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MODELING REGIONAL DISTRICT HEATING SYSTEMS – THE CASE OF SOUTH-WESTERN SWEDEN

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ABSTRACT

Biomass has become the main fuel for district heating (DH) systems in Sweden and is used both in heat-only boilers and, increasingly, in combined heat and power (CHP) plants. DH contributes also to increased sustainability through the utilization of waste heat (WH) which substitutes for primary energy use. Both the geographical distribution of WH sources and the scale effects of bio CHP plants are driving forces for the merging of DH systems. In this study, we are assessing opportunities for connecting local DH systems by transmission pipelines in the Västra Götaland region of Sweden and the system effects and costs of such investments. The assessment is carried out assisted by the optimizing MARKAL_WS model, in which the municipal DH systems in the region are represented individually as well as their relative geographical distribution. The results indicate that linking of local DH systems into larger regional systems can assist economic and environmental sustainability since it enables utilization of, currently unexploited, industrial waste heat resources. However, the cost-effectiveness of pipeline investments is dependent on the size of the available WH capacity. Furthermore, increased use of WH leads to less electricity generation from CHP in the region.

1. INTRODUCTION

In Sweden, due to the oil crises in the middle of 1970's and a high taxation on oil combined with governmental subsidies for domestic fuels such as peat and biomass (Swedish Governmental Energy Commission, 1995), oil has been almost phased out in the Swedish district heating (DH) sector. Furthermore, the national tradable green certificate system, in which electricity consumers are urged to buy certificates corresponding to a certain quota of their total electricity consumption, encourages investment in biomass-based combined heat and power (CHP) plants as the most cost-effective technology (Bergek and Jacobsson, 2010). Consequently, biomass accounts for a large share of the fuel use in Swedish DH systems and is used both in heat-only boilers and, increasingly, in CHP plants. At the same time, results of various studies have shown that the utilization of waste heat (WH), which substitutes for primary energy use in DH, contributes toward economic and environmental sustainability (e.g. Gebremedhin and Moshfegh, 2004; Karlsson et al., 2009).

Future development of the supply side of Swedish DH systems faces a number of challenges. The value of biomass is likely to increase, and thus the price, as a consequence of more serious climate mitigation, and this will certainly affect the cost-effective utilisation of constrained biomass resources. Already today, in a number of systems, WH from industries and municipal solid waste incineration supplies large amounts of the base load heat but a further increase of the WH supply requires in many cases large grid investment since sources are geographically scattered, and also introduces business uncertainty when DH utilities to a lesser extent can control their heat supplies. The interest for extension of the DH grids through connection of several local systems and industries into a regional grid has thus recently attracted increasing attention.

The purpose of this study is to analyze possibilities and potential system effects of regional integration between several local DH systems and industries. The study evaluates the potential effects of the integration on DH systems and different potential industrial waste heat deliveries in regard to total system cost, environmental impacts including CO_2 emission and resource use, and DH technology choices.

A few studies on the subject of regional integration of DH systems and industries in Sweden have earlier been carried out. For example, Gebremedhin and Moshfegh (2004) studied a locally deregulated heat market in regard to system cost reduction through integration and availability of different actors with various heat supply sources. Karlsson et al. (2009) assessed the economic and environmental potential of connecting industrial plants and local district heating systems to provide a joint DH grid in a regional heat market, in which the region includes three different DH provider companies in three municipalities and three energy intensive industries. In these previous studies, only a limited number of DH systems and industries have been included i.e. three DH systems and three or four industries. Further, both of the mentioned studies apply cost optimizing energy system modeling; however, the investment cost of building new pipelines was not included. In present study, we choose Västra Götaland, a region in the south-western of Sweden, as our case study and include all the local DH systems in the region. Additionally, the investment cost of DH systems' integration pipelines is included in this assessment.

