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Analysis

An agent-based spatial simulation to evaluate the promotion of electricity from agricultural biogas plants in Germany

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ABSTRACT

In this paper we investigate how changes in the support scheme may affect electricity generation from agricultural Combined Heat and Power (CHP) biogas plants in Germany. An agent-based simulation model for investment decision-making is coupled with GIS data. The spatial-temporal diffusion model accounts for the limited availability of substrate resources, alternative plant sizes and different heat use combinations. For illustration, we apply the model to the German federal states of North Rhine-Westphalia and Bavaria, for which we estimate an additional economical capacity potential of 409 MW_{el}. Overall, we conclude that current feed-in payments per unit of electric power provided are probably not too far off the optimum level, if one considers the maximum diffusion of CHP units possible. However, the current feed-in system may overtly favor small generating units, thereby failing to incentivize coordination among farmers for joint resource utilization in larger and more efficient plants. In addition, optimization of the biogas conversion process and feedstock use would also be highly beneficial.

1. Introduction

Our aim in this paper is to assess the potential diffusion of biogas technology based on the current German feed-in tariff scheme for electricity from renewables. In addition, we want to roughly assess whether the incentive payments promote an efficient use of available substrates and to estimate the potential cost of electricity feed-in from agricultural biogas.

To this end, we develop an agent-based simulation model linked to Geographic Information System (GIS) data in order to investigate the spatial–temporal diffusion of agricultural biogas plants, given constraints on the local availability of feedstock resources. The structure of the simulation framework proposed by Madlener and Schmid (2009) and Schmid and Madlener (2008) is extended to include alternative heat use technologies and dynamic cost functions of substrate and heat delivery. Key parameters are altered in order to account for differences in the regulatory framework and the geo-political aggregation used for the GIS data. To illustrate its usefulness, we apply our model to the German federal states of North Rhine-Westphalia and Bavaria. Due to marked differences in the structure and resource endowments of these two economies, as well as the size and number of existing biogas units, North Rhine-Westphalia and Bavaria constitute two important and contrasting cases for our study of the German biogas market.

German policies in the biogas sector are especially relevant in light of two considerations. First, Germany plays a leading role in the European biogas market (Fig. 1). At 3.7 million toe[1], its aggregate biogas production was equivalent to 49% of the EU's output in 2008. Second, the country has witnessed a substantial increment in biogas facilities over the last decade, thanks to guaranteed tariffs for electricity fed into the grid, which are part of an ambitious nation-wide policy aimed at increasing the share of renewable energy sources (Scholwin et al., 2008).

The German federal government supports the generation of power and heat from biogas through the *Act on Granting Priority to Renewable Energy Sources* (Erneuerbare-Energien-Gesetz, EEG), which includes feed-in tariffs for electricity and heat production. With regard to biogas plants, the tariffs are directed to biogas obtained from landfills, the treatment of biowaste or sewage water, and renewable primary products, such as animal manure and energy crops. The EEG was introduced in 2000, followed by amendments in 2004, 2009 and 2012 (EEG, 2000, 2004, 2009, 2012). The 2004 amendment introduced a differentiated feed-in tariff system for agricultural biogas plants. In particular, since then, the use of agricultural substrates has been promoted and the adoption of energy crops has become profitable through an additional premium per kWh (Renewables Bonus[2]). Furthermore, additional premiums are granted for the external use of heat (CHP Bonus) and the implementation of innovative agricultural biogas technologies (Technology Bonus[3]).

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[1] Tons of Oil Equivalent.

[2] The Renewables Bonus is paid when biogas is produced from primary renewable products (e.g. agricultural wastes, but no industrial or urban wastes).

[3] Regarding the biogas plants considered in our study, the Technology Bonus applies to the Organic Rankine Cycle (ORC) process only.

