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Cost-effective biogas utilisation – A modelling assessment of gas infrastructural options in a regional energy system

Martin Börjesson*, Erik O. Ahlgren

Energy Systems Technology, Division of Energy Technology, Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

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ABSTRACT

The current utilisation of biogas from anaerobic digestion is low compared to the technical potential. This study investigates requirements for policy support to overcome techno-economic barriers of biogas utilisation and effects of different biogas distribution strategies. Two potential sectors for biogas use are covered: the transport sector and the district heating sector. A quantitative, optimising, energy system modelling approach is applied and the region of Västra Götaland, Sweden, is studied. The model has a high geographical resolution and locations of both biogas feedstock and potential markets are taken into account. The results show that a small part of the technical biogas potential can be cost-effectively utilised without biogas subsidies or larger infrastructural investments. Comparably low subsidies give significant increases in cost-effective biogas utilisation levels, but utilisation close to the full technical potential is linked to high subsidies. From a techno-economic perspective, biogas is best used as vehicle gas. Since local vehicle gas markets are limited, enhanced biogas distribution conditions not only imply larger total cost-effective biogas utilisation, but also a larger share of biogas as vehicle gas. Compared to distribution strategies based on truck transports and regional biogas grids, an expanded natural gas grid presents possibilities but also risks.

1. Introduction and purpose

Biogas produced from anaerobic digestion of organic feedstock can potentially be an important contributor to a future, more environmentally benign, energy system. Biogas is a highly versatile fuel which can be utilised as transport fuel as well as for heat and electricity generation. The biogas potential is limited and can only account for a small share of the total energy supply, but the environmental benefits can be noteworthy. In life cycle assessments, the greenhouse gas (GHG) emission abatement of replacing fossil fuel with biogas, produced from residues such as manure and organic municipal waste, has been calculated to as high as 103–148% [1]. The climate benefits are thus higher than the emission savings of the fossil fuel that is replaced, which is possible due to indirect emission savings, for instance, from increased recycling of nutrients for fertilising of soils and less emissions from traditional handling of the organic waste (e.g., less leakage of methane from manure storage) [1]. The fact that a significant share of the potential biogas feedstock constitutes waste products with few alternative areas of use, including organic municipal and industrial waste, sewage sludge and manure, is an advantage which implies that the risk of unexpected and unwanted system effects, associated with several other biofuel options, e.g., based on food-crops, is small. Besides environmental benefits, increased biogas utilisation could also imply a more diversified energy mix, substitution of natural gas and oil use and thus improvements in energy security of supply.

Despite potential benefits, current biogas use is low compared to its theoretical potential. In Sweden, biogas production was 1.4 TWh in 2008 [2] while the potential based on physical feedstock availability is about 15 TWh/year [3].[1] About half of the produced biogas was used for heating purposes, one-tenth for electricity generation and one-fourth as transport fuel [6]. A significant part (14%) was combusted without utilisation of the released heat energy, basically due to mismatch between biogas supply and demand, lack of

Abbreviations: CHP, combined heat and power; CO_2, carbon dioxide; DH, district heating; EU ETS, European Union emission trading system; GHG, greenhouse gas; HOB, heat-only boiler; HP, heat pump; MARKAL, market allocation (an energy system model); MARKAL_WS, MARKAL_West Sweden (an application of MARKAL); MILP, mixed-integer linear programming; NG, natural gas; NGCC, natural gas combined cycle.

* Corresponding author. Tel.: +46 31 772 52 44; fax: +46 31 772 35 92.
E-mail addresses: martin.borjesson@chalmers.se (M. Börjesson), erik.ahlgren@chalmers.se (E.O. Ahlgren).

[1] For comparison: the total energy supply in Sweden is about 600 TWh/year [4]; the road transport sector fuel use is about 90 TWh/year [5].

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storage capacity and distribution options, as well as to avoid emissions of methane into the atmosphere. The large gap between actual biogas use and available feedstock indicates that expansion in biogas utilisation is being obstructed by barriers. The Swedish Energy Markets Inspectorate has identified three important problem areas: 1) insufficient profitability in biogas production, 2) gas markets are limited and fragmented, and 3) lack of gas infrastructure [2]. Clearly, in addition to general cost issues, gas distribution is a central problem area in need of attention if the best use of the available biogas potential is to be achieved and market demands met in a cost-effective way.

Since natural gas and biogas are two energy gases with very similar properties and can be distributed in the same distribution systems, the linkage between natural gas strategies and the future of biogas cannot be overlooked. However, the characteristics of this linkage are not obvious. In recent years, whether or not an expansion of the natural gas grid, which currently only covers the south-western part of Sweden, will lead to an increased use of biogas has been an issue of debate (e.g., Refs. [7–9]). While acknowledging that generalisations can be misleading, some trends of the debate are worth noticing; while the gas industry tends to emphasize the synergistic effects between natural gas and biogas, environmental organisations are inclined to question that investments in fossil fuel infrastructure could be in line with political targets seeking to reduce fossil fuel use. Conclusions from researchers regarding the future of natural gas and its connection to renewable energy are diverse. While some consider that natural gas can play an important part as a bridge to a renewable energy system [10], others warn that increased use of natural gas will displace bioenergy and claim that local markets are large enough for the existing biogas potential and thus, that no new natural gas pipelines are needed [11].

