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Biomass gasification in cost-optimized district heating systems—A regional modelling analysis

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ABSTRACT

Biomass integrated gasification combined cycle (BIGCC) plants could, in combined heat and power (CHP) generation, increase the power-to-heat ratio compared to conventional biomass steam turbine plants. Furthermore, biomass gasification could also be used for the efficient production of biofuels for transport. In this study, different applications of biomass gasification in connection to district heating (DH) are analysed and contrasted to conventional technology options. An application of the cost-optimizing energy system model MARKAL with a detailed description of the DH sector in a southwestern region of Sweden was developed within the study and used in the analysis. Policy measures for CO_2 reduction and for promotion of "green" electricity are assumed, and required subsidy levels for large-scale production of transport biofuels are calculated. The model also operates with different supplies of biomass: a local supply at a lower cost and an international supply of refined biomass at a slightly higher cost. The study shows that investments in BIGCC CHP are often cost-efficient in cases with low ambitions regarding transport biofuels. However, due to limitations in heat demand and in local, lower cost, supply of biomass, investment in biofuel production means less investment in BIGCC CHP and, thereby, a smaller electricity production.

1. Introduction and purpose

There are mainly two driving forces for modern use of biomass for energy purposes: climate concerns and energy security. With increasingly more ambitious CO_2 emission reduction targets and a will to reduce dependence on imported energy carriers, the demand for biomass is likely to increase. Although biomass resources are renewable, the potential is limited, and an increasing pressure on efficient resource utilization is probable.

The purpose of the present study is to examine the cost-effectiveness of biomass gasification technologies compared to conventional technology alternatives in the district heating (DH) sector. The study investigates whether, and under what conditions, combined heat and power (CHP) generation through biomass gasification in so-called biomass integrated gasification combined cycle (BIGCC) plants could be part of the production in cost-optimized DH systems. Production of biofuels for transport through biomass gasification is also analysed and, in particular, what impact on cost-optimized DH systems a large-scale introduction of biofuel production would have and what subsidy levels that would be required for such an introduction. Furthermore, environmental effects in terms of impacts on CO_2 emissions are addressed. A region in the southwestern part of Sweden, defined by the county of Västra Götaland and the conurbation of Göteborg, with its specific energy demands and energy infrastructure is used as a case study.

A global problem like the climate issue requires international agreements and strategies. However, a local or regional perspective is central for the actual implementation of actions for emission reduction, and allows in several aspects a higher degree of detail than what is possible with more aggregated approaches on higher geographical levels. Local circumstances and geographical considerations, which often are important factors in choice of energy technologies, are more easily integrated in the analysis. In addition, regional energy systems analyses can, besides adding insights of efficient energy technology choices in general, also provide understanding regarding factors such as suitable plant locations. Since biomass markets often are local or regional (although refining of the biomass to, e.g., pellets or briquettes opens up wider markets through decreased transport costs) this perspective is also essential when it comes to analyses of biomass-derived products such as biofuels and "green" electricity. The importance of regional and local initiatives for environmental issues has been addressed in various forums. In the United Nations Programme Agenda 21, local actions for sustainable development is encouraged and recognized to play a vital role (UN, 1993), and the European Commission has in its plan for energy efficiency improvements recognized that large saving

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potentials could be realized by greater decentralization of energy management to local and regional levels (European Commission, 2000). A few energy systems studies have applied the regional perspective. Two examples are Salvia et al. (2004), in which the Basilicata region, Italy, was modelled to analyse cost-effective CO_2 reduction strategies focusing on the civil and waste management sectors, and Carlson (2003), in which the heating sector of the Östergötland region, Sweden, was analysed with the primary objective of examining the consequences of including external costs for emissions. A review of studies done on modelling for decentralized energy planning is given in Hiremath et al. (2007).

The present study has partly its origin in the so-called Biokombi Rya project (Nyström et al., 2007). The Biokombi Rya project had as its main objective, on different system levels, to investigate the possibility and possible benefits of integrating biomass gasification with a 600 MW_{fuel} natural gas combined cycle (NGCC) plant, the Rya CHP, recently taken in operation in the city of Göteborg in the Västra Götaland region of Sweden. However, in the present study, the possibility of retrofitting existing natural gas plants with biomass gasification is not in focus. Instead, the approach is more general considering investments in different types of gasification-based production, and the biomass gasification technologies are treated as alternatives in the entire studied region and not primarily as an option in Göteborg. Other studies that in different ways are concerned with economic performance of biomass gasification utilities are for instance Dornburg and Faaij (2001), Marbe et al. (2004) and Fahlén and Ahlgren (in press). The latter focuses on biomass gasification in connection with district heating in a similar way as the present study, although there are several methodological differences.

2. Background

Gasification makes it possible to use biomass in gas combined cycle (CC) plants and, thereby, to reach a significantly higher electrical efficiency than in conventional biomass steam turbine (ST) plants. However, regarding CHP production, the heat efficiency and the total efficiency (electricity and heat) are lower than in a conventional biomass ST CHP plant with flue gas condensation (Nyström et al., 2007).

