, it appeared that areas with larger non-residential wood-burning technologies did not have fewer regulations on residential wood heating. If anything, areas with multiple scales of wood-burning energy technologies may be more invested in creating clear and consistent rules about the use of burning wood for energy.

3.3. Biomass Power

Although utility-scale power generation is subject to more federal and state regulation than residential or commercial heating, local land use regulations have also played a critical role in determining where woody biomass plants could be located. Prior research showed that when a woody biomass power plant was proposed for Rapid River, Michigan, developers sought to change the zoning code [44]. After hearing resistance to the plant from community members, local decision-makers chose not to update the existing code to keep the barrier to development in place. This effectively shut down the Rapid River project. However, when controversy arose over a proposed woody biomass plant in Flint, Michigan, state environmental officials claimed that their hands were tied because the location of the plant was determined by local zoning code and approved by local authorities [45]. These prior studies suggest that local land use regulations play a key role in shaping the location of where biomass power stations are allowed or prohibited.

3.4. Socioeconomic Trends and Profiles of Communities with Wood Burning Technologies

3.4.1. Profile of Communities Based on Regulatory Complexity

To examine the socioeconomic characteristics of places that had different approaches to regulating wood-burning energy technologies, the RF analysis was used to model variables that were linked to different levels of regulatory complexity. While the model showed some statistically significant relationships, not all covariates played a significant role in these models and therefore only statistically significant trends are discussed in these results.

Education was significantly correlated with communities with no regulations (value = 0). Additionally, the population per square mile was important. In other words, these regions had lower percentages of educated people, especially fewer college-educated people, and smaller population densities. Communities with relatively simple regulations (value = 1) also tended to have smaller populations and there was diversity in mean income. The percentage of high school graduates was lower in these places than places with the highest levels of regulatory complexity, but higher than regions with no regulations.

Similar patterns held for places with some wood-energy-specific regulations (value = 2). In these communities, the population, median income, size of the region, and percent-educated were significant to the profile of the community. As levels of regulatory complexity increased, population density also increased along with the mean and median income and the percentage of the population with a college education. For the places with the most regulations on wood-burning (value = 3), the same trends held; however, for the first time in the RF analysis, the percent employed and diversity index were significant to the profile, though they did not provide much explanatory power to the model. Overall, these regions were the most diverse of all the regulation levels and had a large percentage employed. These characteristics are typical of more urban development, which tend to have more diverse populations, greater employment opportunities, and higher incomes than

in more rural areas. These results are consistent with prior studies that have shown how socioeconomic factors relate to the adoption of zoning ordinances in rural communities [31].

3.4.2. Comparison of Areas with Wood Burning Regulations to Areas with No Regulation

To compare characteristics of places that had some kind of ordinance on burning to those without any regulations, we developed another RF model. Communities without any zoning or related ordinances tended to have lower population densities compared to those with regulations. Areas without regulations had fewer commercial-scale boilers and the percentage of the population that was educated—especially at the college level—was lower. Communities that had local land use regulations related to wood energy were typically smaller in total area compared to those without ordinances. These communities also had higher mean income, greater diversity in the population, and higher percent educated at both the high school and college level.

3.4.3. Comparison of Areas with Specific Regulations on Outdoor Wood Boilers

Within our project area, 95 jurisdictions had specific regulations on outdoor wood boilers. We ranked these jurisdictions from 1 to 5 based on how many of the different standards each place had adopted; areas were given a 6 if outdoor wood boilers were completely prohibited. Due to the small sample size, we had to reclassify the data from 6 categories to 2 in order to run the RF model. This type of semi-supervised learning technique traditionally works well with small sample sizes. However, in this case there was large disparity in the sample size across classes and low sample sizes with some of the original classes. Areas with outdoor wood boiler regulations initially ranked as 0 or 1 were reclassified as 0. Those places with levels 2–6 were classified together as class 1 for the RF model. Collapsing the data in this way allows for a comparison between areas with little to no regulation versus more detailed or restrictive regulation.

