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Making money from waste: The economic viability of producing biogas and biomethane in the Idaho dairy industry

Markus Lauer[a,*], Jason K. Hansen[b], Patrick Lamers[b], Daniela Thrän[a,c]

[a] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH (German Biomass Research Centre), Torgauer Strasse 116, 04347 Leipzig, Germany
[b] Idaho National Laboratory, 1955 N. Fremont Ave., Idaho Falls, ID 83415, USA
[c] UFZ Helmholtz-Zentrum für Umweltforschung GmbH (Helmholtz Centre for Environmental Research), Permoserstrasse 15, 04318 Leipzig, Germany

HIGHLIGHTS

- Anaerobic digestion can increase the income of (dairy) farmers.
- ≥3000 cows per farm are required for an economically viable plant operation.
- Joint, cooperative anaerobic digestion plants allows a higher manure utilization.

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ABSTRACT

Farm operations in the USA and Europe have seen a radical change in the last decades: small sized farms are disappearing, and farm size and total livestock on larger farms are increasing. The resulting spatial density of animals causes several environmental impacts. Anaerobic digestion is one promising technical solution to alleviate most of these impacts while simultaneously providing a regional energy source. This analysis assesses the economic viability of using dairy-cow manure for either (i) the on-farm production and use of biogas to generate electricity and heat or (ii) the upgrading biogas to biomethane, a natural-gas substitute. A non-linear optimization model was developed to optimize plant capacity for anaerobic digestion and maximize the net present value for each option by farm size. In this study, we used Idaho‘s dairy farms as a case study. The analysis implies that at least 3000 cows per farm are required for an economically viable anaerobic-digestion plant operation. For farms with up to 3600 animals, the highest net present value was achieved for the on-farm use of biogas. Farms larger than that achieved their best economic results via the production of biomethane. In total about 45% of Idaho’s dairy manure could be utilized by economically feasible biogas and biomethane plants. A higher manure utilization rate could be achieved through joint, cooperative anaerobic digestion plants and manure transportation. The results can be transferred to other regions and countries, respectively, to reduce the negative impact of intensive livestock farming.

1. Introduction

The European and American dairy sectors have been subject to significant changes: The number of dairy farms has been continuously decreasing, whereas, the average number of cows per farm has been increasing [1,2]. For example, over the last three decades, Idaho has become the third largest milk-producing state in the USA. This process was characterized by two main developments: compared to 1980, the annual milk production per cow in 2012 almost doubled, and the absolute number of milk cows increased from 153,000 to 592,000 by 2017 [3,4]. Due to, among other factors, economies of scale, the state witnessed a reduction in the total number of dairy farms within the last three decades while the average farm size increased to 1240 cows per farm in 2017 [3,4]. In 2007, the average farm size in Idaho was 633 cows [5]. Besides the United States (U.S.), similar developments have been observed in Western European countries, such as the Netherlands [6].

Due to the increasing size of dairy farms and their spatial concentration, the environmental impact of intensive livestock farming has become problematic. According to [7–9], areas with dairy farms are characterized by a high mean nitrate concentration in the groundwater and soil. Besides the increasing concentration of nitrates, dairy farms may also be a health risk when water systems and soil are polluted by manure and pathogens [10]. Several sites with multiple total coliform

* Corresponding author.
E-mail address: markus.lauer@dbfz.de (M. Lauer).

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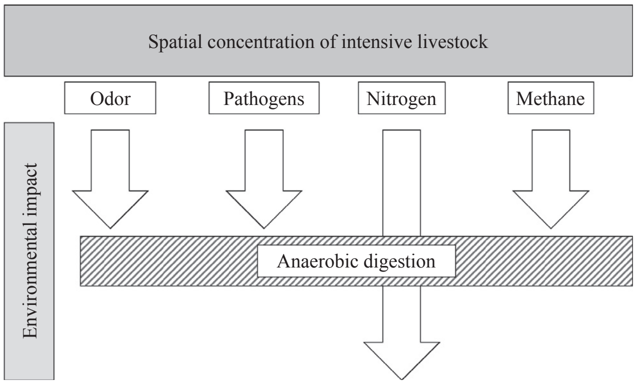

Fig. 1. The effect of anaerobic digestion on environmental impacts caused by the spatial concentration of intensive livestock.

bacteria were located near large dairy farms. In addition, the spatial concentration of livestock result in odor emissions that decrease the life quality of neighboring communities and impact human health, e.g., eye and nose irritation or headache [11].