While the technical biogas potential, based on the physical feedstock availability and technical aspects, is well mapped [3,12], the techno-economic potential, i.e. when technology costs and energy market conditions are taken into account, is less well investigated. Furthermore, studies that examine the influence of different infrastructural conditions on biogas use with a quantitative modelling approach, while taking the geographical locations of both the biogas feedstock and of potential markets into account, are rare. The present study applies this approach and investigates techno-economic system aspects of increased biogas utilisation. In particular, requirements for policy support and implications of different options for gas distribution and gas infrastructure, including an expanded natural gas grid, are examined. The impacts on CO_2 emissions and fossil fuel dependence are also analysed. The analysis covers two potential sectors for biogas use: as vehicle gas in the transport sector and for heat or combined heat and power (CHP) generation in the district heating (DH) sector. The main questions of investigation are:

- What biogas subsidy levels are required to overcome the techno-economic barriers of increased biogas utilisation?
- How do different biogas distribution strategies affect the techno-economic potential of biogas?

Techno-economic barriers here refer to the direct technology-related incremental costs linked to biogas systems compared to other fuel and energy technology options, but do not include other possible economic barriers linked to, for instance, lack of information, financing problems or effects on the macroeconomic level. In a similar manner, the techno-economic potential refers to the cost-effective utilisation levels when energy technology costs and energy price conditions are considered but, again, without non-technology-related economic aspects considered. Production of biomethane based on biomass gasification is not considered in the study.

The study focuses on the problems related to distribution *between* local biogas markets rather than *within* local systems. Therefore, a regional geographical level, incorporating several local systems, is chosen for the analysis. This allows the capturing of an appropriate level of detail with a manageable amount of data, which might be problematic at a higher geographical scale (national, European, global, etc.). In the present study, the studied region is defined by the county of Västra Götaland, located in the south-west of Sweden (by the northern to middle part of the Swedish western coastline). The region covers an area of 24,000 km^2 and has a population of 1.6 million people, corresponding to about 6% and 17% respectively of national totals [13]. The county seat and largest city is Göteborg with about 0.5 million inhabitants [13]. The region consists of 49 municipalities, of which all belong to one of the four local government federation areas in the region: the Göteborg region (12 municipalities,[2] 54% of the population), Fyrbodal (14 municipalities, 16% of the population), Skaraborg (15 municipalities, 16% of the population), and Sjuhärad (8 municipalities, 13% of the population).

There are currently 31 biogas production plants in the Västra Götaland region, which in 2009 had a total production of 160 GWh of biogas [14]. About three-fourths of the production sites are at sewage treatment plants and landfills, while the rest are co-digestion plants (in which several different kinds of substrates can be treated) as well as farm-based plants of a smaller scale [14]. In the region, there are currently four biogas upgrading plants [14] as well as 39 public filling stations for vehicle gas[3] [15]. While some of the filling stations are connected to the natural gas grid, others are connected by pipeline to local biogas production sites, while yet others depend on truck deliveries of compressed gas. In 2009, the use of vehicle gas in the region was about 140 GWh of which 60% was biogas and the rest natural gas [16]. The natural gas grid in Sweden, which distributes natural gas from Denmark, enters the country in the south and stretches along the west-coast up to about 50 km north of Göteborg [17]. This basically means that the Göteborg region has access to natural gas from the grid, while the other areas of the Västra Götaland region have not.

In contrast to the model used in the present study, energy system models often lack an appropriate description of geographical aspects and tend to rely on highly aggregated and average values, e.g., regarding distribution costs or demand levels. Studies which explicitly focus on distributional and infrastructural issues tend instead to apply a simplified approach regarding the influence on the technology mix in the energy conversion systems (e.g., heat and electricity sectors). Nevertheless, a few earlier studies with adjacent set-ups and/or focus of investigation are available in the literature. Madlener and Schmid [18] study the viability and spatial diffusion of agricultural biogas in Switzerland by means of a multi-agent simulation model fed with geographically explicit data on the community level. Ball et al. [19] and Broek et al. [20] use bottom-up energy system optimisation modelling while taking location aspects and spatial constraints into account in the investigation of gas infrastructure. In the former study, in regard to a potential future hydrogen economy in Germany, and in the latter, in regard to

[2] Here excluding the municipality of Kungsbacka which sometimes is included in the Göteborg region even though it is not located in the county of Västra Götaland but in the county of Halland.

[3] In the present study, the term "vehicle gas" is used for methane-based gas, either natural gas or (upgraded) biogas, for usage as transport fuel. Thus, it does not refer to liquefied petroleum gas (LPG), any other gas usable as transport fuel or "gasoline".