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Economic and policy factors driving adoption of institutional woody biomass heating systems in the U.S.☆

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ABSTRACT

Abundant stocks of woody biomass that are associated with active forest management can be used as fuel for bioenergy in many applications. Though factors driving large-scale biomass use in industrial settings have been studied extensively, small-scale biomass combustion systems commonly used by institutions for heating have received less attention. A zero inflated negative binomial (ZINB) model is employed to identify economic and policy factors favorable to installation and operation of these systems. This allows us to determine the effectiveness of existing policies and identify locations where conditions offer the greatest potential for additional promotion of biomass use. Adoption is driven by heating needs, fossil fuel prices, and proximity to woody biomass resources, specifically logging residues, National Forests, and fuel treatments under the National Fire Plan.

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1. Introduction

Active forest management is associated with abundant stocks of woody biomass that can be used as fuel and feedstocks for bioenergy and bioproducts (Gregg and Smith, 2010; Rummer et al., 2005; U.S. DOE, 2011). Many private and public facilities in the United States (U.S.) currently use woody biomass as fuel in decentralized heating systems and cite a variety of benefits related to biomass heat, including on-site disposal of manufacturing byproducts, lower fuel costs, substitution of fossil fuel with local renewable fuels, reduced emissions, and support of local forest management and forest industry (Nicholls et al., 2008; Wood and Rowley, 2011).

The purpose of this study is to expand the knowledge of economic and policy factors that influence the installation and operation of these systems, with the goal of informing the adoption of institutional biomass heating, which is currently in a period of expansion. The effects of state-level public policy are explicitly quantified, while federal policy is quantified implicitly through examination of federal land ownership and associated management practices, including wildfire risk mitigation through the National Fire Plan (NFP). In addition, this analysis includes variables associated with climate, energy prices, affluence, population, transportation infrastructure, and regional variation. Results provide institutions with a deeper understanding of the factors favorable to facility siting that can be used when considering the installation of new heating systems. This research also provides policy makers with knowledge about what effects, if any, different policies have on adoption, and identifies specific locations where efforts to stimulate new installations are likely to be effective.

Additional context is needed to understand why, after two centuries of using biomass for heat in an industrialized economy in the U.S., these

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relationships are not already well understood and widely known. Section 2 reviews literature by discussing the history, status and drivers of institutional biomass use, and Section 3 provides a discussion of methods, data sources and their theoretical justification, followed by model diagnostics. Section 4 presents the results, followed by a discussion in Section 5, and conclusions in Section 6.

2. Status and drivers of institutional biomass use

2.1. Modern use of biomass energy

Though it constitutes a small proportion of total energy consumption and production, biomass currently accounts for about one quarter of the total primary non-fossil energy produced in the U.S. (U.S. EIA, 2014; U.S. DOE, 2016) and use has been increasing since 2002 (U.S. EIA, 2005). Modern use of biomass fuels in industrialized countries is dominated by industrial co-generation of heat and power, private residential heating, and district heat and electric power generation using advanced biomass combustion, gasification and pyrolysis technologies (Bridgewater et al., 2002; Dong et al., 2009; McKendry, 2002; Wood and Rowley, 2011). Biomass collected from forests falls into four primary categories: 1) fuelwood, which is wood cut specifically for use as fuel, 2) logging residues, which are the tops, limbs, foliage and sometimes stumps of trees cut for roundwood products, 3) mill residues, which are the wood and bark byproducts generated by primary mills during the production of primary wood products, and 4) trees cut or otherwise killed by silvicultural operations such as pre-commercial and fuel reduction thinning (USDA Forest Service, 2009). These biomass sources and agricultural crop residues are now complemented by dedicated biomass energy crops including both woody and herbaceous species grown specifically for energy use.

Many industrialized countries around the world are actively setting renewable energy goals that can, in part, be met by using biomass for energy. Some nations in the European Union (E.U.) have embraced policies promoting biomass fuels as a means to reduce foreign energy and fuel imports, while meeting emissions standards set within the E.U. (Dong et al., 2009; Qian and McDow, 2013). In the U.S., the federal government and some state and local governments have also been aggressively pursuing policies that encourage the use of biomass for energy. In particular, forest biomass use has been promoted as a mechanism to improve forest conditions (Dykstra et al., 2008; Noss et al., 2006), reduce greenhouse gas emissions (Malmsheimer et al., 2008; Nicholls et al., 2006), and ensure affordable energy is available in the future. In fire-prone regions, the link between biomass energy and improving forest conditions is closely connected to biomass harvest from treatments implemented for fuel reduction and forest restoration, which remove primarily dead, dying and subdominant trees to reduce the intensity of wildfire when it occurs (Evans and Finkral, 2009).