2. METHOD

Since we assess a complex energy system, we choose a computer-based model to represent the system comprehensively and in a structured manner. The modeling approach enables evaluation and comparison of economic, environmental and technical aspects of studied systems quantitatively under different conditions and scenarios. MARKAL (Lolou et al., 2004), a well-established cost-optimizing bottom-up model generator, comprises the properties required for this assessment. In MARKAL, an objective function minimizes the total system cost within a large number of constraints, generally through linear programming (LP). In this study, we adapt and further develop the MARKAL_West_Sweden (MARKAL_WS) model application. The model, which represents the energy system of the Västra Götaland region, was developed and applied in Börjesson and Ahlgren (2010; 2012). In the present study, the connection of local DH systems is studied and the system cost is optimized, including perfect foresight, over 30 years. A model discount rate of 5% is used.

MARKAL_WS has a time horizon reaching between 2004 and 2029 and is divided into six model periods (i.e. the length of each time period is 5 years). It is comprised of 37 DH systems with different system characteristics, such as demand levels, installed capacities and energy technology options. Each DH system is described in great detail in regard to available technologies and investment options for DH generation. Other parts of the energy system, such as fuel extraction and end-use technologies, are described in a less detailed way.

In this version of the MARKAL_WS model, a better description of the WH capacity from the large industrial chemical cluster in Stenungsund is added. Stenungsund is a municipality with a population of about 10 000 people located about 50 km north of Göteborg, which is the main city in the region with about 550 000 residents. Currently, the chemical industries supply Stenungsund DH system with heat; however, the WH capacity is considerable larger than the demand in Stenungsund (see Hackl et al., 2010). In this model version, we also add investment options for DH transmission pipelines between each of the 37 local DH systems represented in the model. We then assess the effects of different WH capacity levels in the Stenungsund chemical cluster on investments in pipelines and on other cost-effective technology and fuel choices of the region. Each simulated WH capacity level is assumed to be constant throughout the studied time horizon. The WH is assumed to be available for DH without cost, i.e. any monetary transactions between industry and DH companies as payment for the waste heat is considered to be within the system boundaries.

In the model, the total cost of the energy system is optimized with regard to an individual demand for DH in each DH system. We assume that DH demand is independent of the price fluctuations. The duration curve of DH is defined by three seasons: summer, winter and spring/autumn (intermediate). There is an unlimited market for electricity generation from CHP plants. The generated electricity is sold at exogenously given market prices which give rise to a lowering of the system cost.

We apply "lumpy" investment option in MARKAL to change exact linear LP model to a mixed-integer programming (MIP) model. With a linear model, technologies can be built at any capacity level (without economies or diseconomies of scale), while with a MIP model selected technologies can only be built at discrete capacity level. In this study, the integration pipelines between different local DH systems are can only be built at discrete investment costs while other technologies are handled in a linear manner.

In this paper, a currency exchange rate of 9 SEK=1 EUR is used.

2.1 INTEGRATION PIPELINES

The possible integration pipelines between local DH systems in the region are described by investment cost, operation and maintenance cost, efficiency and life time. The most significant parameter is the investment cost. In the model, the investment cost of integration pipelines is assumed to be 1000 EUR/m (for simplicity, independent of capacity level). The length of each pipeline is estimated based on distances between the respective cities. Investments in the new integration pipelines can be made from model year 2014. The investment cost is based on data presented by the Swedish DH Association (2007) and data collected through interviews with DH provider companies, which have already invested in such integration pipelines (e.g. Kungälv Energi and E.ON) The pipeline operation and maintenance cost is assumed to be 0.1 EUR/MWh (excluding energy losses) (based on Reidhav and Werner, 2008). In the model, the lifetime of pipelines is 30 years.

2.2 CO_2 TAX AND ENERGY PRICES

In this study, a simplified energy policy situation is simulated and only one policy tool is applied: a cost for CO_2 emissions. This CO_2 tax is defined in the model in an exogenous way, is included in all model scenarios, and is assumed to increase linearly during the studied period from 20 EUR/ton CO_2 in model year 2009 to 80 EUR/ton CO_2 in the model year 2029, i.e. at the end of model time horizon.

