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Anaerobic digester systems (ADS) for multiple dairy farms: A GIS analysis for optimal site selection

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HIGHLIGHTS

- This study examines the feasibility of regional ADS for multiple dairy farms.
- GIS is used to identify candidate sites and optimal locations for ADS in a dairy region.
- Model includes environmental, social, infrastructure, and energy return criteria.
- Empirical analysis provides scenario results on 1–15 ADS in the study region.
- Method could be applied to other regions with different conditions and criteria.

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ABSTRACT

While anaerobic digester systems (ADS) have been increasingly adopted by large dairy farms to generate marketable energy products, like electricity, from animal manure, there is a growing need for assessing the feasibility of regional ADS for multiple farms that are not large enough to capitalize their own ADS. Using geographical information system (GIS) software, this study first identifies potential sites in a dairy region in Vermont, based on geographical conditions, current land use types, and energy distribution infrastructure criteria, and then selects the optimal sites for a given number of ADS, based on the number of dairy farms to be served, the primary energy input to output (PEIO) ratio of ADS, and the existing transportation network. This study suggests that GIS software is a valid technical tool for identifying the potential and optimal sites for ADS. The empirical findings provide useful information for assessing the returns of alternative numbers of ADS in this region, and the research procedures can be modified easily to incorporate any changes in the criteria for this region and can be applied in other regions with different conditions and criteria.

1. Introduction

Anaerobic digester systems (ADS) have been adopted by more and more large dairy and livestock farms in the United States and many other nations in the past decade as a technology for generating marketable energy products, such as electricity and natural gas, from animal and food processing waste (Wang et al., 2011). Despite rising interest in ADS, adoption rates remain low compared to the number of dairy and swine farms in the United States that produce organic by-products suitable for ADS. According to the U.S. Environmental Protection Agency (EPA) (2012), there were 176 operating ADS on U.S. farms in 2011, producing about 541 million kilowatt-hours (kWh) of energy. It is estimated there are 81241 swine and dairy farms that are feasible candidates for ADS (United States Environmental Protection Agency, 2010). In addition to these farms, there are many smaller animal farms that could potentially use ADS to convert animal manure into marketable energy products. According to 2007 U.S. Agricultural Census data, there were a total of 1,083,022 animal farms in the United States with beef cattle, dairy cows, hogs and pigs, layer hens, and other animals (USDA, 2009).

ADS are based on biological methanogenesis, a natural degradation process performed by microorganisms in numerous environments such as animal intestines and landfills (Chynoweth et al., 2001). ADS apply the methanogenic process to biological waste streams, including animal manure, municipal solid waste, grease sludge, spoiled animal feed, and other organic by-products, to generate biogas and other products such as compost and animal bedding. Biogas consists of 55–80% methane, and the remaining portion is primarily composed of CO_2, hydrogen sulfide (H_2S), and water (Lusk et al., 1996).

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1.1. Inputs, outputs and revenue of ADS

According to EPA (2012), most of the on-farm ADS in the United States have used methane to generate electricity to meet the farm needs, and farms then supply the excess electricity to the grid to serve household and business needs. It is also technically feasible to inject biogas into natural gas pipelines or use it in farm or transport vehicles (Hansen et al., 2007), but this requires that the biogas be scrubbed of impurities such as CO_2, H_2S, and water at additional system cost (Lusk et al., 1996). To illustrate the potential use of biogas in transport vehicles, a 10-farm cooperative in Indiana with six digesters has adapted their tractor trailer milk hauling fleet, carrying 300,000 gallons of milk a day, to be fueled by compressed biomethane from the digesters (Callahan, 2011).

ADS also provide additional useful products to farms and businesses. The liquid by-product from the digesters contains all of the same basic nutrients as the manure and is spread or injected on nearby cropland. The digester process heats the manure to a temperature that kills many pathogens and after the digestion, the slurry is run through a screw-press separator, removing the solids from the liquid to provide materials that have been used as animal bedding and compost that is sold to farms, gardeners, landscapers, and homeowners. The heat from the generator can also be used to heat water for washing milking equipment and to warm the farmhouse or barns in the winter (Wang et al., 2011).

