energies

MDPI

Article

Influence of Policy, Air Quality, and Local Attitudes toward Renewable Energy on the Adoption of Woody Biomass Heating Systems

Jesse D. Young [1], Nathaniel M. Anderson [2,*] and Helen T. Naughton [3]

1 School of Forestry, Northern Arizona University, Flagstaff, AZ 86011, USA; jdy28@nau.edu
2 Rocky Mountain Research Station, United States Forest Service, Missoula, MT 59801, USA
3 Department of Economics, University of Montana, Missoula, MT 59812-5472, USA; helen.naughton@mso.umt.edu
* Correspondence: nathanielmanderson@fs.fed.us; Tel.: +1-406-329-2122

Received: 1 October 2018; Accepted: 17 October 2018; Published: 23 October 2018

Abstract: Heat produced from woody biomass accounts for a significant portion of renewable energy in the United States. Economic and federal policy factors driving institutional adoption of woody biomass heating systems have been identified and examined in previous studies, as have the effects of state policies in support of biomass heating. However, plans for a number of mid- to large-scale biomass facilities have been abandoned after being proposed in communities with many of the factors and policies considered favorable to the adoption of such systems. In many of these cases, opponents cited potential negative impacts on local air quality, despite being generally in favor of renewable energy. This study employed a zero inflated negative binomial (ZINB) statistical model to determine if state policies, air quality, and local attitudes toward renewable energy have a significant effect on the adoption and retention of distributed-scale biomass combustion systems used for institutional heating. State policy appears to have a negligible effect, while the influences of historic and current air pollution and local emissions appear insignificant. However, local attitudes in favor of renewable energy are associated with the adoption and retention of distributed-scale woody biomass heating systems. This is an indication of the importance of local support in determining the fate of future biomass energy projects.

Keywords: bioenergy; woody biomass; heating; ZINB; policy; nonattainment; point source; local attitudes

1. Introduction

The United States of America (USA) has a variety of policies in place that encourage the expansion of renewable energy production as a means to ensure affordable, stable domestic energy and reduce greenhouse gas emissions. Currently in the USA, there are hundreds of private and public facilities that have adopted distributed-scale heating systems that use biomass as a fuel [1]. A variety of benefits can be associated with biomass heat, including on-site disposal of manufacturing byproducts (e.g., wood waste), lower fuel costs, substitution of fossil fuel with local renewable fuels, reduced emissions, and support of local forest management and forest industry [2,3]. In 2014, there were 401 known biomass heating systems installed in USA institutions such as schools, hospitals, government buildings, prisons, military bases, and other public buildings [1], primarily in Northeast states, the Lakes states, and Northwest states (Figure 1). Economic and federal (i.e., national) policy factors driving institutional adoption were identified in a previous study by Young et al. [4,5], and state policies in support of biomass systems were identified and examined by Becker, Mosely, and Lee [6] (Table 1). These studies have shown the adoption of biomass heating in the USA to be driven by heating needs, fossil fuel prices, and proximity to woody biomass resources [5].

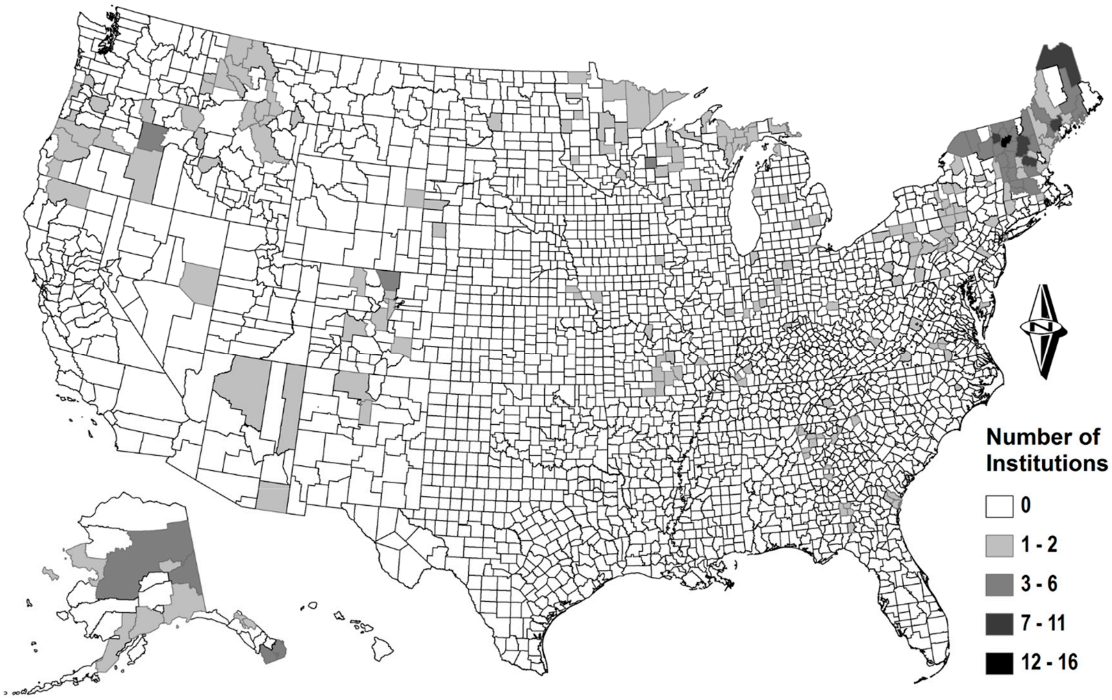

Figure 1. Number of institutions in each county using distributed-scale biomass heating in 2014, according to the Wood2Energy (W2E) database [1].

Though factors and policies supporting the of adoption of these systems have been identified, there are many municipalities and counties in the USA that are not using woody biomass space heating in any institutions, despite what are considered favorable characteristics such as cold temperatures, high fossil fuel costs, and close proximity to biomass sources. A recent choice experiment study carried out in Pennsylvania, USA, by Yoo and Ready [7] provides some insight as to why. Biomass combustion was viewed unfavorably by the population, as compared to other renewable energy options, and was associated with potential negative net benefits if adopted. In this light, additional research into potential factors limiting biomass adoption is required to fully understand the institutional use of biomass heating systems and possible constraints on the expansion of this renewable energy option.

With this goal in mind, the objective of this study is to examine the potential effects that policy, emissions, air quality and the public's attitude towards renewable energy, have on the adoption and retention by institutions of distributed-scale biomass heating systems. These variables have been hypothesized to have impacts on adoption, but have not been examined in previous studies on a nation-wide scale. The remainder of this section presents additional background, followed by a discussion of data sources, methods and model diagnostics in Section 2. Section 3 presents the results and Section 4 provides a discussion, with conclusions in Section 5.

1.1. Land Ownership and Policy Influence on Biomass Use

In the USA, there are a number of federal and state policies that support distributed-scale woody biomass energy production, which is part of a $6.5 billion woody biomass energy market [8]. The forest products industry has the largest market share at 68%, followed by residential heating with 20%, electric power generation with 9%, and commercial heating with the remaining 3% [9,10]. Distributed-scale biomass heating systems are most commonly used in commercial and institutional settings, which is the focus of this study.

Table 1. Policy instruments encouraging the use of woody biomass, derived from Becker et al. [6].

Policy Type	Policy Examples/Description
Tax Incentives	Sales tax credits—Qualified purchases of equipment designed to harvest, transport, or process biomass receive state sales tax exemption or reduction. Corporate or Production tax credits—Reduction or exemption in taxes based on use of biomass or production of biomass energy products. Personal tax credits—Reduction in income tax or tax credits for individual who have installed qualified renewable energy systems. Property tax credits—Reduction in property tax or tax credits for property (including equipment) used to transport biomass or site biomass facilities.
Cost Share and Grants	Cost-Share—Funds biomass use through fee waivers or additional resources used to purchase or operate biomass related equipment. Grants—Funds biomass use through competitive grants that can be used to purchase biomass equipment as well as biomass research and development. Rebates—Funds biomass use by paying for the purchase and/or installation of qualified biomass technologies.
Rules and Regulations	Renewable Energy Standards—The requirement that a percent of utility companies energy sales be derived from renewable sources. Interconnection Standards—Grid connection governance. Green Power Programs—Consumers have the option to purchase renewable energy. Public Benefit Funds—Portion of monthly energy bill is used for renewable energy development. Equipment Certifications—Minimal efficiency standards for biomass processing equipment. Harvest Guidelines—A set of best management practices for removing and procuring biomass.
Financing	Bonds—Government borrowing to finance construction of biomass boilers that heat industrial and institutional facilities. Loans (micro, low interest and zero interest)—Financial support for the purchase of equipment.
Procurement	Procurement—The use of bio-based products is mandated or incentivized in construction, transportation, and other sectors. Net Metering—Local utilities are required to buy back excess renewable electric power from producers.
Technical Assistance	Training Programs—Develops technical expertise of business owners and staff through courses and certification. Technical Assistance—Helps coordinate research and disperse information, as well as offering assistance for grant writing and business planning.

Federal and state policies in the USA influence both the supply of woody biomass as fuel and the installation of energy systems that use biomass. Proximity to biomass resources is consistently cited as strongly correlated with adoption of biomass energy systems. In the USA this factor is closely connected with land ownership and forest management policies, which vary widely across the country. The USA federal government owns about 28% of the land base, or 260 million ha [11]. The largest federal landholding agencies in the USA are the Bureau of Land Management (BLM; 100 million ha), the United States Forest Service (USFS, 78 million ha), and the Fish and Wildlife Service (FWS; 36 million ha) [11]. There is significant regional variation in federal ownership, with most federal lands occurring in the west of the country (93%), and relatively little in the east. Federal ownership accounts for almost half of the land base in the western continental USA (47%) and 62% of the land base in Alaska (Figure 2) [11]. However, national parks and wilderness areas are included in these proportions, and neither are a significant source of woody biomass from a market perspective. Timberlands are unreserved forestlands that meet a minimum productivity threshold, and are more closely tied to biomass supply. About 78% of USA timberlands are in private ownership, compared to only 22% in public ownership [12].