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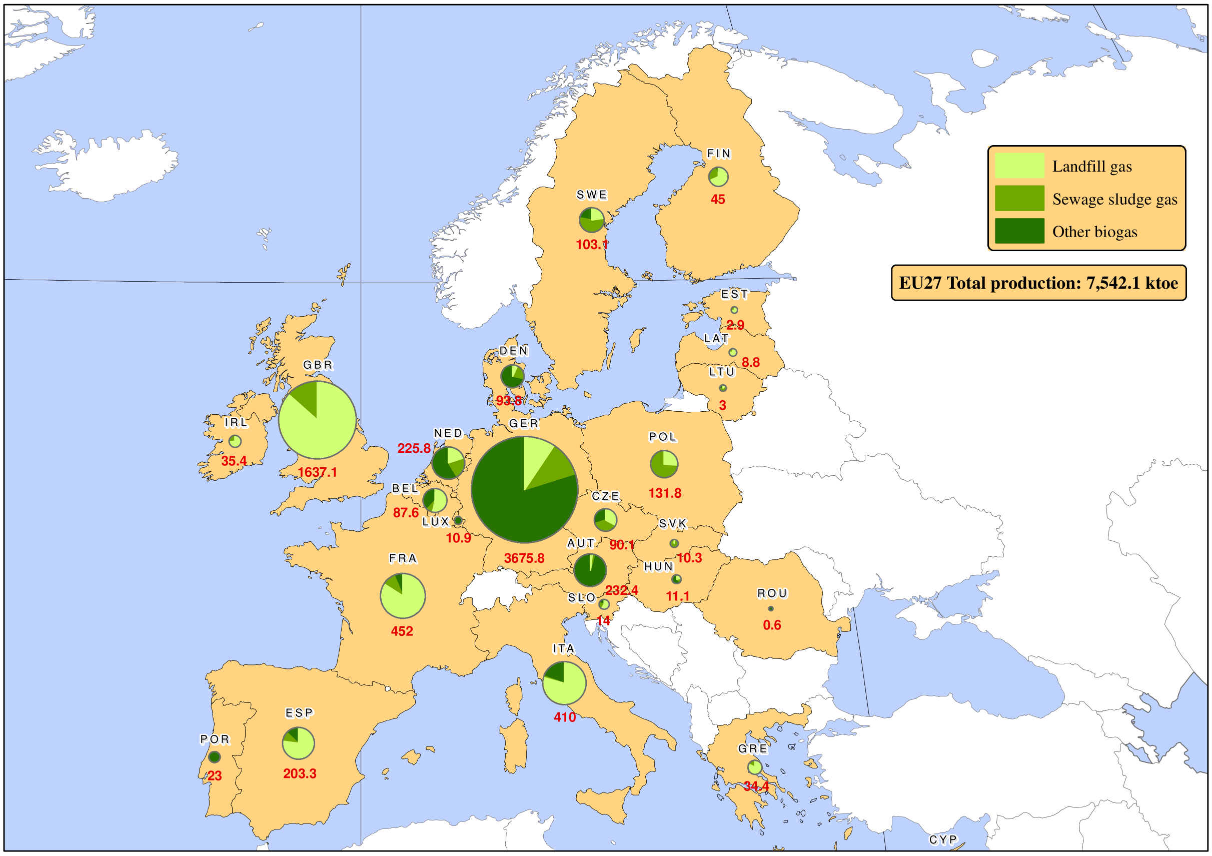

Fig. 1. Biogas production in the EU-27 in 2008. Source: Observ'ER, 2010. The state of renewable energies in Europe. 9th EurObserv'ER Report. Barometer prepared by Observ'ER in the scope of the "EurObserv'ER" Project, Paris, France.

In 2008, there were about 4099 agricultural biogas plants in Germany, with an installed capacity of 1435 MW_{el}. These generated an estimated 4.1 TWh of heat and 9.2 TWh of electricity (Thrän et al., 2009). Interestingly, small-farm anaerobic digestion or fermentation plants contributed some 71% to the total supply (Scholwin et al., 2008). Biogas contributed about 7.7% of the electricity generated from renewable energy sources and about 1.1% of the total gross electricity consumption in Germany in 2008 (BMU, 2008).

Despite a common support program, the adoption and diffusion rates of biogas technology significantly vary across the sixteen German federal states. In 2007, most biogas plants were located in Bavaria (38.5% of the total), followed by Lower Saxony (15.9%) and Baden-Württemberg (14.5%). North Rhine-Westphalia's share was only 6%. Similarly, Bavaria had the highest share of installed power generation capacity from agricultural biogas plants (24.4%), closely followed by Lower Saxony (23.8%), while North Rhine-Westphalia accounted for only 6.9%. However, with respect to the average generating capacity of single biogas plants, Bavaria displayed the lowest value (201 kW_{el}) among all federal states.[4] North Rhine-Westphalia (340 kW_{el}) roughly mimicked the national average of 330 kW_{el} (Scholwin et al., 2008).

Differences in the spatial diffusion of biogas plants among the federal states may be attributable to variations in the underlying local socio-economic conditions. South and South-West Germany are characterized by decentralized, farm-scale plants. Centralized large-scale plants are mostly located in the North and the East. Negro and Hekkert (2008) suggest that this situation is due to the higher cattle density in the South compared to the North. In Bavaria and Baden-Württemberg, agricultural biogas plants are usually set up on single farms with cattle breeding. Also, agricultural biogas plants in North and East Germany are usually managed by several farmers cooperatively. As groups of farmers are involved in cooperative projects, the availability of substrates and capital is usually higher and allows for the construction of larger plants.

With our spatial agent-based simulation model, we are able to account for the unique characteristic of each region and to simulate the diffusion of biogas technology over time. Two reasons motivate our decision to focus on North Rhine-Westphalia and Bavaria. First, data availability on the location of biogas plants is limited due to privacy protection laws. We obtained confidential statistics for biogas facilities in the two selected federal states thanks to the willingness to cooperate of the Landwirtschaftskammer NRW (LWK) and the Bayerische Landesanstalt für Landwirtschaft (LfL). Second, North Rhine-Westphalia and Bavaria have complementary characteristics with respect to agricultural production and the diffusion of biogas units.

With the use of GIS data, we are able to determine the local availability of substrate resources for biogas production given the underlying agricultural production of the local communities. At the same time, we evaluate investments in biogas plants of variable sizes based on Germany's current tariff schemes for electricity fed into the grid. In addition, we take into account alternative uses of waste heat.

The remainder of this paper is structured as follows. Section 2 discusses the methodology and provides a literature overview. Section 3 introduces the key model features. Section 4 presents the data set and its geographical resolution. Section 5 illustrates the simulation results from applying the model. Section 6 concludes and draws attention to the main policy implications of our analysis.

[4] The three federal states Hamburg, Brandenburg and Saxony-Anhalt had the highest average power generating capacities from agricultural biogas plants, amounting to 1 MW_{el}, 670 kW_{el} and 580 kW_{el}, respectively.