In addition to the marketable energy products and additional economic benefits mentioned above, ADS provide many environmental benefits. First, they reduce the potency of greenhouse gases (GHG) released into the atmosphere as a result of animal rearing by capturing and combusting methane, a GHG that has 21 times as much atmospheric warming potential as CO_2 (EPA, 2010; Pöschl et al., 2010). According to a recent estimate by the EPA (2012), the on-farm ADS in the United States prevented the direct emission of about 1.2 million metric tons of CO_2 equivalent in 2011. Second, the combustion of biogas to generate electricity for the grid displaces the use of fossil fuels for energy generation and thus contributes to additional emission reductions of GHGs and other air pollutants (EPA, 2012) of the grid. Pöschl et al. (2010) estimated that, for every kWh of electricity produced from on-farm ADS, there is a net reduction of 414 g of CO_2 emissions. Third, the ADS significantly reduce the odors associated with manure storage and spreading and may reduce nutrient load runoff into rivers and lakes by providing an improved option for waste management. Liquid manure that has had the fibers removed is more easily incorporated into the soil, thereby reducing potential runoff of pooled manure on the ground surface.

It has been estimated that, if all animal manures on U.S. farms were treated through anaerobic digester systems (ADS), the resulting biogas could generate nearly 1 quad (10^{15} BTU or 1.055×10^{18} J) of energy each year, or 1.8% to 3% of annual U.S. electricity consumption (Cuéllar and Webber, 2008). However, it is a great challenge to expand ADS to more and more farms, especially small and medium farms.

Besides animal manure from farms, there is great potential to convert organic by-products from food processing facilities into energy products via ADS, and some of the alternative wastes may in fact increase the biogas production from animal manure. Research has shown that adding whey, a by-product of cheese production, to on-farm ADS can increase biogas production from cow manure when steps are taken to maintain pH levels above 5.7 during the methanogenic stage of digestion (Ghaly, 1996; Kavacik and Topaloglu, 2010). It is an accepted practice for cheese producers in Vermont is to pay a small fee to farms with ADS, known as a tipping fee, for dumping their whey into the ADS. The whey would otherwise need to be treated in an energetically consumptive manner at a wastewater treatment site at greater cost. Farms with ADS garner a small amount of revenue from the tipping fees and have also noted increases in biogas production.

1.2. Public policy and financial support for ADS

The environmental and energy production benefits of ADS have spurred financial assistance from the U.S. Department of Agriculture (USDA), which has partially funded the installation of commercially proven livestock to waste ADS. Energy and conservation programs that have provided financial and technical support to on-farm ADS are presented in Table 1 (USDA – AgSTAR, 2012).

Despite the benefits and planning and financial support of ADS in the United States, adoption rates have remained low compared to available sites for ADS and most interest has focused on large-scale systems. A study of ADS implementation in the United States found there to be no operating ADS on dairy farms with fewer than 400 cows (Lazarus and Rudstrom, 2007). Farm size has been found to affect the interest level of farm operators in ADS installation, with those on smaller farms having less interest in the technology, a result of the high capital expense of installation and the economies of scale typically regarded as necessary to support ADS (Swindal et al., 2010).

The connection between ADS technology and large scale is argued to be largely a social construction promoted by its incorporation into the debates over agricultural industrialization (Welsh et al., 2010). The close association between ADS and large farms in the United States results primarily from government policy and programs that favor large-scale operations, as all the operating ADS are heavily subsidized by government agencies (Wang et al., 2011). ADS, it is argued, should instead be considered scale neutral, as they have been adopted by different sizes of operations, from small farms in China and the developing world, to large-scale industrial farms in the United States and Europe (Welsh et al., 2010). The focus of ADS investment at large farms in the U.S. can be viewed largely as a result of engineering and economic studies during the early phases of ADS farm adoption in the 1970s that found economies of large scale necessary to support adoption (Penn State Extension, 2013) and these perceptions have persisted into the research, development, and financial support systems of present ADS policy.

Installing the ADS on large-scale farms alone will not realize the energetic potential from the majority of animal manure in the United States because there are so many small and medium farms across the country. For example, in the state of Vermont, there are a total of 1002 dairy farms and of these, 95.6% have fewer than 500 cows. Together these smaller farms account for 68.2% of the total number of cows in the state (United States Department of Agriculture, 2009). This pattern is similar across the United States, where a total of 66,606, or 95.3%, of dairy farms house fewer than 500 cows each, together accounting for 53.3% of the total number of dairy cows in the nation (USDA, 2007).

The on-farm ADS have been primarily limited to large farms for at least two reasons. First, larger farms with a greater number of animals are more likely to be able to obtain capital from grants, loans, and their own funds to make the huge investment in ADS. For example, all the Vermont dairy farms that installed ADS between 2005 and 2008 had more than 700 cows, and their average initial investment on a system that generates electricity was $2.2 million (Wang et al., 2011). Second, the industrial research and development of ADS has focused on large farms because of the efficiencies of scale and lack of demand for small digesters. The revenue from ADS results mainly from the sales of electricity and the by-products of digestion, but output, and the resultant cash flow, are directly determined by the quantity of manure feeding into the system.