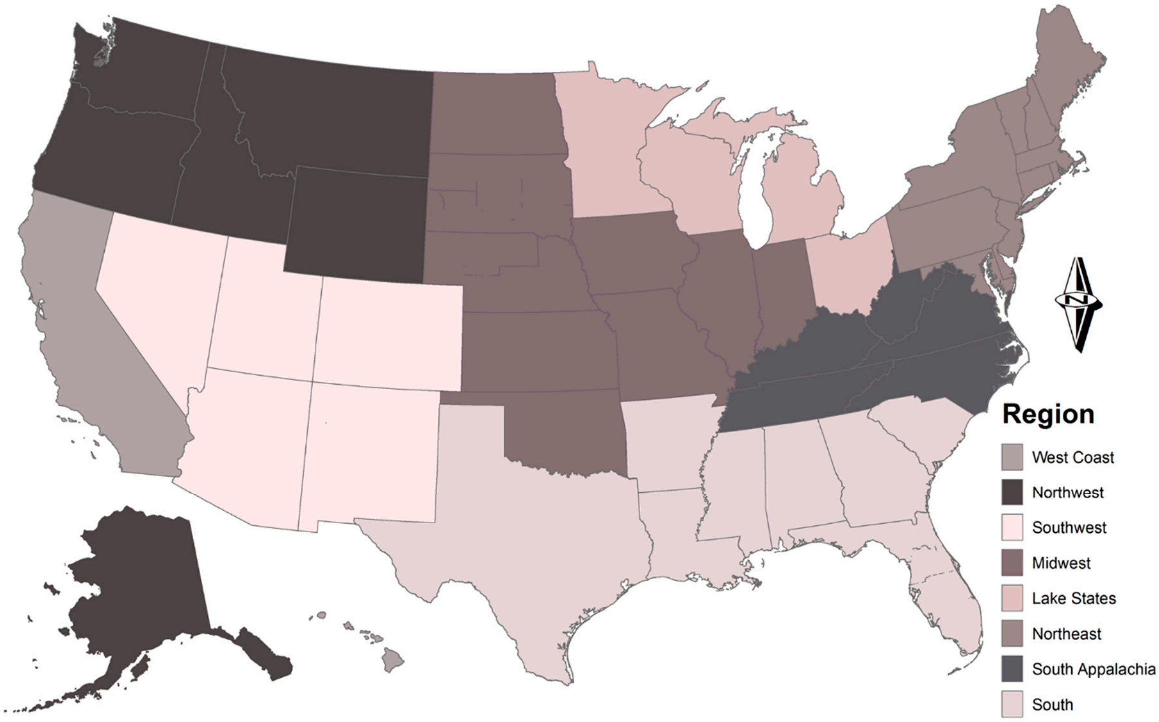

Figure 2. Map of regions used as indicator variables.

Private timberlands and some state lands provide significant amounts of biomass for energy, especially in the Northwest and South, which have widespread industrial timberlands and forest industry at large scale. Though timber production on federal land has declined significantly over the past 25 years, federal agencies have implemented a number of policies to encourage the removal and use of woody biomass resources on federal, state and private lands [13]. The USFS, BLM and other agencies prescribe silvicultural treatments for timber harvest and forest restoration, carry out forest thinning and biomass removal near communities at risk of wildfire [14], conduct research, provide education and consultation to the public [15], and award grants to businesses, schools, Indian tribes and others for biomass utilization. The USA Department of Energy (DOE), which is also a federal land holding agency (7.9 million ha), is particularly active in the education and research arenas, and cooperates with the United States Department of Agriculture (USDA) on biomass initiatives. The authority to conduct such activities is granted by a variety of laws and policies, including the National Fire Plan [16], the Biomass and Research Development Initiative (BRDI) [17], and the Healthy Forest Restoration Act [18].

Despite federal policies and agencies holding a major influence on the biomass market in the USA, state policies better reflect local and regional preferences, and challenges within local markets [19]. For example, many states have designed and implemented policies aimed at increasing the economic viability of biomass consumption. California aggressively pursued biomass energy production in the 1980s through the Interim Standard Offer 4 (ISO4), which provided guaranteed bioenergy rates for a limited time [20]. In 2008, Michigan passed the Clean, Renewable, and Efficient Energy Act (Public Act 295) to support its renewable energy sector [21]. For a comprehensive discussion on state policies in support of biomass refer to Becker, Mosely, and Lee [6].

1.2. Effects of Historic and Current Air Pollution on Biomass Use

Although there are a number of federal and state polices that support woody biomass as a renewable energy source, biomass use faces significant and unique constraints when compared to other renewables such as wind, solar/photovoltaic, and hydro. Unlike other renewable energy production, biomass energy is most commonly carried out through a combustion process that is associated with local and global air pollution. Modern combustion and gasification systems typically have lower emissions than their older counterparts [22] as the result of a variety of technological innovations, such as catalytic emissions controls [23]. However, the expansion of woody biomass heating and combined heat and power (CHP) can be limited by perceptions of biomass as a dirty fuel associated with smoke, especially in places subject to atmospheric inversions, seasonal wildfire smoke, and historical use of wood for residential heating in conventional wood stoves. In addition, the USA has a history of poor air quality as a result of utility and industrial combustions of fossil fuels that has resulted in human and environmental damage from smog [24–26], acid rain [27,28] and greenhouse gas emissions from the utility sector [29].

To reduce risk to human health and the environment from emissions, the USA Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) under the Clean Air Act (CAA) of 1970 for six criteria pollutants: particulate matter (PM) with a diameter greater than 2.5 micrometers (μm) but smaller than 10 μm (PM_{10}) and particulate matter 2.5 μm in diameter or smaller 2.5 ($PM_{2.5}$); sulphur dioxide (SO_2); nitrogen oxides (NOx); ozone (O_3); carbon monoxide (CO); and lead (Pb) [30]. Under the CAA, if NAAQS set by the EPA are exceeded for an area or county, steps are taken to classify the area as a "nonattainment area", which makes new industrial boilers subject to New Source Performance Standards (NSPS) to reduce and maintain criteria pollutants to acceptable levels [30]. Old facilities built before the passage of the CAA of 1970 are "grandfathered" under the law and are not subject to NSPS [31]. NSPS regulations for new boilers are set at three levels ($\leq$2.9 megawatt (MW), >2.9 and <8.8 MW, and $\geq$8.8 MW). Most new institutional biomass boilers are $\leq$2.9 MW, and are only required to tune-up their boiler unit every two years [32].

In addition to its potential to release criteria pollutants, support for renewable biomass energy is also affected by emissions of greenhouse gases (GHG). There are a number of communities in the USA that have commonly cited increased emissions as a reason for opposition to the installation of biomass fueled systems [33,34], some of which are ultimately abandoned due to fears of reduced air quality. Abandoned biomass systems include a biomass power project in Gretna, Florida, worth $250 million [35], a 43 MW biomass power plant in Tallahassee, Florida [36], a $16 million biomass gasification plant in Missoula, Montana [37], a $74 million plant in Torrance County, New Mexico [38], as well as two similar projects in Scott [39] and Crawford counties, Indiana [39,40]. Additionally, there are a number of biomass plants in Massachusetts that have faced aggressive public opposition, leading to government action to assess the environmental credentials of biomass plants to determine their eligibility for incentives and tax credits in support of renewable energy [35,36]. This resulted in a new Massachusetts state law that limits access to renewable energy certificates (REC) for biomass facilities that run at conversion efficiency rates less than 60% [35,41]. If applied nationally, a standard of this strict nature would classify about 50% of current operating biomass systems in the USA as non-renewable [41].

1.3. Effects of Local Attitudes and Community Acceptance on Renewable Energy

In addition to government regulation of emissions, local attitudes and community acceptance are important aspects of the adoption of renewable energy technologies [42,43]. Although local and global emissions are predominantly from the utility, industrial and transportation sectors, negative attitudes about emissions may have a negative effect on the adoption of smaller local biomass heating projects. However, local attitudes about the long-term effects of climate change and the role of renewable energy in mitigation may outweigh local emissions concerns, especially in the context of smaller distributed-scale systems that are under local control and in response to community energy initiatives [44]. Policies in support of biomass and biomass plants themselves are most successful when there is strong support by the local community [44]. In particular, polices related to climate change mitigation and adaptation are most successful when policy makers are keenly aware of influential social factors such as the public's awareness of climate change, the perceived risk climate change imposes, local support for renewable energy policy or policy preference, and the public's awareness of appropriate behaviors in response to climate change [45].

1.4. Purpose, Goals and Objectives

Public policy in the USA has encouraged expanding renewable energy production as a means to ensure affordable, domestic energy supply and to reduce greenhouse gas emissions. Hundreds of institutions across the USA have adopted the use of woody biomass as fuel in distributed-scale heating systems [1], and economic and federal policy factors driving adoption have been identified in previous studies [5,6]. Key economic factors include higher fossil fuel prices and more affluent communities, while effective policy drivers appear to be federal in scope and closely tied to the availability of woody biomass resources, especially proximity to biomass from logging and fire mitigation activities [5]. Even so, many communities that appear to have conditions favorable to institutional wood heating do not currently have any such facilities, indicating that there may be additional factors at work. Media reports and anecdotal evidence suggests that local opposition to woody biomass energy can be driven by unfavorable attitudes toward this energy source associated with air pollution.

The goal for this study is to gain a better understanding of the drivers of adoption beyond those that have been provided by previous research, and help inform public policy focused on the adoption of renewable energy technology. The primary objective of this study was to examine the potential effects that state policy, historic and current air quality, and the public's attitude towards renewable energy have on the adoption and retention of distributed-scale biomass heating systems. These variables were examined using a zero inflated negative binomial (ZINB) statistical model in order to determine the effects, if any, on the number of biomass heating facilities reported at the county level. We hypothesized that favorable state policies, comparatively good air quality, and public support for renewable energy are positively related to the presence of these systems.

2. Methods

2.1. Data

Tables 2 and 3 include a complete list of variables used in the ZINB model and this analysis, along with their sources, units and descriptive statistics. All 3142 counties or county equivalents (e.g., Parishes in Louisiana) in the USA are included. The USA capital, Washington D.C., is not included because the necessary data were not available. Counties are the smallest geographic unit with full USA Census and Energy Information Administration (EIA) data coverage. The Forest Inventory and Analysis Unit (FIA) of USFS reports forest residue production at the national scale on a county basis, but not at higher resolution to preserve the confidentiality of industry survey respondents. The response variable is the count of institutions using biomass in heating systems in each county. The count for each county was obtained from the Wood2Energy (W2E) database [1]. Of the 3142 counties there are 225 counties with institutional biomass heating systems and a total of 401 institutions using biomass fuels for heat (Figure 1). We used the 2014 W2E database because it was the most recent and up-to-date nation-wide census available at the time of the study; matched temporally with datasets used as predictors, which are discussed below; and is a benchmark year for the 2014 CAA amendment, which affects some biomass boilers [32]. The W2E is currently updated on a rolling basis as a comprehensive database of wood to energy conversion facilities in the USA and Canada [1].

2.1.1. Policy Variables

The literature often cites cost share, grants, public financing and other public policies as critical to the development of new biomass facilities due to the high start-up costs and long payback periods of these systems [46,47], but this hypothesis has not been adequately tested in the case of biomass heating systems. Data for the variable State 'Total Policies' encouraging the use of woody biomass was obtained from a previous study by Becker, Mosely, and Lee [6]. In a model extension 'Total Policies' is further divided into different policy types (Tables 1 and 3). An increase in the number of policies encouraging the use of biomass is expected to increases the count of institutions in a county using biomass.

Table 2. Variables used in the zero inflated negative binomial (ZINB) model. Resolution of the data is by county, with 3142 counties in the dataset, except for natural gas price and total policies, which are at the state resolution.

