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Simulation and introduction of a CHP plant in a Swedish biogas system

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ABSTRACT

The objectives of this study are to present a model for biogas production systems to help achieve a more cost-effective system, and to analyse the conditions for connecting combined heat and power (CHP) plants to the biogas system. The European electricity market is assumed to be fully deregulated. The relation between connection of CHP, increased electricity and heat production, electricity prices, and electricity certificate trading is investigated. A cost-minimising linear programming model (MODEST) is used. MODEST has been applied to many energy systems, but this is the first time the model has been used for biogas production. The new model, which is the main result of this work, can be used for operational optimisation and evaluating economic consequences of future changes in the biogas system. The results from the case study and sensitivity analysis show that the model is reliable and can be used for strategic planning. The results show that implementation of a biogas-based CHP plant result in an electricity power production of approximately 39 GW h annually. Reduced system costs provide a profitability of 46 MSEK/year if electricity and heat prices increase by 100% and electricity certificate prices increase by 50%. CO_2 emission reductions up to 32,000 ton/year can be achieved if generated electricity displaces coal-fired condensing power.

1. Introduction

There is a growing concern about environmental pollution and climate changes based on CO_2 emissions on the one hand and the depletion of fossil fuel reserves on the other hand. Securing the EU energy supply is another important matter. Therefore the expanded use of renewable resources, efficient energy production and the reduction of energy usage are priorities on the European political agenda and a key to a sustainable future. In order to encourage the production and use of biofuels, the EU is focusing its efforts on renewable energy in the fields of electricity and transport. Biological utilization of biomass is of growing importance. This is the point where biogas comes in. Biogas is produced from organic materials which are treated in anaerobic condition. This biogas can be used as fuel for vehicles or for producing heat or electricity. In Europe the increase in biogas production has been also focused to the benefit of electricity produced by CHP plant. In 2009, 4.8 TW h electricity was produced from biogas in CHP plant, i.e. an increase of approximately 18% compared to 2008 [1]. However, it is worth to mention that in Europe a major portion of biogas production is still burned off in flare stacks [2].

The most common use of biogas in Sweden is as a local fuel for transportation with production from a biogas plant. Biogas production does not always correspond to local demand, which varies considerably during the year. Consequently, certain amounts of biogas must be flared off each year, e.g. in 2006 about 13% of biogas production was flared [3]. CHP plant is a possibility, not only to avoid flaring of biogas and thereby utilizing this renewable resource efficiently but also to decrease CO_2 emissions globally. There is a target in EU energy policy to increase renewable energy share in final energy usage to at least 20% by 2020 (in 2007 the share was about 15%) [4]. This means that to adopt Directive 2001/77/EC, the EU needs to set targets and eliminate barriers to encourage growth in the share of electricity from renewable energy sources. The share of electricity from renewable energy sources was 13% in 2001 and increased to 16% in 2006. This share needs to double in order for the EU to reach its overall renewable energy target of 20% by 2020; see the new directive on renewable energy 2009/28/EC. According to EU sources, the share of electricity from biogas is expected to be 80 TW h by 2020 [5].

Another source of revenue from biogas plants is the production of biofertilizer, which can replace artificial fertilisers and reduce nitrogen input in agriculture. Thereby, using biogas and its by-

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product biofertilizer will reduce not only the global warming but also the over-fertilising issue [6]. Biogas also helps to solve waste management problems because production of biogas from organic waste reduces waste volumes.

Sweden's energy policy and waste management together can help to fulfil EU directives while also promoting production of biogas from organic waste used both as fuel for vehicles and to produce heat and electricity, which in turn contributes to climate protection through the substitution of fossil fuels. The Swedish national target is to increase the production of electricity from renewable energy sources to 17 TW h by 2016 compared to 2002 [7].

Several incentive systems and measures have been introduced in Sweden in order to achieve these goals and promote the use of biogas. The main policy to increase production of renewable electricity in Sweden is the quota obligation system with tradable green certificates (the "electricity certificate system"), introduced in 2003. This gives biomass a competitive advantage over non-renewable energy sources. Incentives include tax exemption, governmental investment programmes, reduced valuation tax for company car users and free parking in several cities [8]. Some other special Swedish strategies and policies to encourage biogas are:

- Biogas exempted from energy tax (1995).
- Tax on landfilled waste (SEK 250/ton) (2000).
- Law saying that all landfill gas must be taken care of (2001).
- A ban on landfilling of combustible waste (2002).
- A ban on landfill of organic waste (2005).
- By 2010, at least 50% of household waste materials should be recovered (including biological treatment) and at least 35% of food waste is to be recycled by biological treatment (2006).
- Landfill tax raised to SEK 435/ton (2006).