Like areas with fewer general regulations on wood burning, areas with little to no regulation on outdoor wood boilers had low population densities and lower education levels. Although it was not statistically significant, these areas tended to have lower diversity as well. Places that had more regulations on outdoor wood boilers tended to have greater populations and population densities. These areas also had higher median income, more diversity, and higher education levels.

The results of the community profile analyses were consistent with other studies that have focused on the adoption of renewable energy technologies as a means of rural economic development [46]. Across the globe, rural areas tend to have lower incomes and less educated populations [47]. For these areas, distributed sources of renewable energy such as wood, wind, or solar hold the promise of more jobs and educational opportunities, but are not without risks. Local land use policies and regulations are important means by which communities can accept new opportunities associated with the low-carbon economy while at the same time mitigating risks that come with the transition.

4. Discussion

The development of wood-based bioenergy technologies has been affected by multiple scales of governance, yet most research related to the regulation of woody biomass technologies has focused on federal and state policies [16–21]. The goal of this research was to show how local land use regulations relate to the siting and operation of different types of wood energy technologies, and to illustrate some of the socioeconomic dimensions associated with bioenergy development in rural, forested communities. As renewable energy technologies continue to increase in popularity, local land use codes will need to be responsive to those technologies and to local circumstances. As demonstrated with large-scale wind and solar projects, local land use regulations can serve as a barrier or a conduit to renewable energy development [1–3]. This research shows that this has also been the case with different types of wood-burning energy technologies.

We found that the local regulatory landscape for wood energy across northern Michigan contained variation. More urbanized areas with greater population densities and higher income and education levels tended to have more detailed land use codes related to all scales of wood-burning, including residential wood heating, commercial-scale heating, CHP and power-only generation. Racial diversity as measured by the Shannon–Wiener Index was not statistically significant for places with or without wood-burning regulations. This may reflect the general lack of racial diversity across the project study area; most people living in northern Michigan identify as white. Instead, education and income levels—along with population density—were significant variables in community profiles for areas with detailed regulations and without. These findings were not surprising but important to consider when thinking about disparities between urban and rural populations in terms of how they relate to renewable energy development. Areas that did develop local ordinances to regulate wood energy technologies typically chose to incorporate recommended standards from entities such as the state Extension office rather than create their own. Developing the capacity of rural jurisdictions to develop and administer land use regulations that are tailored to local needs, with support from state, federal, and non-governmental organizations, will continue to be a key part of the shift to an equitable lower-carbon economy.

5. Conclusions and Implications for Policy

This research has important implications for policies related to the integration of renewable energy technologies, particularly in rural areas. Specifically, the research highlights the need to support local governance structures and the implementation of sound land use policies to effectively plan for renewable energy development. This research also raises important questions about equity related to wood-burning energy technologies. In the US, the percentage of households that use wood to heat their homes is highest in rural places and in the lowest income brackets. While many middle-income residents may use wood as a supplemental fuel source, the greatest overall wood fuel consumption is higher for lower income households [48]. Similarly, commercial-scale boilers and industrial-scale biomass power stations tend to be located in economically disadvantaged rural areas. These areas often lack the capacity for developing and enforcing land use regulations.

As different types of renewable energy technologies become more common, local land-use policies and planning processes are critical for ensuring that rural communities have meaningful input in how these technologies are adopted and deployed across heterogeneous landscapes. This paper reveals the importance of zoning and other local land use regulations in the development of wood energy technologies in northern Michigan. It also suggests the need for further research on how local planning processes influence the transition to a lower carbon economy in rural places. Addressing these issues will be critical for creating equitable and sustainable renewable energy policies that benefit all communities.

Author Contributions: Conceptualization, S.M., E.B., E.S. and M.C.; Formal analysis, J.W.; Funding acquisition, S.M.; Investigation, E.S., M.C. and M.M.; Methodology, E.B.; Project administration, S.M.; Visualization, J.W.; Writing—original draft, S.M., E.B. and E.S.; Writing—review and editing, S.M. and B.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Science Foundation’s Science and Technology Studies Program Award #1922030.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors wish to acknowledge Elizabeth Williams for their assistance with the project.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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