Variable	Description	Units	Source
	***Y*—Dependent Variable**		
Institutions	Institutions using biomass heating systems	institutions (count)	Wood2Energy Database, 2014
	γ—Zero Inflated (ZI-Binary)		
Heating degree days (HDD)	1981–2010—Total average heating degree days	HDD (1000)	USA National Oceanic and Atmospheric Administration, 2014
Population density	2010—Population density	people per km^2	USA Census Bureau, 2013
Forest residue	2007—logging residues and other removals	m^3 (1×10^7)	USDA, USFS Timber Product Output, 2007
	β—Negative Binomial (NB-Count)		
Heating degree days (HDD)	1981–2010—Total average heating degree days	HDD (1000)	USA National Oceanic and Atmospheric Administration, 2014
Natural gas price	2008–2010—Commercial natural gas three-year average price	USA dollars ($) per 1000 ft^3	USA Energy Information Administration, 2013
House value	2008–2012—Median value of owner-occupied housing	USA dollars ($) (1000)	USA Census Bureau, 2013
Forest residue	2007—Logging residues and other removals	m^3 (1×10^7)	USDA, USFS Timber Product Output, 2007
Biomass planned removal	2006–2010—Biomass removal planned in National Fire Plan	m^2 (1×10^6)	National Fire Plan Operating and Reporting System, 2006–2010
Federal land	2005, 2012—Proportion of land managed by Federal Agencies	proportion	National Atlas of the USA and the USA Geological Survey, 2005, 2012
Population	2010—Population	people (1×10^5)	USA Census Bureau, 2013
Road density	2013—Primary (interstates) and secondary road (main state and county highways)	m of road per 1000 m^2 area	USA Census Bureau, 2013
Port capacity	2008–2012—Average port capacity of ports	short tons (1×10^5)	USA Army Corps, 2014
County area	2010—County Area	m^2 (1×10^9)	USA Census Bureau, 2013
Total policies	2011—Total number of state policies that effect forest biomass use directly or indirectly	policies (count)	Becker, Moseley, and Lee, 2011
PM_{10} historical emissions	1978–2004—Total number of years county was in PM_{10} nonattainment	years (count)	USA EPA, 2015
PM_{10} recent emissions	2005–2015—Total number of years county was in PM_{10} nonattainment	years (count)	USA EPA, 2015
$PM_{2.5}$ recent emissions	2005–2015—Total number of years county was in $PM_{2.5}$ nonattainment	years (count)	USA EPA, 2015
SO_2 historical emissions	1978–2004—Total number of years county was in SO_2 nonattainment	years (count)	USA EPA, 2015
SO_2 recent emissions	2005–2015—Total number of years county was in SO_2 nonattainment	years (count)	USA EPA, 2015
CO_{2e} emissions	2013—Point Source emissions of greenhouse gases	tonne CO_{2e}	USA EPA, 2013
RPS support	2015—Local support for RPS	proportion	Howe et al., 2015

Among the variables included in the model, 'Total Policies' is the most likely to exhibit characteristics of endogeneity, violating the assumption of exogenous predictors for this model.

Endogeneity gives a false signal of causal association [48], and in this case, could come from at least two sources. First, biomass policies can be passed to support existing biomass plants, rather than to support new plants. Second, it is possible that woody biomass policies are only passed in states with woody biomass resources. These sources of endogeneity are unlikely because small biomass heating systems are relatively rare among institutions in the USA. Because of their low consumption of woody biomass and relatively small impact on the energy sector, they are not generally the focus of policy. Additionally, the wide breadth of renewable policies used in the USA target renewable energy in general or in other sectors (e.g., biofuel), rather than being focused directly on woody biomass. Under conditions of endogeneity, one would expect moderate to high correlation between the number of policies and the number of institutions, but this is not observed in our dataset, which has a correlation of r = 0.03 for 'Total Policies' and a maximum of r = 0.11 for the 'Cost Share/Grant' type policies. Two proxies for federal policies have been included with state policies as controls based on their significance in prior work [4,5]: federal land ownership and the total acres of fuel treatments under the National Fire Plan.

Table 3. Descriptive statistics for the variables used in the ZINB model, including the number of observations (obs.), mean, standard deviation (std. dev.), minimum value (min) and maximum value (max).

Variable	Obs.	Mean	Std. Dev.	Min	Max
Institutions	3143	0.127585	0.675534	0	16
Heating degree days	3143	4.996686	2.191648	0.002182	19.09467
Population density	3143	1.001250	6.657018	0	268.2155
Natural gas prices	3143	10.43197	1.830150	7.38	35.18666
House value	3143	131.8983	80.61617	0	944.1
Forest residues	3143	2.466242	4.632817	0	70.0118
Biomass NFP	3143	2.415140	12.80937	0	250.9294
Proportion federal lands *	3143	0.126889	0.239603	0	1.062016
Population	3143	0.982328	3.129012	0.00082	98.18605
Road Density	3143	0.204257	0.199780	0	2.650168
Port Capacity	3143	1.013043	9.286781	0	234.2816
County Area	3143	2.910467	9.353530	0.00518	376.8557
Latitude	3142	18.40748	63.69796	−126.638	433.3846
Longitude	3142	34.46994	104.9199	−621.637	219.9037
West Coast	3143	0.020045	0.140175	0	1
South	3143	0.258988	0.438149	0	1
Lake States	3143	0.104995	0.306596	0	1
Northeast	3143	0.077633	0.267636	0	1
Northwest	3143	0.072224	0.258900	0	1
Midwest	3143	0.255170	0.436026	0	1
Southwest	3143	0.050270	0.218537	0	1
Total Policies	3142	7.247295	3.757148	2	15
Cost Share Grants	3142	0.931891	1.279653	0	6
Technical Assistance	3142	1.488542	1.570085	0	6
Financing	3142	0.543921	0.675076	0	3
Procurement	3142	1.305856	1.026406	0	4
Rules and Regulations	3142	1.048695	1.222930	0	3
Tax Incentives	3142	1.928390	1.973793	0	10
PM_{10} Historical Emissions **	3143	1.69965	4.823705	0	27
PM_{10} Recent Emissions **	3143	0.1384028	1.17593	0	11
$PM_{2.5}$ Recent Emissions **	3143	0.6757875	2.378869	0	11
SO_2 Historical Emissions **	3143	0.4492523	2.916603	0	27
SO_2 Recent Emissions **	3143	0.0591791	0.609962	0	11
CO_{2e} Emissions	3143	964279.2	2933563	0	49400820
Proportion of RPS Support ***	3143	0.5809858	0.045522	0.4499687	0.7835159

* Proportion of federal land maximum exceeds 1 because the numerator contains both federal land area and inland federal waterways, while the denominator contains only federal land area. This has resulted in a proportion of federal land above one for 22 of 3142 counties. ** Contains both partial and whole counties in nonattainment of the criteria pollutant. *** Proportions are calculated using estimated population in support/not in support of RPS. Supplemental data to Howe et al. [45].

2.1.2. Emissions Variables

In addition to policy effects, the effect of historic and current air pollution on the adoption of distributed-scale biomass heating systems are assessed using data for a number of different variables gathered by the EPA and published in public databases and reports. Variables were chosen to capture the effects of smog and other visible air pollutants, as well as non-visible pollutants such as acid rain contributors and GHG emissions. These emissions were primarily from industrial, utility and transportation sector combustion of fossil fuels, but they can affect the public's preference toward the adoption of biomass heating systems because biomass combustion systems have point source stack emissions (unlike wind, solar and water power, for example). Visible pollutants are quantified using historic and current nonattainment data of PM. Non-visible pollutants are quantified using historic and current nonattainment data of SO_2, which is a major contributor to acid rain. Total GHG emissions are quantified in carbon dioxide equivalent (CO_{2e}) from point source polluters.

The general expectation is that counties with comparatively good air quality and emissions profiles would be more likely to adopt woody biomass heating systems because residents are not subject to smog and other pollutants at levels that would make them oppose any new stack emissions. Furthermore, installation would not be subject to strict regulations and oversight found in areas with poor air quality. However, we recognize two alternatives: (1) counties with comparatively good air quality might be less likely to adopt because these systems would be seen as a threat to existing good air quality, and (2) counties with comparatively poor air quality and emissions profiles are more likely to adopt because these systems are not seen as making much of a marginal difference. The a priori hypothesis was one of a positive statistical relationship between higher air quality and adoption.

Particulate Matter

Effects of PM on adoption were captured using data for criteria pollutants collected by the EPA under the Ambient Air Quality Standards (AAQS), which is a regulatory standard linked to health effects. Like all combustion processes, the combustion of woody biomass creates PM in the form of inorganic material (i.e., ash particles) and organic material (i.e., carbon rich soot, tar and char) [49]. PM from biomass combustion is believed to display carcinogenic properties [50,51], and is known to have negative health effects on cardiovascular and respiratory systems, especially in regards to the development and progression of chronic obstructive pulmonary disease [52].

Nonattainment of PM has historically been measured in three ways. Beginning in 1978, the EPA tracked total suspended particulate (TSP) until 1990, when a 1987 rule took effect, which only regulated PM with a diameter less than 10 μm [53]. Then in 2005 a 1997 rule took effect that began to regulate PM in two distinct categories [53,54]: (1) inhalable coarse particles larger than 2.5 μm and up to 10 μm (PM_{10}) commonly associated with roadways and dust producing industries such as farming and gravel production, and (2) fine particles up to 2.5 μm ($PM_{2.5}$) commonly associated with visible smog and smoke in the air [54]. Due to the structural break in PM definitions in 2005, 'PM_{10} Historical Emissions' is measured as the count of years the county was in AAQS nonattainment from 1978 to 2004, which includes both TSP and PM_{10} nonattainment. Current nonattainment of PM is separated into two distinct variables as allowed by the data available: (1) 'PM_{10} Recent Emissions' as the count of years the county was in nonattainment for PM_{10} from 2005 to 2015, and (2) '$PM_{2.5}$ Recent Emissions' as the count of years the county was in nonattainment for $PM_{2.5}$ from 2005 to 2015. Congruent with the broad hypothesis described previously, an increase in nonattainment for any of the three measures of PM is expected to decrease the expected count of institutions in a county using biomass for heating.

The inclusion of historic and current PM nonattainment requires some general assumptions and temporal considerations. It is assumed that the USA population has a general knowledge of negative health effects and living standards tied to visible PM in the air shed in the form of smog or smoke, and that the installation of distributed-scale biomass boilers will contribute to PM pollution. We also assume that the decision of public officials to install institutional biomass boilers takes into consideration the costs and benefits to the local community, as well as public attitudes toward (e.g., preference for) renewable energies. There is also a temporal consideration that must be considered. This econometric analysis is a cross sectional study using the 2014 state of institutional biomass heating and historical nonattainment to quantify PM as a possible barrier to new installations, whereas NSPS regulations were put into place after the installation of some of the institutional biomass boilers currently in use, and therefore not all installations were affected by new standards passed under the CAA of 1978, 1990, or the 2014 amendment. However, this is not a concern within the context of this study because most institutional biomass boilers are small enough that NSPS regulations would not have affected them until new regulations were passed for boilers installed after February 2014. These new regulations require bi-yearly maintenance and do not include a PM cap [32].