When energy from woody biomass is used primarily as a mechanism to reduce greenhouse gas emissions, it is important to acknowledge both the conditions under which net reductions are likely to occur, and also the potential tradeoffs involved in substituting woody biomass for other fuel and energy options. Woody biomass energy systems are more likely to result in net greenhouse gas emission reductions when replacing carbon intensive fossil fuel systems in an efficient conversion pathway with biomass waste or logging byproducts rather than whole green trees, especially if woody biomass is collected from land that is close to the facility, remains in forested land use, and has high primary productivity (EEA, 2013). If such woody biomass is otherwise likely to be burned for disposal, which is common practice in many parts of the world, additional reductions, especially in methane, are possible (Loeffler and Anderson, 2014). However, even under the most favorable circumstances, woody biomass energy is not without tradeoffs. For example, negative impacts on local air quality may be higher than those of some fossil fuels, especially natural gas, because even highly efficient systems produce detrimental air emissions of fine particles (PM10) and black carbon (Obaidullah et al., 2012). Effects of biomass harvesting on soil properties, including productivity, carbon storage and biodiversity, is also a concern because harvesting can remove nutrients from the site and degrade soils through compaction and erosion (Nave et al., 2010; Page-Dumroese et al., 2010).

Given these potential benefits and concerns, researchers have increased their attention to the economic, policy, ecological and emissions aspects of increased forest biomass use. Several studies have focused on biomass in the electric power sector in the U.S., identifying counties with high estimated potential for co-firing biomass with coal and assessing the influence of economic incentives on adoption (Aguilar et al., 2012; Goerndt et al., 2013), or analyzing the performance and economic viability of relatively new decentralized energy systems (Bridgewater et al., 2002; Wood and Rowley, 2011; Salomon et al., 2011). Others have examined efficient carbon dioxide (CO2) emission reductions achieved when retrofitting small-scale fossil-fuel combined heat and power systems (CHP) to incorporate woody biomass (Pavlas et al., 2006), the optimization of incorporating biomass into large-scale fossil-fuel CHP plants (Tous et al., 2011), or the sustainability of rural district heating in fire-prone communities (Blanco et al., 2015). Less is known about the determinants of adoption in the commercial heating sector, at least partly because the drivers are closely tied to those affecting the electric power sector after 1990 (Aguilar et al., 2011). This study expands the knowledge of the commercial sector by evaluating economic and policy factors that are hypothesized to influence the institutional adoption of decentralized woody biomass heating systems in the U.S.

2.2. The current state of institutional biomass heating

According to some technology developers, public officials and researchers, many small commercial and institutional facilities are ideally suited for cost competitive adoption of woody biomass heating systems under the appropriate market conditions and financial incentives. This includes facilities that are located near forested land or have locally available biomass, and are currently using high priced natural gas, propane or fuel oil as their primary heat source (Galik et al., 2009; Skog et al., 2006; U.S. GAO, 2005). However, it can be more difficult for biomass to be cost competitive when fossil fuels are inexpensive, especially for district heating and power applications.

In contrast to district heating systems, power plants and large industrial boilers, the heat output of small-scale, decentralized biomass-fueled combustion heating systems ranges between one and ten million British thermal units. These systems, referred to as "biomass heating systems" in this paper, rarely include electricity generating capabilities, but can be equipped with automatic fuel handling and feeding systems to enhance their energy and labor efficiency (Maker, 2004). Fuel for these systems is most often pellets, chips, ground biomass, or fuelwood (potentially including the bole, limbs, bark and needles) from trees grown in a forest or plantation, but can also be derived from herbaceous energy crops, wood waste, or byproducts of wood product manufacturing.

Nationwide, in 2014 there were 401 known biomass heating systems installed in U.S. institutions like schools, hospitals, government facilities, prisons, military bases, and other public buildings (Fig. 1) (W2E, 2014). In general, it is recognized that public and private institutions in some regions have been more receptive to using biomass heating systems. According to the Wood2Energy database, these regions include the Northeast states, the Lakes States, and Northwest states (Fig. 2) (W2E, 2014). Adopting communities typically have, on average, lower annual temperatures, higher space heating needs, lower road and population density, and an active forest industry. Despite many similarities, adopting regions vary with respect to other relevant characteristics, including land-ownership patterns, energy prices, market conditions, and a variety of economic and policy factors prevalent at regional and local scales. For example, western states face