Biomass gasification can also be used to produce biofuels for the transportation sector. From the product gas received from the gasification process, a number of biofuels, e.g. dimethyl ether (DME), methanol, synthetic natural gas (SNG), hydrogen and Fischer–Tropsch diesel, can be produced through different types of gas processing and synthesis steps. The energy efficiency is high compared to, for instance, production of ethanol through fermentation of wheat or cellulose (e.g. KAM, 2003; Nyström et al., 2007).

The use of biomass (including waste and peat) accounted, in 2005, for 18%, or 112 TWh, of the total energy use in Sweden (SEA, 2006a). Main users of biomass for energy purposes are the DH and industry sectors, which, in 2005, used 42 and 51 TWh, respectively (SEA, 2006a). The major part of the biomass resources are residues and by-products from forestry and forest products industry (paper and pulp, sawmills, etc.). About 1% (1.5 TWh) originates from the agriculture sector. Energy crops are grown on approximately 70 000 ha, or 2.5% of the total arable land in Sweden. About 70% of this area is used to grow feedstock for production of biofuels, either wheat for ethanol or rape for rape methyl ester (RME/biodiesel), and 20%, or 14 000 ha, is used for cultivation of energy forest, Salix (willow), which primarily is used for heat and electricity production (SOU, 2007). The Swedish Salix industry has a target that the area used for Salix cultivation in 2010 should be increased to 25 000 ha, which is equal to 0.9% of the arable land in the country (Statistics Sweden et al., 2007). Imports of biomass and biofuels to Sweden have been estimated to about 5–9 TWh, and are mainly composed of wood pellets for use in heat production and ethanol for use in the transportation sector (SEA, 2006a).

DH is the dominating heating technology in Sweden with a market share of about 48% of the heating demand for residential and commercial premises (SEA, 2006a). In 2005, the energy supply for DH production (excluding electricity production in CHP plants) totalled to 55 TWh, of which biomass (including waste and peat) accounted for 66%. This is the result of a substantial increase during the last decades, e.g. in 1970 the total energy supply to DH production was 15 TWh, of which 98% was oil (SEA, 2006b). In the DH sector, biomass is primarily used in boilers for heat production, although in recent years the CHP production has risen somewhat (SEA, 2006a). The so far comparably low level of CHP production in the Swedish DH systems and the potential of increasing the production were addressed in Knutsson et al. (2006b).

Energy products, such as heat, electricity and transport fuels, are often influenced by different kinds of policy tools. One example is the EU trading scheme for CO_2 emission allowances, or tradable emission permits (TEPs), which put a price on CO_2 emissions from fossil fuels and, thereby, promotes the use of CO_2-free technologies and fuels. The system has been in operation since January 2005 and includes in its initial stage a limited number of sectors in energy-intensive industries and electricity producers (SEA, 2006a). In Sweden, a CO_2 tax was introduced in 1991, which, in 2005, had a level of 102 EUR/ton CO_2.[1] The application of the tax is different, depending on where the CO_2 emissions take place. It has been applied to full extent to the transportation sector and for production of space heating and to a lesser degree in the industry and for electricity production. Today, the tax is partly being phased out to make way for the EU emission trading system (EU ETS), although it is still in use for sectors that are not included in the system (SEA, 2006a).

In order to stimulate renewable electricity production, a market-based scheme, so-called tradable green certificates (TGCs), has been introduced in Sweden. The TGC system has been in operation since May 2003 and will be so until 2030 (SEA, 2006a). In the TGC system, a green certificate is given to the electricity producer for each produced megawatt hour (MWh) of renewable electricity. The certificate is sold on a market and thus creates an extra income besides the income from the electricity sales. All electricity consumers, except for energy-intensive industries, are obliged to buy certificates in an amount corresponding to a certain share of their total electricity consumption and, thereby, a demand for the green certificates is created. Renewable electricity production technologies, excluding large-scale hydropower and electricity production from combustion of municipal waste but currently including CHP production from peat, are entitled to TGCs (SEA, 2006a). The yearly price averages for the TGCs were between 2003 and 2006 in the interval 21–26 EUR/MWh (Svenska Kraftnät, 2007). Impacts and correlation between TEPs and TGCs for the Nordic countries were modelled and analysed in Unger and Ahlgren (2005).

Also the transportation sector in Sweden is influenced by energy policies, for example, through fuel taxes. In 2006 the fuel taxes, excluding VAT but including the earlier mentioned CO_2 tax, were 0.55 EUR/l petrol (61 EUR/MWh) and 0.41 EUR/l diesel (41 EUR/MWh). To increase the amount of biofuels in the transportation sector, biofuels are currently exempt from the taxation applied for petrol and diesel (SEA, 2006a).

[1] Exchange rates used throughout this paper are 9 SEK = 1 EUR (= 1.14 USD).