In addition to assumptions and temporal considerations, local and state regulations pertaining to air quality, which are limited in number and occur mostly in the Northeast USA [32], are also captured in the qualification of nonattainment areas. This is because it is the responsibility of the localities to initiate a State Implementation Plan (SIP), which is a technical and strategic document outlining an emissions reduction strategy [30]. SIPs can contain regulation for both point source pollutants (i.e., stack emissions) and non-point sources (i.e., vehicle idle laws). If localities fail to submit a SIP or fail to address all EPA mandated items, which is rarely the case, the EPA will institute a Federal Implementation Plan (FIP) designed to bring emissions down to an acceptable level [30]. This interaction between the nonattainment designation and local emissions planning makes the attainment variable broader than a simple federal benchmark for air quality.

Acid Rain

In addition to including PM for capturing the negative effects of visible air pollution, nonattainment for the non-visible criteria pollutant SO_2 was also included to capture the effects that local emissions of acid rain constituents may have on adoption of distributed-scale biomass heating. Nitrogen oxides (NOx) were also considered as a variable, but were not included directly due to a lack of sufficient data coverage. However, the effects of NOx are included indirectly by including the county population, which is closely associated with vehicle emissions, a major source of NOx [55]. Major sources of SO_2 and NOx emissions, respectively, are coal fired power plants, and gasoline and diesel fueled transportation emissions [55,56]. Like PM, SO_2 is included in both 'SO_2 Historic Emissions' and 'SO_2 Recent Emissions', which are measured as the count of years the county was in nonattainment from 1978 to 2004 and 2005 to 2015, respectively. An increase in the number of years a county is in either historic or current SO_2 nonattainment is expected to decrease the likely count of institutions in the county using biomass for heat. In addition, the general assumptions, temporal considerations, and local and state regulations discussed in respects to PM, apply to SO_2 as well.

Well-known regional variation in the pattern of acid rain deposition highlights the importance of including the regional variable in the model. Due to a combination of emissions and weather patterns, as well as the susceptibility of soils, transboundary SO_2 and NOx emissions from Midwest states have been known to effect large geographic areas in the Northeast and Canada [56], and more recently the Southeast [27,57]. The most visible effect has been large scale tree mortality and associated ecosystem degradation on soils that are susceptible to acid rain effects [55,58]. Historically, western states have avoided emitting large volumes of acid rain catalysts due to lower population density and power plants fueled with coal that contains less sulfur than coal used by Midwestern plants [27]. However, in recent years, these trends have changed due to rapid population growth and expansion of cattle feedlots that have contributed large quantities of NOx from vehicle emissions and manure [59]. Resulting acid precipitation can be very damaging to western alpine soils, even at low levels [28]. Although direct links between acid rain and ecosystem degradation are well known [50,56,58,60], similar direct links with human health have not been strongly established [61,62].

Greenhouse Gases

Although local and regional negative health and environmental effects of PM and SO_2 are more direct than the effect of global climate change attributable to GHG emissions, these emissions are also cited by biomass energy opponents and therefore are included in this study. Greenhouse gas emissions are included as 2013 'CO_{2e} Emissions' from new point source emitters under the NSPS [63]. Due to the negative effects of climate change and the public's potential perception of biomass combustion being a net positive contribution to CO_{2e} emissions, it is expected that as local CO_{2e} emissions increase there will be a decrease in the likely count of institutions using distributed-scale biomass heating.

It is important to note that, although each of the above emissions variables could be viewed as having endogenous properties, distributed-scale biomass heating systems emit relatively low levels of PM, SO_2 and CO_{2e} due to their small size and limited use, both historically and currently. Rather than testing biomass emissions explicitly, this paper focuses on total emissions to determine what effect, if any, they have on the adoption and retention of biomass heating systems. Again, this is related to the overall attitudes of people toward combustion-based biomass heating as it relates to local air quality and emissions, and not to a fined-grained, high resolution differentiation between various sources of emissions. Also, as noted above, another important source of emissions is vehicle exhaust, which is the most common source of NOx emissions [55]. This has been controlled for by the inclusion of population, which is highly correlated with vehicle emissions, but also many other potential air pollution constituents.

2.1.3. Local Attitudes

The effect that local attitudes toward renewable energy have on the adoption and retention of distributed-scale biomass heating systems is quantified using county level estimates from previous research [45]. In the past, local attitudes towards renewable energy have not been accessible due the limited sample size of national polling, which cannot be easily disaggregated into states or counties [45]. Recently, Howe and his colleagues have devised a process to acquire local attitudes from national polling data that can accurately estimate county-level opinions [45]. While increased local air pollution may negatively affect the public's preference for biomass combustion as previously described, and cited by stakeholders [35–40], this effect may be outweighed by positive local attitudes towards renewable energy and associated policy incentives, such as renewable portfolio standards (RPS). RPS require utilities to produce a specified portion of their energy from renewable sources. Local attitudes in favor of RPS is measured as a proportion of the county's population [45]. Though local attitudes in favor of RPS may have endogenous properties, this is not of concern in this case because distributed scale biomass heating systems represent a small proportion of the renewable energy sector, and their presence is unlikely to affect local attitudes towards renewable energies relative to the aggregate of other local influences. An increase in the proportion of the population in support of RPS is expected to increase the likely count of institutions in a county using biomass for heating.

2.1.4. Other Control Variables

There are a number of other variables that affect the count of biomass heating systems in a county, and these have been identified and described in previous research [4,5]. These include significant location dependent variables such as heating degree days and the quantity of forest residues from logging operations, as well as significant economic indicators such as natural gas prices and median house value, which represent the cost structures of competing heating fuels and the aggregation of economic activities, respectively. We also controlled for federal policies implicitly through federal land ownership and fuel treatments under the National Fire Plan, which is related to biomass fuel supply. In addition, we included significant geographic controls to control for spatial variability. They include regional indicator variables (Figure 2) and the latitude and longitude of each county geographic centroid. Other significant variables included as controls for local infrastructure are port capacity and road density. For more information on these control variables and their data sources refer to [4,5]. For a complete list of model variables, units and sources used in this analysis and their descriptive statistics refer to Tables 2 and 3.

2.2. Statistical Methods

Of the 3142 counties in our dataset there are 225 counties with institutional biomass heating systems (i.e., non-zero observations) with a total of 401 institutions using biomass for heat. This means that 2917 counties have a count of zero, which must be considered in the statistical design. Ignoring zero inflation can result in biased standard errors and overestimations [64,65]. In addition to considering how excessive zero counts affect model estimates, the origin of zero counts must also be considered [64]. If zeros in count data are believed to come from a single data generating process (DGP) in the sample, and represent true zero counts, then Zero Altered (i.e., Hurdle) models are appropriate [64,65]. However, in our case zero counts are believed to come from multiple DGP with excess zeros due to structural barriers, in part connected to the Law of Location for Extraction Industries, which states that extractive industries are, and must continue to be, located near their raw materials [66]. Counties with zero or very low biomass resources are likely to have zero counts that represent structural zeros. Similarly, counties with a very low population or a very low number of cold days are also likely to have structural zero counts of institutions that use biomass for heat.

Under the condition that structural zeros are believed to be intermixed with true zeros from sampling chance, theory suggests Zero Inflated (ZI) models are superior to their Zero Altered counterparts because structural zeros are modeled independently from true sample zeros [64,67]. Furthermore, in cases where zero inflation is evident, there is a high chance of overdispersion, making the ZINB distribution an attractive alternative to the Zero Inflated Poisson (ZIP) distribution [64]. The ZINB model used in this study models structural zeros and sample zeros independently. Structural zeros result from counties with structural constraints such as a lack of heating needs (i.e., warm temperatures) or lack of biomass resources, and are predicted using a ZI model (logistic model) step. Sample zeros result from counties that are otherwise suitable for woody biomass heating with regards to structural zeros (i.e., they have heating need and biomass resources), but have not adopted biomass heating in any institution. These follow a negative binomial (NB) distribution (i.e., a count model). Theory and count data strongly suggest that a ZINB mixed model is the preferable model in this case because the data appear to be both zero inflated and overdispersed, with multiple DGPs.

In the ZINB model the count of institutions using woody biomass is Y_i, where $i = 1, 2, \ldots, n$ has a probability mass function given by:

$$\Pr(Y_i = y_i) = \begin{cases} p_i + (1-p_i)\left(\frac{\phi}{\mu_i+\phi}\right)^{\phi}, & \text{if } y_i = 0; \\ (1-p_i)\frac{\Gamma(\phi+y_i)}{\Gamma(y_i+1)\Gamma(\phi)}\left(\frac{\mu_i}{\mu_i+\phi}\right)^{y_i}\left(\frac{\phi}{\mu_i+\phi}\right)^{\phi}, & \text{if } y = 1,2,\ldots,n, \end{cases} \quad (1)$$

where $\Pr(Y_i = y_i)$ is the probability of county i containing y institutions using woody biomass, $0 \leq p_i \leq 1$, $\mu_i \geq 0$, ϕ^{-1} is the dispersion parameter with $\phi > 0$, and $\Gamma(\cdot)$ is the gamma function [68]. The mean and the variance are $E(Y_i) = (1-p_i)\mu_i$, and $Var(Y_i) = (1-p_i)\mu_i(1+\mu_i\phi^{-1}+p_i\mu_i)$. When $p_i = 0$, the dependent variable Y_i has NB distributed parameters with the mean μ_i and dispersion parameter ϕ (i.e., $Y_i \sim NB\ (\mu_i, \phi)$) [68].

In application, the parameters μ_i and p_i depend on vectors of explanatory variables z_i and x_i, respectively, resulting in the following models [68]:

$$\log\left(\frac{p_i}{1-p_i}\right) = z_i^T\gamma \text{ and } \log(\mu_i) = x_i^T\beta,\ i = 1,2,\ldots,n, \quad (2)$$

where $\gamma = (\gamma_1, ..., \gamma_q)^T$ and $\beta = (\beta_1, ..., \beta_s)^T$ are unknown parameters for the ZI and NB models, respectively, q is the number of explanatory parameters in the ZI model, and s is the number of explanatory parameters in the NB model.