Another measure that Swedish parliament has been decided in 2009 in order to facilitate the fiscal conditions for biogas is the tax exemption regarding transportation of biogas using the existing natural gas pipeline.

The objective of this study is to present a model for the biogas system, which can help to achieve a more cost-effective system and to analyse the conditions for connection of a combined heat and power (CHP) plant to the biogas system. The relations between connection of CHP, increased electricity and heat production, electricity prices, and electricity certificate trading are investigated. The benefit of connecting a CHP plant to the biogas system in the city of Linköping in a fully deregulated European electricity market has been the focus of the present study. Local electricity production, using a new biofuel power plant, will replace the electricity produced by coal-fired power plants. Since the connection of the new biogas-based CHP plant results in new electricity production, the use of coal-condensing power plants in Europe will be reduced and this measure can thereby decrease global emissions of carbon dioxide. It is important to have optimisation tools that can be used for operational optimisation and evaluation of the economic consequences of future technical or economic changes in a biogas system.

2. The biogas system in the city of Linköping

In Linköping, Sweden's fifth largest city, all the buses and garbage trucks run on biogas. The biogas is produced in the biogas plant in Åby and the sewage water treatment plant in Nykvarn in Linköping. The Åby biogas plant is an organic waste treatment plant, where various waste products are converted to biogas and biofertilizer. The production is based mainly on waste from different food industries (waste fat, vegetable waste), slaughterhouse waste (blood, rumen content and process water), together with animal manure from local farms. The material is mixed into homogeneous slurry in a reception tank, after which it is pasteurised for 1 h at 70 °C by steam-heating, in order to kill bacteria. After cooling, the material is pumped into a digester to be broken down by different types of micro-organisms in an anaerobic environment at about 38 °C. The material remaining after the digestion process is removed continuously from the digester and stored at the plant for a few days before it is transported back to farmers and used as biofertiliser. A simplified view of the biogas process at the Åby plant and biogas production in Linköping is shown in Figs. 1 and 2 respectively.

The wastewater treatment plant Nykvarn is located next to the Åby biogas plant. The gas produced in the sewage sludge digestion process in Nykvarn and the organic waste treatment plant is then pumped to the upgrading facility in Åby. Once upgraded, biogas is conveyed by pipeline at a pressure of 4 bar to the bus depot in Gumpekulla. It is then compressed to 200 bar before it is put into the vehicles. Bus fuel replenishment is done automatically at night by means of slow-filling stations. The bus depot is equipped with a liquid natural gas (LNG) tank. At peak biogas demand, the LNG can be vaporized and mixed with the biogas in the pipeline,

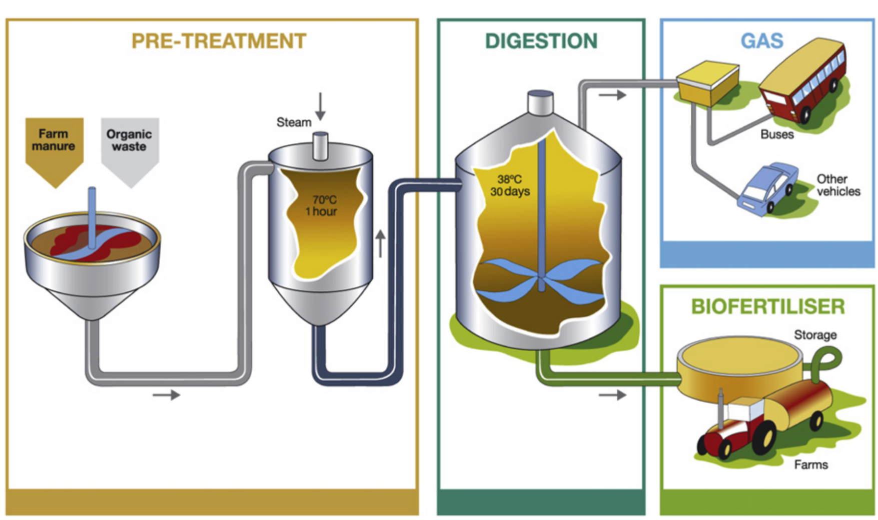

Fig. 1. Simplified view of biogas process at the Åby plant (Source: Svensk Biogas Ltd in Linköping).