The CO_2 cost assumptions as well as fossil prices utilized are based on the 450 scenario in International Energy Agency´s World Energy Outlook (IEA, 2010). Biomass prices are assumed to increase during the studied period due to increased competition. Examples of energy prices used (from 2009→2029, for DH):

- Heavy fuel oil: 28→41 EUR/MWh
- Natural gas (large plants): 21→31 EUR/MWh
- Biomass – wood chips: 20→27 EUR/MWh

The electricity price in Sweden is determined based on marginal production technology of the Nordic electricity system. In this study, marginal production technology and electricity price are assumed to be set by the lowest variable electricity production cost of either coal condensing power plants or natural gas (NG) combined cycle plants.

2.3 MODEL SCENARIOS ASSESSED

In this study, four model scenarios are simulated. Firstly, a base scenario in which no new connections between local DH systems can be built is established; this scenario is referred to as the “without connection” case. However, also this scenario includes three already existing DH systems’ integration pipelines in the region, i.e. Kungälv – Göteborg , Mölndal – Göteborg, and Göteborg – Mölndal with the DH transmission capacities of 19 MW, 30 MW and 40 MW respectively (see also in Results section).

Apart from the base scenario, “without connection”, we study three other scenarios which includes the possibility of building the new integration pipelines. These scenarios are differentiated by three different WH capacity level assumptions for DH deliveries from the chemical industries in Stenungsund. Although there most certainly is, and will be, a large excess capacity of waste heat from this chemical cluster, the precise level is linked to uncertainty. The three WH capacity levels simulated in this study are 75, 150 and 225 MW. The model scenarios are referred to as “WH-75MW”, “WH-150MW” and “WH-225MW” respectively. Consequently, these scenarios investigate the potential for regional DH systems and influence of different WH capacity levels compared to the base case.

3. RESULTS

In this section, the result of the model calculation for the simulated scenarios are presented and compared. Mainly, DH production in the “without connection” case is, in the first part of the studied period, based on bio heat-only boilers (HOBs), NG CHP, municipal waste CHP and heat pumps (HPs), while bio CHP production increases with time and decreases the use of NG CHP, HOBs and HPs. Also, municipal waste CHP is slightly increased during the studied time period, but the amount of available municipal waste constrains further increase (Figure 2 Figure 3).

With the possibility of building new integration pipelines and with a WH capacity level of 75 MW in Stenungsund, the result of the cost-optimized energy system presents that no new pipeline is built in the system. Thus, in regard to primary energy use, technology choice, electricity generation, CO_2 emission and total system cost, in comparison with the base case, the system remains unchanged (Figure 2, Figure 3, Figure 4 and Figure 5).

With the possibility of building new integration pipelines and with a WH level of 150 MW, two new integration pipelines are built in the region: Stenungsund – Kungälv with a DH transmission capacity of 125 MW and Kungälv – Göteborg with a capacity of 124 MW ( ). A new pipeline between Kungälv – Göteborg is added to the existing one since the existing pipeline between Kungälv and Göteborg has only limited capacity of 19 MW.

Figure 1- Västra Götaland region. New and existing integration pipelines

In this scenario ("WH-150MW"), WH from industries in the region accounts for larger share of DH production (Figure 2Figure 3). In comparison with the "without connection" case, biomass and NG are replaced with WH due to lower cost of waste heat for DH utilities. Consequently, electricity generation from biomass based and NG based CHPs decreases by about 19% (Figure 2Figure 3). In this model, CO_2 emission related to primary energy use in industries is not included within the considered system boundaries. With this scenario, CO_2 emission from DH production within the region decreases by 14% since WH replaces a part of the NG primary energy use (Figure 4). However, with an expanded system view for which it is assumed that the generated electricity in DH sector replaces the marginal electricity generation in the Nordic electricity system, the lower electricity generation from CHP in the WH-150MW scenario implies lower CO_2 abatement (reduced "negative" CO_2 emissions) than earlier cases, i.e. "without connection" and "WH75MW" (Figure 4). Total system cost (net of taxes) is reduced (by 15%) and so is the sum of the CO_2 tax (due to less use of NG) (Figure 5). It should be noted that the presented aggregation of the CO_2 taxes implies of cost for the DH sector but revenue for the government.