Three variables are included in the ZI model step with a theoretical basis to generate structural zeros. The first, 'Heating Degree Days' is measured in thousands of heating degree days as determined by the USA National Oceanic and Atmospheric Administration (NOAA) [69]. For every degree below 65 degrees Fahrenheit (°F) on any given day, the county receives a heating degree day equal to the difference between 65 °F and the average temperature, which results in an average of 5000 heating degree days across all counties. This is a proxy for local heating requirements, with the assumption that warm locations with little need for heat are likely to exhibit structural zeros. The second variable, 'Population Density' measured as residents per 1,000,000 square meters (1 square kilometer), was included to further control for the institutional heating needs of the county. Counties with very low population density are less likely to support schools, hospitals, government buildings, prisons, military bases, and other public buildings that require heat at the institutional scale, and are therefore more likely to exhibit structural zeros. The third and final variable in the ZI model, 'Forest Residues', includes both logging residues and other biomass generated by forest management activities, and is measured in tens of millions of cubic meters [70]. Communities that are distant from woody biomass resources are expected to have structural zeros because they are less likely to install systems that require this fuel. An increase in each of the variables in the ZI model step is expected to increase the count of institutions using woody biomass as a fuel source. The NB step of the model includes the predictor variables shown in Table 2, with various hypothesized relationships discussed earlier in this section.

It should be noted that domestic production of woody biomass from forests as measured by the variable 'Forest Residues' is directly connected to active forest management and was included as a proxy for woody biomass supply. It was impossible to accurately and directly quantify woody biomass supply at a national scale at county resolution using market data because such data do not exist. Several other sources of woody biomass could be considered, such as urban wood waste, dedicated energy crops, and biomass imported from other countries. However, in the case of distributed-scale biomass thermal energy in the USA, the vast majority of fuel is provided by forests relatively close to the facility in the form of wood chips, cord wood and bulk pellets [4]. This supports the use of 'Forest Residues' as a metric of woody biomass fuel supply.

2.3. Model Diagnostics

As discussed previously, a variety of different models have been developed that account for large zero counts. An important step in all data modeling is checking both the model assumptions as well as model performance compared to alternative modeling techniques. In this case, competing models include: (1) the un-nested NB model for overdispersed count data that are not zero inflated, (2) the nested Poisson model for count data that are not overdispersed nor zero inflated, and (3) the ZIP for zero inflated count data that are not overdispersed. Recall ZINB models are designed for data that are both overdispersed and zero inflated. Model diagnostics and comparisons were carried out using STATA (STATA 12.1, StataCorp LP, College Station, TX, USA) [71]. Model selection was carried out using a series of three tests: (1) a t-test on the dispersion parameter alpha (α) to determine if there is overdispersion in the response, indicating the NB distribution is preferred to the Poisson distribution (Table 4); (2) a Vuong test [72] of the un-nested ZINB and NB models to determine if overdispersion in the response is the result of zero inflation (Table 5); and (3) a likelihood ratio test of the ZINB model and nested ZIP model to confirm that the ZINB model does a better job modeling zero inflation than the ZIP model (Table 5). These tests were chosen because they are widely used to compare such models [67,68], and are relatively easy to interpret. Test results showed a preference for the NB, ZINB and ZINB models, respectively, with each being statistically significant at the 1% level for all three models. For the Vuong test, the null hypothesis that NB is preferred to ZINB is rejected. For the likelihood ratio test, the null hypothesis that the ZIP is preferred to ZINB is rejected.

In addition to formal statistical tests, the percent of counties correctly predicted was calculated (Table 4), and a comparison of actual and predicted counts was prepared (Table 6). The percent of counties correctly predicted to contain their actual count of woody biomass heating systems within ±0.49 institutions was 92.08% and 92.27% for Models 1 and 2, respectively (Table 4). Furthermore, the percentage of counties that are predicted to have a zero count in Model 1 and Model 2 are 92.92% and 92.94%, respectively, which are very close to the actual percentage of 92.84% (Table 6). In summary, model diagnostics supported the use of the ZINB model in this case.

Table 4. Results for the Zero Inflated Negative Binomial (ZINB) Model 1 and Model 2.

Dependent: Institutions	**Model 1**				**Model 2**			
Independent Variables	Coefficient	OR IRR	Robust SE	p	Coefficient	OR IRR	Robust SE	p
Zero Inflated (ZI-Logistic)								
Heating Degree Days	−0.214 *	0.807	0.122	0.08	−0.194 *	0.824	0.107	0.07
Population Density	−0.050 *	0.951	0.029	0.08	−0.050 *	0.951	0.029	0.09
Forest Residues	−2.111 ***	0.121	0.794	0.01	−2.045 ***	0.129	0.695	0.00
_cons	2.854 ***		0.903	0.00	2.666 ***		0.819	0.00
Negative Binomial (NB-Count)								
Heating Degree Days	0.195 *	1.215	0.105	0.06	0.160	1.174	0.099	0.11
Natural Gas Prices	0.232 ***	1.261	0.058	0.00	0.187 ***	1.206	0.066	0.00
House Value	0.002	1.002	0.001	0.13	0.001	1.001	0.001	0.39
Forest Residues	0.001	1.001	0.007	0.90	0.000	1.000	0.007	1.00
Biomass NFP	0.008 **	1.008	0.004	0.04	0.009 **	1.009	0.004	0.03
Proportion Federal Land	0.851 ***	2.343	0.299	0.00	0.845 ***	2.329	0.289	0.00
Population	−0.022	0.978	0.038	0.56	−0.006	0.994	0.036	0.87
Road Density	−1.302 **	0.272	0.591	0.03	−1.456 **	0.233	0.618	0.02
Port Capacity	−0.014 *	0.987	0.008	0.08	−0.013 *	0.987	0.007	0.07
County Area	0.001	1.001	0.002	0.71	0.001	1.001	0.001	0.56
Latitude	0.009 ***	1.009	0.003	0.01	0.009 ***	1.009	0.003	0.00
Longitude	0.009 ***	1.009	0.002	0.00	0.010 ***	1.011	0.002	0.00
West Coast	1.549	4.707	1.216	0.20	1.492	4.446	1.224	0.22
South	1.039 **	2.828	0.450	0.02	0.650	1.916	0.429	0.13
Lake States	1.240 ***	3.456	0.413	0.00	1.092 **	2.980	0.431	0.01
Northeast	1.161 ***	3.192	0.387	0.00	1.024 **	2.785	0.467	0.03
Northwest	2.730 ***	15.333	0.676	0.00	2.983 ***	19.755	0.716	0.00
Midwest	1.821 ***	6.180	0.457	0.00	1.483 ***	4.405	0.409	0.00
Southwest	3.686 ***	39.868	0.652	0.00	3.646 ***	38.336	0.642	0.00
Total Policies	−0.049 **	0.953	0.025	0.05				
Cost Share Grants					−0.101	0.904	0.096	0.29
Technical Assistance					−0.003	0.997	0.063	0.97
Financing					0.109	1.115	0.129	0.40
Procurement					−0.332 ***	0.717	0.110	0.00
Rules and Regulations					0.052	1.054	0.080	0.51
Tax Incentives					−0.118 ***	0.888	0.045	0.01
PM_{10} Historical Emissions	0.016	1.016	0.015	0.28	0.012	1.012	0.015	0.41
PM_{10} Recent Emissions	0.013	1.013	0.045	0.77	0.033	1.034	0.047	0.48
$PM_{2.5}$ Recent Emissions	0.007	1.007	0.034	0.83	0.006	1.006	0.035	0.86
SO_2 Historical Emissions	0.027	1.027	0.020	0.19	0.028	1.029	0.019	0.15
SO_2 Recent Emissions	0.017	1.018	0.108	0.87	0.008	1.008	0.093	0.93
CO_{2e} Emissions	−0.000	1.000	0.000	0.40	−0.000	1.000	0.000	0.57
RPS Support	6.913 ***	1005.638	1.837	0.00	7.512 ***	1829.667	1.825	0.00
cons	−11.656 ***		1.447	0.00	−10.904 ***		1.463	0.00
lnalpha cons	−0.604 *		0.340	0.08	−0.766 **		0.357	0.03
alpha cons	0.546 ***		0.186	0.00	0.465 ***		0.166	0.01
N	3142				3142			
Log Likelihood	−783.66				−776.67			
Chi Square	524.44				626.96			
% correctly predicted ± 0.499 residual	92.08%				92.27%			

The base case for the regional control is South Appalachia. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 5. Tests of ZINB model fit.

	Vuong Test [a] ZINB vs. NB		Likelihood Ratio Test [b] ZINB vs. ZIP	
	Statistic (V [c])	***p*-Value**	**Statistic (z-score)**	***p*-Value**
Model 1	4.18	<0.0001	29.31	<0.0001
Model 2	4.16	<0.0001	24.79	<0.0001

[a] H_0: NB is preferred to ZINB. [b] H_0: ZIP is preferred to ZINB. [c] V is the Vuong statistic as described by Vuong [72].

Table 6. Actual count versus predicted count using the model.

Institutions	Actual	Predicted	Difference
Model 1			
0	92.84%	92.92%	−0.08% pts.
1	04.87%	04.90%	−0.03% pts.
2	01.15%	01.11%	0.04% pts.
3	00.60%	00.42%	0.18% pts.
4	00.16%	00.22%	−0.06% pts.
5	00.06%	00.13%	−0.07% pts.
Model 2			
0	92.84%	92.94%	−0.10% pts.
1	04.87%	04.91%	−0.04% pts.
2	01.15%	01.08%	0.07% pts.
3	00.60%	00.41%	0.19% pts.
4	00.16%	00.21%	−0.05% pts.
5	00.06%	00.13%	−0.07% pts.

Note: Actual, Predicted, and Difference values for institution counts 6 to 16 are not included, but are all <0.01% and <0.01% pts., respectively.

3. Results

3.1. Model 1

The response variable is the number of institutions using biomass heating systems within a county's borders, and in the base model (Model 1) is predicted depending on local air quality, emissions and local attitudes towards RPS. In Model 2 biomass energy policy was further split by policy type to evaluate which policy instruments are associated with an increased number of woody biomass heated institutions. Looking at Model 1 (Table 4) most of the variables are robust to results from previous studies [4,5]. The odds of a structural zero (odds ratios (OR), Table 4) significantly decreases with higher heating degree days, higher population density, and higher forest residues. Variables that significantly increase the likelihood that an institution is using a woody biomass heating system (incidence rate ratio (IRR), Table 4) include 'Heating Degree Days', 'Natural Gas Prices', the available 'Biomass Planned' under the National Fire Plan, and the proportion of 'Federal Lands'. On the other hand, an increase in 'Road Density' and 'Port Capacity' significantly decreases the likelihood of institutions using woody biomass, possibly because high levels of infrastructure indicate highly urbanized areas.

Also, in the NB model step, 'Total Policies' is negatively associated with institutional biomass heating at the 5% significance level. For each additional biomass policy, the likely count of institutional biomass heating systems changes by a factor of 0.953, ceteris paribus (Table 4). A priori, we hypothesized that policy variables would have a positive effect on the number of institutions. Additionally, and the significant negative association is counterintuitive given the prior work of Aguilar et al. [19] and Song et al. [73], who note that regional government incentives provided by a variety of policy instruments can stimulate biomass consumption. There are many possible explanations for this result, but to understand this phenomenon further Model 2 separates 'Total

Polices' into policy types based on prior work by Becker, Mosely, and Lee [6] (Tables 1 and 3), which is discussed in the next section.