In summary, there is an urgent need to reduce the environmental impact of intensive and spatially concentrated livestock farming. One technical option to reduce these impacts is anaerobic digestion of related effluents (Fig. 1). Anaerobic digestion reduces both odor emissions and pathogens [12,13]. Compounds of odor emissions are broken down to odorless or less-offensive odor compounds [12,14]. Anaerobic digestion of swine-manure slurry destroys 97.94–100% of total indigenous coliform populations and at least 99.67% of indigenous *Escherichia coli* populations. Similar effects on the bacteria concentration of cattle slurry were shown by [15]. Furthermore, oxygen is required to break down manure in water systems. Anaerobic digestion helps to reduce water contamination through organic material, thereby decreasing total oxygen demand (TOD) level. TOD measures the amount of oxygen needed to break down organic material [16]. However, anaerobic digestion cannot prevent the negative impact of nitrogen contamination imposed by concentrated livestock farming on water systems. Indeed, anaerobic digestion increases the value of manure due to the conversion to ammonia or nitrogen, which is characterized by a higher plant availability; however, the total concentration of nitrogen remains constant [14,16]. Besides the reduction of odor and pathogens, anaerobic digestion decreases greenhouse-gas (GHG) emission from manure used as fertilizer on fields, mainly methane [17–21]. Methane contributes to global warming with 25 times the global-warming potential of CO_2 over a period of 100 years [22]. Electricity generated by manure-based biogas reduces the GHG emission significantly; a German case study calculated a reduction about 1.45 kg CO_2e kWh^{-1} generated power due to the improved manure management and the substitution of the German electricity mix [23].[1] According to [24], the reduction of methane emissions in the U.S. can be one cost-effective measure to decrease the negative impact of climate change. In this paper, we calculate the economic viability of anaerobic-digestion plants to reduce the negative environmental impacts of dairy farms using the state of Idaho as a case study.

Anaerobic digestion plants have been slow to take off in the U.S., and a limited number of studies have analyzed the economic rationale (e.g., [25–28]). The U.S. Environmental Protection Agency (EPA) suggests that biogas plants are economically viable at a farm size of 500 dairy cows or more [29]. Klavon et al. [30] analyzed the profitability of small-scale digesters in the U.S. for farm sizes of 250 dairy cows or fewer. All digesters considered in these studies are characterized—without cost sharing—by a negative cash flow under the chosen assumptions. Similarly, Yiridoe et al. [12] carried out the effect of nonmarket co-benefits, such as odor or pathogen reduction, on the economic viability of on-farm biogas energy production. Without the consideration of nonmarket co-benefits, energy production from biogas on dairy farms for sizes up to 500 cows is not economically feasible [12]. Murray et al. [31] determined potential levelized costs and potential of biomethane (also based on manure) in the U.S., i.e., defined as biogas upgraded to natural-gas properties for the injection and substitution of fossil natural-gas in the natural-gas grid. Biomethane may cover 3–5% of the national gas market in the U.S. at a calculated price of $5–6/MMBtu. In addition, biomethane produced by manure would enter the natural-gas market if the price is above $6/MMBtu [31].

Nevertheless, the above-mentioned studies do not combine the economic viability of anaerobic digestion from the perspective of dairy farmers with the reduction of environmental concerns. In Idaho, the number of large dairy farms is comparably high relative to other states in the U.S. [32]; for this reason, anaerobic digestion may be one option to reduce the environmental impact of intensive livestock farming of dairy cows and to increase the economic viability of Idaho's dairy farmer. The present paper intends to fill this gap by using Idaho as a case study for the calculation of the economic viability of anaerobic digestion.

We assess the economic viability of two alternative (yet not mutually exclusive) technical options for anaerobic digestion: (i) the on-farm use of biogas to generate electricity and heat; (ii) the upgrading of biogas to biomethane and the injection into the grid to substitute natural gas.

The objectives are defined as follows:

i Assess the biogas potential by calculating the size class distribution of dairy farms in Idaho
ii Calculate the economic viability of on-farm biogas use and the injection of biomethane into the natural-gas grid via a non-linear optimization model to optimize the net present value of anaerobic digestion by farm size
iii Characterize the results and perform sensitivity analysis to determine alternative ways to increase the economic potential of manure utilization.

2. Methodology

2.1. Size distribution of dairy farms in Idaho

The economic viability of anaerobic digestion in Idahós dairy industry is related to the number of cows per farm. Utilizing data from the Idaho Department of Agriculture [4], we calculated the size class distribution of the farms, depending on the number of cows as well as the number of farms per size class to show the suitability of Idaho as a case study. We defined 81 size classes, each with a size of 100 cows. The largest dairy farm in Idaho has 18,000 cows compared to 8000 cows of the second largest one; consequently, we summarized the largest size class (no. 33) defined by more than 8000 cows per farm. To assess the economic potential of anaerobic digestion across the technology options, the accumulated proportion of the farms' sizes must be determined.

2.2. Economic assessment

The economic viability of anaerobic-digestion plants using manure from Idahós dairy cows depends on the economic feasibility of the project from the perspective of the operator/investor. Thus, the net present value (NPV) method was used to assess the profitability of the project from dairy farmer's perspective. The NPV method summed the annual discounted cash flow, consisting of the difference of cash inflows (benefits) and cash outflows (costs) over a certain period, resulting in the NPV. If the NPV becomes positive, the investment decision will be economically feasible based on the assumptions chosen [33]. Therefore,

[1] Further benefits of anaerobic digestion are shown, for example, in [12].