Profitable expansion of biomethane production considering biomass intake and digestate offtake-A mixed method Swedish case study

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Abstract

Background

The COVID-19 pandemic and the Russia-Ukraine war have underscored vulnerabilities in global supply chains, emphasizing the need for robust systems to ensure continuous supply of energy and food. Anaerobic digestion has emerged as a key technology in addressing these challenges, and as a result, ambitious biomethane production goals have been set within the EU (EC, 2022). By converting low-grade biomass, such as manure and agricultural residues, into biomethane and nutrient-rich digestate, biogas plants contribute simultaneously to renewable energy generation and nutrient recycling (Lindfors et al., 2022). But like any other large-scale bioenergy generation, they rely on extensive transportation of biomass across the landscape.

Expanding biomethane production requires scaling up in a way that balances profitability, resource efficiency, and environmental constraints. Several interlinked trade-offs should be considered. Increased biomass intake and improved substrate mixes will lead to more biomethane output and thereby more revenue, but also lead to higher costs for biomass acquisition, transport, and potentially necessary preprocessing. Additionally, larger volumes of digestate necessitate off taking over larger areas to avoid over-applying nutrients such as nitrogen (N) and phosphorus (P). This leads to additional distribution costs as raw digestate usually contains ca 95% water. Digestate processing could help mitigate prohibitive distribution costs over long distances.

Digestate processing can be done in different ways. For example, phase separation can generate solid and liquid biofertilisers, while further processing of the liquid phase through evaporation or ammonia stripping can create a concentrated liquid biofertiliser (Feiz et al., 2022). An expansion solution respects the spatial limits on nutrient demand and the trade-off between the cost of digestate processing, cost of transporting biofertilisers, and the market preferences for biofertiliser products, i.e., farmers' willingness to pay for them. Therefore, a spatially explicit trade-off analysis is essential to guide profitable expansion (Metson et al., 2020).

Aim

In this paper we will investigate how biogas plants can sustainably and cost-efficiently expand

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their production considering the spatial variability of biomass supply and regional demand for nutrients. We also investigate how market factors-such as biomethane selling prices and the price differentiation between synthetic fertilisers and alternative biofertiliser products-can affect solutions for profitable expansion.

Method

We base our study on a case biogas plant in Sweden and apply an integrated approach comprising spatial analysis, techno-economic analysis, and optimization. This includes:

- Spatial analysis: We use geospatial databases to map biomass availability (manure types, cereal straw, other green residues, and ley crops), nutrient demand based on crop data, and the road network. We create a grid consisting of 5 km x 5 km cells and use actual road distances to assess the cost of transporting solid and liquid materials between the cells.
- Techno-economic analysis: Together with biogas companies, we construct a model for biomethane production under varying scenarios. This includes revenues from biomethane and biofertilisers as well as processing and transportation costs.
- Optimization: We employ optimization to find a solution for maximized economic returns while meeting the constraints of not overapplying nutrients. The model optimizes biomass selection (types, quantities, and supply cells), digestate processing strategies (no processing, partial, or full processing), and nutrient redistribution (matching biofertiliser products with demand cells).

Expected Results

The study will provide methodological insights for investigating opportunities and constraints for sustainable expansion of biomethane production considering regional supply of biomass and offtake of digestate. Specifically, the paper will:

- Demonstrate a tested method for finding a combination of biomass intake, digestate processing techniques, and nutrient redistribution that maximizes profit but avoids overapplying nutrients.
- Improve our understanding of how market dynamics (price of biomethane and different types of fertilisers) influence solutions for profitable expansion.
- Discuss the broader methodological implications considering integration of spatial and economic analysis using optimization, offering a relevant approach for other biomass-to-bioenergy systems as well as biorefineries.

This paper aims to fill critical knowledge gaps for sustainable biogas production expansion, contributing to the dual goals of energy security and enhanced nutrient recycling, thus the transition toward a resilient and circular bioeconomy.

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