Model 1 provides no statistical or economic evidence that county-level emissions and air quality influence the adoption and retention of institutional biomass heating systems. This includes both emissions of visible PM pollutants that are connected with smog and smoke and also high levels of SO_2. In addition, GHG emissions measured in CO_{2e} from new point source emitters held no statistical or economic influence. These results are robust to the removal of local attitudes towards RPS and the removal of median house value from the model. Though the prior hypothesis was one-tailed in favor of high air quality connected to stronger adoption, the result stands also for the opposite relationship.

In contrast to the emissions-adoption relationship, there is evidence that local attitudes towards RPS standards have both a statistical and economic impact on the likelihood of adopting and retaining institutional biomass heating systems. The addition of one standard deviation in local support for RPS as a proportion of the county population (roughly 0.046) is associated with just over a 1.37 (= 1005.638 exp(0.046)) factor increase in the expected count of institutions using biomass (Tables 3 and 4).

3.2. Model 2

In order to further explore the negative association between 'Total Policies' and institutional biomass heating, Model 2 separates 'Total Policies' by policy type as described in Table 4. Likelihood ratio tests were carried out for model comparison between Model 2 and the nested Model 1 (Table 7), resulting in a chi-squared value of 13.98 (p-value = 0.016), giving moderate evidence that Model 2 is preferred. Of the policy types examined, 'Financing' policies encourage institutional use of woody biomass the most (p-value = 0.40, and IRR = 1.12), but this evidence is inconclusive and does not hold statistical significance (Table 4).

Table 7. Likelihood ratio test for model comparison of fit, with degrees of freedom (d.f.), chi-squared statistic and p-value.

Likelihood Ratio Test	d.f.	Chi Squared	p-Value
Model 1 nested in Model 2	5	13.98 *	0.0157

* $p < 0.05$.

In contrast, 'Procurement' and 'Tax Incentive' policies appear to have significant negative effects (p-value < 0.01, IRR = 0.72 and p-value = 0.01, IRR = 0.89) (Table 4). It is worth emphasizing that both of these policy instruments have an interesting relationship with institutional biomass heating. In the forest sector, procurement often refers to raw material supply, including biomass, fiber and logs. In contrast, 'Procurement' policies in this context are focused on down-stream, end use of bioenergy and bio-based products such as electricity and liquid fuels. For example, utilities may be forced to purchase renewable energy from decentralized producers through net metering policies. Such policies do not target biomass procurement directly. In the case of 'Tax Incentives', many of the institutions in the modeled population are tax exempt and would therefore not be influenced by 'Tax Incentive' policies. Alternatively, there may be unobserved heterogeneity in the policy variables that is not explained within the model. One potential control that may relieve some of the heterogeneity is the inclusion of a count of firms in competing biomass sectors that are more accurately targeted by 'Procurement' and 'Tax Incentive' (e.g., number of large-scale industrial operations such as sawmills using biomass in the county).

Other policy types are largely insignificant, with IRRs that are very close to one, meaning an additional policy will have very little influence on the number of institutions using biomass. As supported by Becker, Mosely, and Lee [6], biomass policies focused primarily on the manufacturing and utility sectors many not be supporting the institutional heating sector. Another possible explanation is that the small degree of cross-sectional variation in state-level policy types may be limiting the statistical associations that can be quantified [48].

4. Discussion

Despite negative air quality effects being commonly cited in public opposition to biomass energy, and apparently being central in the demise of some proposed projects, based on this analysis the effects of these factors seem to be negligible in the context of distributed-scale biomass heating systems. There is no evidence that historic or current local air quality and emissions effect the adoption of these systems when controlling for other influential factors. Our primary hypothesis was that counties with good air quality would be more likely to adopt these systems because air quality was not a major concern, and that counties with poor air quality would be less likely to adopt because of a perceived or real aggravation of already poor conditions. Alternatively, one might suppose that communities with low air quality perceive further marginal degradation as insignificant compared to areas with relatively good air quality, and therefore might be more likely to install these systems. It is also conceivable that communities with good air quality would be less likely to adopt these systems because they want to protect good air quality by minimizing new point source emissions. None of these hypotheses appear to be supported by the data, at least as it relates to PM and SO_2 attainment and GHG emissions as metrics of air quality and emissions. This is not to say that a failure to detect an effect means that there is none, but other variables clearly have more significant association with adoption. Furthermore, it is possible that more direct metrics of air pollution impacts on human health might be more strongly associated with adoption.

This study does provide evidence that local attitudes toward renewable energy, as measured by support for RPS, are positively associated with the installation and retention of these systems. Although Yoo and Ready [7] indicate that biomass use can be viewed as unfavorable when compared to other renewable energy options, possibly due to emissions from combustion, distributed-scale biomass heating systems may not experience the same push back as large industrial and utility projects due to their relatively small impact on local air quality. In other words, objections to local energy projects at the distributed-scale based on emissions and their potential negative effects may be outweighed by support for renewable energy over fossil fuels. This hypothesis needs further investigation, especially with regards to the scale of projects and in the context of projects that are opposed on the basis of acute local impacts, but not their general characteristics (colloquially known as "not in my back yard", or NIMBY).

In addition, communities that adopt distributed-scale biomass heating may place a higher value on healthy forests that are resistant to wildfire and climate change related stressors (e.g., drought and insects) when compared to the value placed on the impacts to air sheds as a result of additional emissions from these systems. Communities close to forest resources may associate biomass energy with lower wildfire risk tied to fuel treatments, especially in the western USA. In a large choice modeling experiment, Campbell et al. [74] showed that residents of three western states (Montana, Colorado and Arizona) had a positive mean willingness to pay for benefits associated with bioenergy from woody biomass, including better forest health, reduced likelihood of large wildfires and better air quality due to reduced wildfire smoke. If these benefits are associated with biomass as a renewable energy source and reflected in public attitudes and social acceptance of these systems, the perception of emissions tradeoffs may be complex and opposition or support of a particular project may be nuanced. The results of this study provide some insight into this relationship. Consistent with prior work [4,5], the statistical models presented in this study indicate that institutional adoption of woody biomass heating is driven by heating needs and fossil-fuel prices, as would be expected. Cold temperatures and high fossil fuel prices are associated with adoption. Woody biomass supply is also an important variable, and there is evidence that proximity to federal land and fuel treatments under the National Fire Plan significantly influence the adoption and retention of woody biomass heating systems. This result is congruent with an association between fuel treatments to reduce fire risk and the adoption of these systems.

In contrast, the association with biomass-oriented public policy is fuzzy. There appears to be a negative effect of aggregate policies on adoption, but these results conflict with our expectations and the work of Aguilar et al. [19], who highlight policies as one of the potential driving forces for using woody biomass as a fuel source. Based on a model variant that separates 'Total Policies' by policy type (Model 2) there is only very weak evidence that the presence of financial policies, such as project financing, may support biomass adoption. Typically, public financing is seen as alleviating large start-up costs that take an extended period of time for institutions to recoup. Financing of these systems has a direct impact on adoption, compared to indirect mechanisms such as biomass fuel subsidies, for example [75]. In contrast to financing policies, procurement and tax incentive policies have a negative association with the presence of woody biomass heating systems, possibly due to the fact that they target large-scale utilities, not distributed-scale systems. It may also be that this study lacks variables designed to capture effects applicable to different sectors of the biomass energy space, ranging from very large power plants to residential firewood. In general, it appears that pro-biomass energy polices may not be effectively targeting small biomass heating systems, and are instead more focused on the manufacturing industry, which is a conclusion supported by Becker, Mosely, and Lee [6].

Some of the limitations of this study point toward potentially fruitful areas of future research. This study relied heavily on existing national databases and previous research that provided national scale data at county resolution [1,6,16,45,53]. This fact was limiting from the standpoint that variables included for analysis had to be reported at the county level for every county in the USA. However, these databases are updated periodically, sometimes on an annual basis, which provides an opportunity to repeat the study over time. If using our approach, this would also require replication of appropriately designed policy studies and opinion surveys [6,45] and would provide insight into relationships that are likely to change over time. In addition, the current W2E database and web tool [1] includes biomass power, CHP, biofuel, and pellet mill facilities, which provides an opportunity to replicate this methodology for other bioenergy sectors.

Opportunities also exist to refine both the scale and resolution of the approach presented here. This study included variables to capture regional variation (Figure 2), and it is possible to replicate the study for individual regions. At the regional scale, data may be available for additional variables that were excluded from this analysis due to a lack of coverage or nation-wide relevancy. This study, along with previous research [4,6,45], provides a strong foundation for regional-scale analyses. At the local level, the tradeoffs between support for renewable energy and opposition to specific projects is likely to have significant nuance that is not addressed by a national or regional study. Direct survey of communities that considered bioenergy systems and then either adopted or rejected them e.g., [35–41] could provide additional insight on multiple fronts. For example, we do not know of any database that includes detailed information about the financing or other policy support of existing biomass systems, but a survey of institutions would allow for a higher resolution analysis of specific policies that were or were not factors in the installation and operation of these systems. More broadly, we believe that there is excellent opportunity for the integration of econometric studies such as this one, with technoeconomic models used to value specific bioenergy projects [76,77], policy and social science research [6,45], life cycle assessment [78], and non-market valuation using choice modeling and other methods [74]. An integrated approach would help provide a more holistic view of the costs, benefits and potential value of biomass energy projects.

5. Conclusions

The USA has used a variety of policy instruments to encourage the expansion of renewable energy production as a means to ensure affordable, domestic and stable energy supply and to reduce greenhouse gas emissions. Local attitudes toward biomass energy can have a negative effect on the support and adoption of large biomass facilities used to achieve these goals, especially with regards to point source emissions from biomass combustion. This study found no evidence that past or current air quality and emissions affect the adoption of distributed-scale biomass heating systems. Similarly, public policies did not show a strong association with adoption. However, support for renewable energy, as measured by support for renewable portfolio standards, was associated with greater adoption of these systems. In combination with the association between biomass heating and biomass supply from forest management, it appears that communities with sufficient heating needs and comparatively high fossil fuel prices, are more likely to adopt institutional biomass heating when they support renewable energy and are close to active forest management, especially management to improve forest health and reduce wildfire risk.

