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Determinants of wind and solar energy system adoption by U.S. farms: A multilevel modeling approach☆

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HIGHLIGHTS

- This is the first national examination of wind and solar energy adoption on U.S. farms.
- Controlling for state policies distinguishes this study from past research of technology adoption.
- We find net metering and interconnection policies increase the likelihood of farm adoption.
- Results suggest that the design of renewable energy policies may limit their impact on farms.

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ABSTRACT

This article offers the first national examination of the determinants of adoption of wind and solar energy generation on U.S. farming operations. The inclusion of state policies and characteristics in a multilevel modeling approach distinguishes this study from past research utilizing logit models of technology adoption which focus only on the characteristics of the farm operation. Results suggest the propensity to adopt is higher for livestock operations, larger farms, operators with internet access, organic operations, and newer farmers. The results find state characteristics such as solar resources, per capita income levels, and predominantly democratic voting increasing the odds of farm adoption. This research suggests the relevance of state policy variables in explaining farm level outcomes is limited, although in combination best practice net metering and interconnection policies—policies designed to encourage the development of small scale distributed applications—are shown to increase the likelihood of farm solar and wind adoption. The prevalence of electric cooperatives—which are often not subject to state renewable energy policies and often service farms—is negatively related with the propensity to adopt and suggests that policy design may be a factor.

1. Introduction

Renewable energy (RE) is increasingly being recognized for its ability to off-set rising, and volatile energy prices, decrease carbon emissions through reducing fossil-fuel consumption, and decrease reliance on foreign fuel sources. However the costs of energy from renewable fuel sources is often higher than that from conventional sources, and the institutions and systems which deliver energy may impede development of alternative sources. For precisely these reasons, federal and state polices are in place to promote the use of alternative energy for electricity generation by reducing institutional barriers and offering financial incentives. The use of alternative fuels for electricity has been increasing in the last decade both for utility scale electricity production and smaller on-site consumer applications, often referred to as distributed generation. Notably, wind generation in the electric power sector increased an average 33 percent year-on-year since 2000, while solar has seen a recent surge with an average 27 percent annual increase since 2007 (U.S. Energy Information Administration, 2011a). Photovoltaic solar installations outside of the electric power sector (also referred to as customer sited installations) doubled in capacity from 2008 to 2009 and increased again by 62 percent from 2009 to 2010 (Sherwood, 2010, 2009). Small wind

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systems—turbines with capacity ratings less than or equal to 100 kW that are suitable for residential, farm or other on-site generation—has had equally impressive increases over the last decade showing an average increase in capacity of 41 percent year-on-year since 2001 (American Wind Energy Association, 2011).

Farming operations are a natural fit for small scale alternative fueled generation technologies. Wind and solar applications, like other RE options, can help farming operations stabilize electricity and energy expenditures, decrease carbon emissions, and increase agricultural production (for example, a solar powered water pump could make irrigation possible where extending the electric grid may be prohibitively expensive). Indeed, the American Wind Energy Association notes the industry considers the farm sector a large market opportunity (). However, the occurrence of RE applications remains rare on US (American Wind Energy Association, 2011) farming operations. Little is known about the characteristics of the farming operations employing alternative fuel sources for electricity at the national level, and the impact of existing state policies in promoting RE on farms has only recently started being investigated (Xiarchos and Lazarus, 2013). The objective of this article is to estimate determinants of adoption of wind and solar technologies on US farms while accounting for the influence of state policies on adoption rates.

The inclusion of state policies and characteristics in a multilevel modeling approach distinguishes this study from past research utilizing logit models of technology adoption which focus on the characteristics of the farm operation only. Using a multilevel modeling approach (also known as mixed effects or hierarchical modeling) allows for estimation of farm-level *and* state-level factors which influence adoption of renewable technologies as well as empirically identifying the relative importance of farm and state-level factors in explaining the model variance.

This article analyzes data from the first national survey of farm operators about renewable energy—including solar and wind—production on farming operations. Analysis is based on data from the 2007 Census of Agriculture and the 2009 follow on On-farm Renewable Energy Production Survey (OFREPS) (National Agricultural Statistics Service, 2009b, 2011). Until recently, no nationally representative sample of solar and wind technologies on U.S. farms was available, and therefore this article presents the most comprehensive picture of farm operation adoption of renewable technologies to date.

