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Policy incentives and adoption of agricultural anaerobic digestion: A survey of Europe and the United States

Mook Bangalore [a], Gal Hochman [b, *], David Zilberman [c]

[a] School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ 08854, USA
[b] Department of Agricultural, Food, and Resource Economics, Rutgers University, New Brunswick, NJ 08854, USA
[c] Department of Agriculture and Resource Economics, University of California Berkeley, Berkeley, CA 74720, USA

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A B S T R A C T

Despite extensive and widespread knowledge of the advantages of agricultural anaerobic digestion (AD), adoption of the technology has not been uniform across the globe. What explains this uneven adoption across countries? Policy and empirical evidence from five case study countries – Germany, Denmark, Netherlands, Austria and the United States – indicate that rather than comparative technological advantage or abundance in feedstock availability, differences in adoption was the outcome of differences in policy incentives, notably the feed-in tariff, a finding that offers empirical support to the threshold model of adoption. The stable financial support of a feed-in tariff provided to investors in agricultural AD, particularly in Germany, led to wide adoption. The evidence also suggests that differences in the enactment of the feed-in tariff was influenced by energy security concerns for policy leaders, but by learning-by-doing in terms of policy implementation and lower operating costs for policy followers.

1. Introduction

Technological adoption is rarely uniform across countries. The question as to why some countries exhibit high rates of adoption while others lag behind has been of interest to researchers across a wide variety of technologies and settings. Moreover, when the social benefits of a technology are high, the question becomes even more important to the policy and research community. In this paper, we focus on the adoption of agricultural anaerobic digestion (henceforth AD), a technology which reduces waste, produces renewable biogas and a fertilizer by-product, and also has the potential to reduce emissions of greenhouse gasses (California EPA 2008, [1]). Feedstock fed into a digester can include landfill gas, sewage gas, in addition to agricultural products.

We focus on AD from agricultural sources in this paper, due to its high social benefits (Centore et al. 2014, [2], and references therein). AD accepts a variety of feedstocks – including animal manure, energy crops and residues, and food waste. Facilities often co-digest, or combine feedstocks for efficiency. In addition to the two valuable outputs of AD, biogas and digestate (remaining material), the process can also provide ecological and economic benefits. AD also controls odors and eliminates pathogens in the feedstock, and thus is widely used for sewage sludge treatment and manure management (California EPA 2008, [1]; Cuellar & Webber 2008, [3]; Wilkinson 2011a, [4]). The technology also has the potential to reduce GHG emissions. Compared to landfilling without energy recovery and conventional manure storage techniques, AD results in fewer emissions of CH4 (whose global warming potential is 23 times that of CO_2) and other GHGs (Bracmort 2010, [5]; Haight 2005, [6]; Steinfeld 2006, [7]). Economically, AD decentralizes the energy supply and can increase rural employment and development (Holm-Nielsen 2009, [8]). Despite this widespread knowledge of the benefits and technology of AD, adoption patterns across countries are far from uniform.

The United States (US), along with Germany and Denmark, piloted a few projects starting in the 1980s (AgSTAR 2012b, [9]). However, Europe and the United States have had divergent experiences in AD, as did Germany compared to the rest of Europe. Germany and Denmark were the pioneers of the technology, first developing AD in the early 1990s, with Germany experiencing strong growth through 2012. The US, however, only began to experience growth starting in 2003.

This paper describes the development of agricultural AD in Austria, Denmark, Germany, the Netherlands, and the United States from the 1990s to 2012. By surveying the policy environment of

* Corresponding author.
E-mail address: gal.hochman@rutgers.edu (G. Hochman).

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agricultural AD in the different countries and tracking policy changes across time, this paper identifies salient factors affecting adoption and establishes their correlation with the rate of adoption of agricultural AD in the investigated countries. The paper then uses political economics to hypothesize the factors which lead some countries to enact favorable policy incentives for agricultural AD.

The next section describes the methodology and data used in the analysis. Section 3 follows and employs a stylized model to identify, conceptually, the key factors affecting adoption of agricultural AD. The adoption of this technology in Europe and in the US is then discussed in Sections 4 and 5, respectively. Discussion and concluding remarks are offered in Section 6.

2. Our approach – methods and data

The aim of this paper is to better understand the factors affecting adoption rates of the agricultural AD technology, and thus explain why rates are not uniform across countries. We employ a qualitative case study based approach, whereby initially we develop a simple model that conceptually identifies salient factors that we then investigate empirically using secondary data.

The conceptual model suggests that high electricity prices, high penalties for pollution, and subsidies for investment yield higher adoption. It follows that regulation that increases the cost of pollution, as well as a stable policy overtime that subsidizes investment in renewable technologies (e.g., feed-in-tariffs – henceforth denoted FIT), lead to higher adoption.