In practice, results indicate that advocates of expanding distributed-scale biomass heating and CHP technologies may improve their chances of meeting this goal by stimulating support for renewable energy, making clear links to broader benefits associated with forest biomass, and encouraging policies that target this sector directly, rather than assuming that broad pro-biomass and utility-sector policies will have an encouraging effect on the adoption of distributed-scale systems. Air quality does not appear to be a major factor in this case, but should not be underestimated as a factor that can influence public opinion in specific cases. In this light, it may be beneficial for local and state governments to adopt targeted policies that better support the installation of distributed-scale biomass heating systems directly, using well-targeted policies coupled with public outreach focused on the benefits of renewable energy. This is of particular importance for rural areas that have limited access to natural gas and have to rely on propane or fuel oil. In such cases, higher energy prices provide additional incentive for biomass heating. Under the right conditions, this renewable energy transition can ensure affordable energy to rural institutions while displacing fossil fuels and generating additional benefits from forest restoration.

Author Contributions: Conceptualization, J.D.Y., N.M.A. and H.T.N.; Data collection and curation, J.D.Y.; Statistical design, J.D.Y., N.M.A. and H.T.N.; Analysis, J.D.Y.; Funding acquisition, N.M.A.; Project administration, N.M.A. and H.T.N.; Writing—original draft, J.D.Y. and N.M.A.; Writing—subsequent drafts and editing, J.D.Y., N.M.A. and H.T.N.

Funding: This project was supported by Biomass Research and Development Initiative Competitive Grant number 2010-05325 and Agriculture and Food Research Initiative Competitive Grant number 2013-68005-21298 from the United States Department of Agriculture, National Institute of Food and Agriculture (NIFA). Additional support was provided by the United States Forest Service, Rocky Mountain Research Station.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

BLM	USA Bureau of Land Management
BRDI	Biomass Research and Development Initiative
CAA	Clean Air Act
CHP	Combined heat and power
CO_{2e}	Carbon dioxide equivalent
d.f.	Degrees of freedom
DGP	Data generating process
DOE	USA Department of Energy
EIA	USA Energy Information Administration
EPA	USA Environmental Protection Agency
FIA	Forest Inventory and Analysis of USFS
FIP	Federal implementation plan
FWS	USA Fish and Wildlife Service
GHG	Greenhouse gas
HDD	Heating degree day
IRR	Incidence rate ratio
ISO4	Interim Standard Offer 4
MW	Megawatt
NAAQS	National Ambient Air Quality Standards
NB	Negative binomial

NIMBY	"Not in my back yard", opposition on the basis of acute local impacts, but not their general characteristics
NOAA	USA National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NSPS	New Source Performance Standards
Obs.	Observations
OR	Odds ratio
PM	Particulate matter
PM10	Particulate matter with a diameter greater than 2.5 µm but smaller than 10 µm
PM2.5	Particulate matter 2.5 µm in diameter or smaller
REC	Renewable energy certificate
RPS	Renewable portfolio standard
SE	Standard error
SIP	State implementation plan
SO2	Sulfur dioxide
Std. Dev.	Standard deviation
TSP	Total suspended particulate
USA	United States of America
USDA	United States Department of Agriculture
USFS	United States Forest Service
W2E	Wood2Energy, see [1]
ZI	Zero inflated
ZINB	Zero inflated negative binomial
ZIP	Zero inflated Poisson

References

1. W2E. Wood2Energy Database 2014, the University of Tennessee, Center for Renewable Carbon, U.S. Endowment for Forestry and Communities. Available online: http://www.wood2energy.org/ (accessed on 26 September 2018).
2. Nicholls, D.L.; Monserud, R.A.; Dykstra, D.P. *A Synthesis of Biomass Utilization for Bioenergy Production in the Western United States*; Gen. Tech. Rep. PNW-GTR-753; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Portland, OR, USA, 2008; 48p.
3. Wood, S.R.; Rowley, P.N. A techno-economic analysis of small scale, biomass-fueled combined heat and power for community housing. *Biomass Bioenergy* **2011**, *35*, 3849–3858. [CrossRef]
4. Young, J.D. Economic and Policy Factors Driving Adoption of Institutional Woody Biomass Heating Systems in the United States. Master's Thesis, University of Montana, Missoula, MT, USA, 16 May 2015.
5. Young, J.D.; Anderson, N.M.; Naughton, H.T.; Mullan, K. Economic and policy factors driving adoption of institutional woody biomass heating systems in the United States. *Energy Econ.* **2018**, *69*, 456–470. [CrossRef]
6. Becker, D.R.; Moseley, C.; Lee, C. A supply chain analysis framework for assessing state-level forest biomass utilization policies in the United States. *Biomass Bioenergy* **2011**, *35*, 1429–1439. [CrossRef]
7. Yoo, J.; Ready, R.C. Preference heterogeneity for renewable energy technology. *Energy Econ.* **2014**, *42*, 101–114. [CrossRef]
8. Summit Ridge Investments. *Eastern Hardwood Forest Region WOODY Biomass Energy Opportunity*; Summit Ridge Investments: Granville, Vermont, USA, 2007; 98p.
9. U.S. Energy Information Administration. *Renewables Energy Annual for 2008*; Energy Information Administration: Washington, DC, USA, 2009. Available online: https://www.eia.gov/renewable/annual/ (accessed on 26 September 2018).
10. U.S. Energy Information Administration. *Definitions of Energy-Use Sectors and Related Terms*; Energy Information Administration: Washington, DC, USA, 2010. Available online: http://www.eia.doe.gov/neic/datadefinitions/sectors25B1.htm (accessed on 28 September 2018).
11. Congressional Research Service (CRS). *Federal Land Ownership: Overview and Data*; Congressional Research Service: Washington, DC, USA, 2012; 24p, Available online: https://fas.org/sgp/crs/misc/R42346.pdf (accessed on 28 September 2018).

12. U.S. Census Bureau. *Statistical Abstract of the United States: 2012*; United States Census Bureau: Washington, DC, USA, 2012; 1460p. Available online: https://www.census.gov/library/publications/2011/compendia/statab/131ed.html (accessed on 28 September 2018).
13. Becker, D.R.; Larson, D.; Lowell, E.C. Financial Considerations of policy options to enhance biomass utilization for reducing wildfire hazards. *For. Policy Econ.* **2009**, *11*, 628–635. [CrossRef]
14. Schoennagel, T.; Nelson, C.R.; Theobald, D.M.; Carnwath, G.C.; Chapman, T.B. Implementation of National Fire Plan treatments near the wildland–urban interface in the western United States. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 10706–10711. [CrossRef] [PubMed]
15. U.S. Government Accountability Office. *Natural Resources. Federal Agencies are Engaged in Various Utilization of Woody biomass, but Significant Obstacles to Its Use Remain, GAO-05-373*; United States Government Accountability Office: Washington, DC, USA, 2005; 17p. Available online: https://www.gao.gov/products/GAO-05-741T (accessed on 28 September 2018).
16. NFPORS. *National Fire Plan Operations and Reporting System*; U.S. Department of the Interior: Washington, DC, USA. Available online: https://usgs.nfpors.gov/NFPORS_training/help/help.html?Request=Location (accessed on 26 September 2018).
17. Public Law No. 106-224, Title III, 114 Stat. 428. 2000. Available online: http://www.gpo.gov/fdsys/pkg/PLAW-106publ224/html/PLAW-106publ224.htm (accessed on 26 September 2018).
18. Public Law No. 108-148, Title II, 117 Stat. 1901. 2003. Available online: http://www.fs.fed.us/spf/tribalrelations/documents/policy/statutes/PL_108-148_HFRA.pdf (accessed on 26 September 2018).
19. Aguilar, F.X.; Saunders, A. Policy instruments promoting wood for energy uses: Evidence from the continental U.S. *J. For.* **2010**, *108*, 132–140.
20. Dykstra, D.P.; Nicholls, D.L.; Monserud, R.A. Biomass Utilization for Bioenergy in the Western United States. *For. Prod. J.* **2008**, *58*, 6–16.
21. Leefers, L. Wood-Based Electric Power Generation in Michigan: Wood Use and Policies. *For. Prod. J.* **2011**, *61*, 586–591. [CrossRef]
22. Uski, O.J.; Happo, M.S.; Jalava, P.I.; Brunner, T.; Kelz, J.; Obernberger, I.; Jokiniemi, J.; Hirvonen, M.R. Acute systemic and lung inflammation in C57Bl/6J mice after intra-tracheal aspiration of particulate matter from small-scale biomass combustion appliances based on old and modern technologies. *Inhal. Toxicol.* **2012**, *24*, 952–965. [CrossRef] [PubMed]
23. Van Loo, S.; Koppejan, J. *The Handbook of Biomass Combustion and Co-Firing*; Earthscan Publishing: Washington, DC, USA, 2008; 442p.
24. Bowman, B.C.; Forsberg, A.B.; Jarvholm, B.G. Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society. *Scand. J. Work Environ. Health* **2003**, *29*, 251–260. [CrossRef]
25. Koenig, J.Q.; Jansen, K.; Mar, T.F.; Lumley, T.; Kaufman, J.; Trenga, C.A.; Sullivan, J.; Liu, L.J.; Shapiro, G.G.; Larson, T.V. Measurement of offline exhaled nitric oxide in a study of community exposure to air pollution. *Environ. Health Perspect.* **2003**, *111*, 1625–1629. [CrossRef] [PubMed]
26. Lipsett, M.; Hurley, S.; Ostro, B. Air pollution and emergency room visits for asthma in Santa Clara County, California. *Environ. Health Perspect.* **1997**, *105*, 216–222. [CrossRef] [PubMed]
27. Krajick, K. Long-term data show lingering effects from acid rain. *Science* **2001**, *292*, 195–196. [CrossRef] [PubMed]
28. Lieb, A.M.; Darrouzet-Nardi, A.; Bowman, W.D. Nitrogen deposition decreases acid buffering capacity of alpine soils in the southern Rocky Mountains. *Geoderma* **2011**, *164*, 220–224. [CrossRef]
29. Squalli, J. Renewable energy, coal as a baseload power source, and greenhouse gas emissions: Evidence from U.S. state-level data. *Energy* **2017**, *127*, 479–488. [CrossRef]
30. Salzman, J.; Thompson, B.H. *Environmental Law and Policy*, 3rd ed.; Foundation Press: New York, NY, USA, 2010; pp. 87–112.
31. Flatt, V.B.; Connolly, K.D. *'Grandfathered' Air Pollution Sources and Pollution Control: New Source Review under the Clean Air Act*; A Center for Progressive Regulation White Paper; Center for Progressive Regulation: Washington, DC, USA, 2005; 13p.
32. Villeneuve, J.; Palacios, J.H.; Savoie, P.; Godbout, S. A critical review of emissions standards and regulations regarding biomass combustion in small scale units (<3 MW). *Bioresour. Technol.* **2012**, *111*, 1–11. [CrossRef] [PubMed]