This research provides insights into factors that are correlated with adoption of solar and wind technologies on U.S. farms and examines the relative importance of state characteristics and policies on farm-level decisions. In agreement with other studies exploring the adoption of new technologies on farms we find farm size, internet availability, organic practices and farming as a primary occupation positively influence the probability a farm operation adopting RE technologies. Livestock operations are more likely to adopt wind or solar technologies than grain and oilseed farms, while the number of years an operator has been farming negatively influences the probability of adoption. Evidence is found that in combination best practice net metering and interconnection polices can increase the likelihood of farm adoption. However, no evidence is found that other state policies or incentives significantly impact adoption.

1.1. Literature review

There exists extensive literature examining farm adoption of new technologies and practices (for example, Banerjee et al., 2009; Bergtold et al., 2012; D'Souza et al., 1993; Kutter et al., 2009; Lewis et al., 2011; Prokopy et al., 2008). For example, Daberkow and McBride's (2003) estimation of adoption of precision agriculture technologies on US farms finds education, computer literacy, full-time farming and farm size, type and location all positively influenced the likelihood of adoption. Soule et al. (2000) find farm size, farmer education, and highly erodible land increased the likelihood of conservation tillage being employed on a field. Foltz and Chang (2002) find larger farms with younger more educated operators are more likely to adopt rBST—a hormone found to increase milk production per cow.

Literature specifically addressing farm adoption of solar and wind technologies is more limited. Beckman and Xiarchos (2013) examine the determinants of renewable energy adoption and system size on California farms and find the probability of adoption increases with non-farm income sources, electricity prices, and organic practice; it decreases with the number of years farming. Xiarchos and Lazarus (2013) find state-level adoption rates are positively correlated with higher rates of organic farms, internet access and land ownership. Other studies examining household adoption of RE technologies include a study by Willis et al. (2011) which found household adoption of these renewable technologies to be significantly determined by the age of the household, where older households are less likely to adopt renewable energy technologies. A study in Germany finds new residential structures are more likely to adopt solar hot water heating systems, but limited evidence of household characteristics as determinants of adoption (Mills and Schleich, 2009).

However, it is not farm and household characteristics in isolation which should be expected to determine technology adoption. National and state enacted policies are designed to directly influence the decision parameters of adoption through price incentives and institutional changes. These policies vary from state to state, and therefore some states or policies may be more effective at encouraging RE adoption. State policies, such as a Renewable Portfolio Standards (RPS), have been shown to be effective in increasing utility scale capacity of renewable generation (Menz and Vachon, 2006; Shrimali and Kniefel, 2011; Yin and Powers, 2010). Xiarchos and Lazarus (2013) examination of policy influences find that higher RPS goals increase state-level adoption rates of solar and wind, while increases in electric cooperative service shares in the state decrease adoption rates. The inclusion of state-level characteristics distinguish this study from past research of technology adoption which generally focuses on characteristics of the farming operation. In addition, looking at how state-level policies are correlated with customer-level adoption distinguishes this study from other research examining the effectiveness of state RE policy measures.

The remainder of the paper first offers an overview of the renewable energy technologies studied in this paper (solar and wind), their on-farm applications, and state policies designed to encourage customer sited renewable energy adoption. The next section outlines the methodology and then the model specification. Finally, the empirical results are presented with a discussion of the policy implications.

2. Materials and methods

2.1. On-farm renewable energy production survey

Electricity represents around 18 percent of total energy consumed on-farm and 2.5 percent of average farm expenditures (USDA-NASS, 2009). Generating electricity using renewable fuels such as solar and wind on-farm could reduce these electricity expenditures as well as expenditures on other fuels if renewable energy is used to replace them. On-farm[2] applications include

[2] On-farm renewable energy applications are distinguished from commercial (utility scale) applications such as wind turbines located on farm operations under wind rights lease agreements. This is consistent with the definition in the survey