The analysis includes case studies of countries within Europe where agricultural AD is most developed – Germany, Denmark, Austria and The Netherlands, in addition to the US. The data used for the case studies is collected from the regulatory agencies pertaining to the specific state as well as from the existing literature. The state level policy analysis is descriptive, and uses secondary data on policy and deployment from the following regulatory agencies:

- **European Countries:** European Renewable Energy Council, Eurostat, IEA Bioenergy Task 37, IEA/IRENA Policies and Measures Database, European Commission, Bloomberg New Energy Finance, German Environment Agency, Denmark Environmental Protection Agency, E-Control Austria, EU-Bionet III Netherlands and Central Bureau of Statistics – Netherlands.
- **US Federal:** Environmental Protection Agency's AgSTAR Program, Database of State Incentives for Renewables & Efficiency.
- **US State-level:** Database of State Incentives for Renewables & Efficiency.

A more detailed description of the various data sources is supplied below in Sections 4 and 5.

The case study based analysis leads us to conclude that high electricity prices led countries to enact policies that subsidize decentralized electricity generation. Agricultural AD, which produces decentralized energy, was highly subsidized due the technology's nascent stage of development and high social benefits from waste management (Hochman et al. 2015, [10]). Our analysis shows that adoption followed policy: lucrative and stable incentives for the adoption of agricultural AD (high and stable FIT over time) led to adoption of the technology; in particular, in Germany. It empirically shows that the observed outcomes are consistent with economic rationale.

What would lead the government to enact a costly policy such as a FIT? One reason would be to reduce the compliance costs associated with the pollution penalty. Another reason may be energy security and independence and improved balance of trade: if energy prices from conventional fuels are high, and if imports are expensive, the government may want to incentivize investment in decentralized energy that can be produced within the country (Fig. 1).

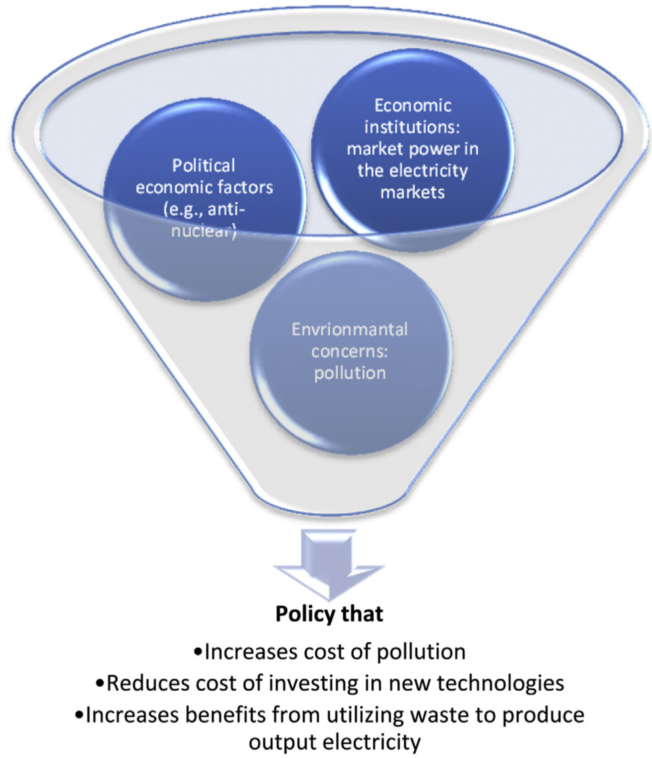

Fig. 1. The process leading to the adoption of agricultural AD.

3. The adoption of agricultural AD

Livestock production yields, in addition to output, pollution (e.g., methane). Dairy farms produce dairy products and meat, but are also a key source of nitrogen and phosphorus pollutants to surface and groundwater. The complexity of these agricultural production systems resulted in a large body of literature on animal waste (Moffitt et al. 1978, [11]; Hochman and Zilberman 1979, [12]; Fleming et al. 1998, [13]; Innes 2000, [14]; Iho et al. 2013, [15]; among many others). This body of literature builds on the environmental economic literature that studies the effect of economic activities and policy on Research and Development (R&D) and the adoption of new technologies (Khanna and Zilberman 1997, [16]; Sunding and Zilberman 2001, [17]; Jaffe et al. 2003, [18]).

The economic literature on adoption aimed to explain the patterns of adoption over time-in particular, the different timing, of adoption across locations. One strand of this literature, the threshold model, predicts that adoption occurs when the perceived benefits from adoption exceed the perceived costs and that early adopters gain the most from the adoption of the new technology (Zilberman et al. 2012, [19]). It explains the gradual rate of adoption across location by heterogeneity of socio-economic and biophysical conditions across locations and by learning by doing. Adoption occurs first by individuals and at the locations with the highest net gains from adoption. Learning-by-doing reduces the cost of the technology and increases the gain from its adoption, leading to adoption by individuals that initially were less inclined to adopt the technology.

To understand the adoption process, consider the situation of a