33. Plate, R.R.; Monroe, M.C.; Oxarart, A. Public perceptions of using woody biomass as a renewable energy source. *J. Ext.* **2010**, *48*, 1–15.
34. Sovacool, B.K. Exploring and Contextualizing Public Opposition to Renewable Electricity in the United States. *Sustainability* **2009**, *1*, 702–721. [CrossRef]
35. Zeller, T. Net Benefits of Biomass Power Under Scrutiny. *The New York Times*, 19 June 2010. Available online: http://www.nytimes.com/2010/06/19/science/earth/19biomass.html?_r=0 (accessed on 28 September 2018).
36. Gibson, L. Facing the Vocal Opposition. Available online: http://biomassmagazine.com/articles/3741/facing-the-vocal-opposition/ (accessed on 28 September 2018).
37. Moy, C. *Air Quality Permit: UM Biomass Boiler Will Double Nitrogen Dioxide Emissions*; Missoulian: Missoula, MT, USA, 2011; Available online: http://missoulian.com/news/local/air-quality-permit-um-biomass-boiler-will-double-nitrogen-dioxide/article_705eba96-6b06-11e0-b14b-001cc4c03286.html (accessed on 28 September 2018).
38. Associated Press. *Biomass Energy Project Halted in New Mexico*; WildEarth Guardians: Santa Fe, NM, USA, 2007; Available online: https://wildearthguardians.org/press-releases/biomass-energy-project-halted-in-new-mexico/ (accessed on 28 September 2018).
39. Greene, L. *Political Pressure Stopped Scott County Biomass Burner: Citizens Packed Meetings, Confronted the Mayor, Ran for Office*; Bloomington Alternative: Bloomington, IN, USA, 2012; Available online: http://www.bloomingtonalternative.com/articles/2012/05/26/10960 (accessed on 11 January 2016).
40. Cable, L. Citizens Hear from Biomass Authority. *Clarion News*, 18 November 2009. Available online: http://www.clarionnews.net/Articles-i-2009-11-18-212722.114125_Citizens_hear_from_biomass_authority.html (accessed on 26 September 2018).
41. Cichon, M. Massachusetts Finalizes Strict Regulations on Biomass Plants. *Renewable Energy World*, 21 August 2012. Available online: http://www.renewableenergyworld.com/articles/2012/08/massachusetts-finalizes-strict-regulations-on-biomass-plants.html (accessed on 28 September 2018).
42. Wustenhagen, R.; Wolsink, M.; Bürer, M.J. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy* **2007**, *35*, 2683–2691. [CrossRef]
43. Gaede, J.; Rowlands, I.H. Visualizing social acceptance research: A bibliometric review of the social acceptance literature for energy technology and fuels. *Energy Res. Soc. Sci.* **2018**, *40*, 142–158. [CrossRef]
44. van der Schoor, T.; Scholtens, B. Power to the people: Local community initiatives and the transition to sustainable energy. *Renew. Sustain. Energy Rev.* **2015**, *43*, 666–675. [CrossRef]
45. Howe, P.D.; Mildenberger, M.; Marlon, J.R.; Leiserowitz, A. Geographic variation in opinions on climate change at state and local scales in the USA. *Nat. Clim. Chang.* **2015**, *5*, 596–603. [CrossRef]
46. Paepe, M.D.; d'Herdt, P.; Mertens, D. Micro-CHP systems for residential applications. *Energy Convers. Manag.* **2006**, *47*, 3435–3446. [CrossRef]
47. Thornley, P.; Cooper, D. The Effectiveness of policy instruments in promoting bioenergy. *Biomass Bioenergy* **2008**, *32*, 903–913. [CrossRef]
48. Hitaj, C. Wind power development in the United States. *J. Environ. Econ. Manag.* **2013**, *65*, 394–410. [CrossRef]
49. Olsson, M. Residential Biomass Combustion—Emissions of ORGANIC Compounds to Air from Wood Pellets and Other New Alternatives. Ph.D. Thesis, Department of Chemical and Biological Engineering, Chalmers University of Technology, Goteborg, Sweden, 2006.
50. Campbell, P.; Fehringer, G.; Halapy, E.; Sloan, P.; Theis, B.; Kreiger, N.; Insight on cancer environmental exposures and cancer. *Environ. Expos. Cancer* **2005**, *4*, 72. Available online: https://www.cancercareontario.ca/sites/ccocancercare/files/assets/CCOInsightEnvironmental.pdf (accessed on 22 October 2018).
51. Torres-Duque, C.; Maldonado, D.; Pérez-Padilla, R.; Ezzati, M.; Viegi, G. Biomass Fuels and Respiratory Diseases: A Review of the Evidence. Forum of International Respiratory Societies (FIRS) Task Force on Health Effects of Biomass Exposure. *Proc. Am. Thorac. Soc.* **2008**, *5*, 577–590. [CrossRef] [PubMed]
52. Ling, S.H.; van Eeden, S.F. Particulate matter air pollution exposure: Role in the development and exacerbation of chronic obstructive pulmonary disease. *Int. J. COPD* **2009**, *4*, 233–243. [CrossRef]
53. U.S. Environmental Protection Agency. *Green Book*; United States Environmental Protection Agency: Washington, DC, USA, 2015. Available online: https://www.epa.gov/green-book/green-book-data-download (accessed on 28 September 2018).

54. U.S. Environmental Protection Agency. *Particulate Matter (PM) 2010*; United States Environmental Protection Agency: Washington, DC, USA, 2010. Available online: https://www.epa.gov/pm-pollution (accessed on 28 September 2018).
55. U.S. Environmental Protection Agency. *Nitrogen Oxides (NOx) Control Regulations 2014*; United States Environmental Protection Agency: Washington, DC, USA, 2014. Available online: http://www3.epa.gov/region1/airquality/nox.html (accessed on 28 September 2018).
56. Driscoll, C.T.; Lawrence, G.B.; Bulger, A.J.; Butler, T.J.; Cronan, C.S.; Eagar, C.; Lambert, K.F.; Likens, G.E.; Stoddard, J.L.; Weathers, K.C. Acidic deposition in the notheastern United States: Sources and inputs, ecosystem effects, and management strategies. *BioScience* **2001**, *51*, 180–198. [CrossRef]
57. Bulger, A.J.; Cosby, B.J.; Webb, J.R. Current, reconstructed past, and projected future status of brook trout (Salvelinus fontinalis) streams in Virginia. *Can. J. Fish. Aquat. Sci.* **2000**, *57*, 1515–1523. [CrossRef]
58. DeHayes, D.H.; Schaberg, P.G.; Hawley, G.J.; Strimbeck, G.R. Acid rain impacts on calcium nutrition and forest health: Alteration of membrane-associated calcium leads to membrane destabilization and foliar injury in red spruce. *BioScience* **1999**, *49*, 789–800. [CrossRef]
59. Baron, J.S.; Del Grosso, S.; Ojima, D.S.; Theobald, D.M.; Parton, W.J. Nitrogen emissions along the Colorado Front Range: Response to population growth, land and water use change, and agriculture. *Ecosyst. Land Use Chang.-Geophys. Monogr. Ser.* **2000**, *153*, 117–127.
60. Oleksyn, J.; Karolewski, P.; Giertych, M.J.; Werner, A.; Tjoelker, M.G.; Reich, P.B. Altered root growth and plant chemistry of *Pinus sylvestris* seedlings subjected to aluminum in nutrient solution. *Trees* **2000**, *10*, 135–144.
61. Maugh, T.H. Acid rain's effects on people assessed. *Science* **1984**, *226*, 1408–1410. [CrossRef] [PubMed]
62. U.S. Environmental Protection Agency. *Effects of Acid Rain—Human Health 2012*; United States Environmental Protection Agency: Washington, DC, USA, 2012. Available online: http://www3.epa.gov/acidrain/effects/health.html (accessed on 28 September 2018).
63. U.S. Environmental Protection Agency. *Facility Level Information on GreenHouse Gases Totals (Flight) 2013*; United States Environmental Protection Agency: Washington, DC, USA, 2013. Available online: http://ghgdata.epa.gov/ghgp/main.do (accessed on 28 September 2018).
64. Hu, M.C.; Pavlicova, M.; Nunes, E.V. Zero-inflated and hurdle models of count data with extra zeros: Examples from an HIV-risk reduction intervention trial. *J. Drug Alcohol Abuse* **2011**, *37*, 367–375. [CrossRef] [PubMed]
65. Zuur, A.F.; Ieno, E.N.; Walker, N.J.; Saveliev, A.A.; Smith, G.M. Zero-truncated and zero-inflated models for count data. In *Mixed Effects Models for Extensions in Ecology*; Springer: New York, NY, USA, 2009; pp. 261–293.
66. Renner, G.T. Geography of industrial localization. *Econ. Geogr.* **1947**, *23*, 167–189. [CrossRef]
67. Phang, Y.N.; Loh, E.F. Statistical analysis for overdispersed medical count data. *Int. J. Math. Comput. Phys. Quantum Eng.* **2014**, *8*, 292–294.
68. Garay, A.M.; Hashimoto, E.M.; Ortega, E.M.M.; Lachos, V.H. On estimation and influential diagnostics for zero-inflated negative binomial regression models. *Comput. Stat. Data Anal.* **2011**, *55*, 1304–1318. [CrossRef]
69. U.S. National Oceanic and Atmospheric Administration (NOAA). National Climatic Data Center, 1981–2010, U.S. Climate Normals. Available online: http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-baseddatasets/climate-normals/1981-2010-normals-data (accessed on 6 February 2015).
70. Milbrandt, A. *A Geographic Perspective on the Current Biomass Resource Availability in the United States*; Technical Report NREL/TP-560-39181; National Renewable Energy Laboratory: Fort Collins, CO, USA, 2005; 62p.
71. StataCorp. *Stata Statistical Software: Release 12*; StataCorp: College Station, TX, USA, 2011.
72. Vuong, Q.H. Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica* **1989**, *57*, 307–333. [CrossRef]
73. Song, N.; Aguilar, F.X.; Shifley, S.R.; Goerndt, M.E. Factors affecting wood energy consumption by U.S. households. *Energy Econ.* **2012**, *34*, 389–397. [CrossRef]
74. Campbell, R.M.; Venn, T.J.; Anderson, N.M. Heterogeneity in preferences for woody biomass energy in the US Mountain West. *Ecol. Econ.* **2018**, *145*, 27–37. [CrossRef]
75. Stubbs, M. *Biomass Crop Assistance Program (BCAP): Status and Issues*; Congressional Research Service: Washington, DC, USA, 2015; Available online: https://fas.org/sgp/crs/misc/R41296.pdf (accessed on 28 September 2018).

76. Campbell, R.; Anderson, N.; Daugaard, D.; Naughton, H. Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty. *Appl. Energy* **2018**, *230*, 330–343. [CrossRef]
77. Campbell, R.; Anderson, N.; Daugaard, D.; Naughton, H. Technoeconomic and policy drivers of project performance for bioenergy alternatives using biomass from beetle-killed trees. *Energies* **2018**, *11*, 293. [CrossRef]
78. Patel, M.; Zhang, X.; Kumar, A. Techno-economic and life cycle assessment on lignocellulosic biomass thermochemical conversion technologies: A review. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1486–1499. [CrossRef]