In scenario "WH-225MW", the same two integration pipelines as in "WH-150MW" are built: Stenungsund-Kungälv and Kungälv-Göteborg; however, in this case with the capacities of 195 MW and 185 MW respectively. In comparison with the "WH-150MW" scenario, more biomass and NG are replaced with WH. Electricity generation from biomass CHP and NG CHP plants, which are the main producers of electricity in the region, decreases by 27% compared to the "without connection" case (Figure 2Figure 3). In comparison with the "without connection" case, CO_2 emissions from DH production within the region decreases by 27% due to the larger share of WH in the heat supply (Figure 4Figure 4). However, with an expanded system perspective taking also effects in the marginal electricity generation into account, the larger use of waste heat and smaller utilization of CHP furthermore reduces the CO_2 abatement effect in this scenario compared to earlier cases (Figure 4Figure 4). Regarding the total system cost and aggregated CO_2 emission taxes, model calculates a reduction of 24% and 6% respectively compared to the "without connection" case (Figure 5).

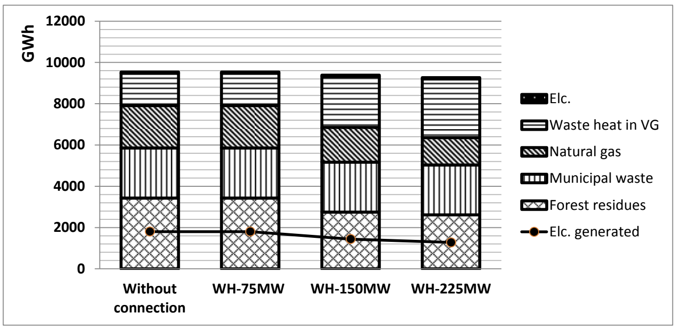

Figure 2- Fuel and electricity use and electricity generation in model year 2019

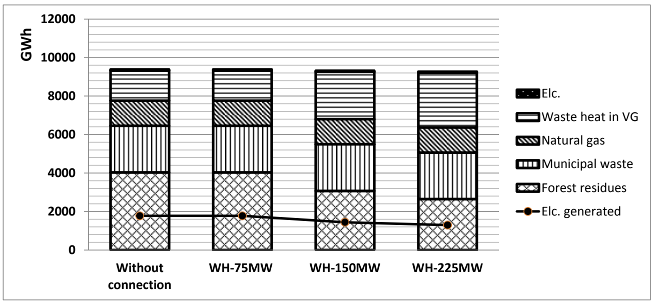

Figure 3- Fuel and electricity use and electricity generation in model year 2024

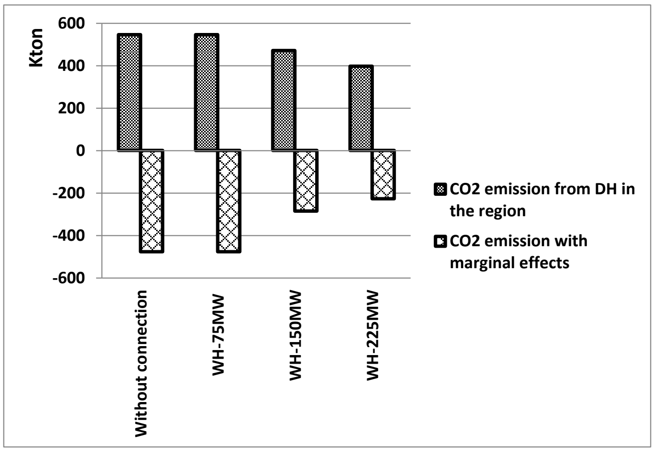

Figure 4- CO_2 emission in model year 2019

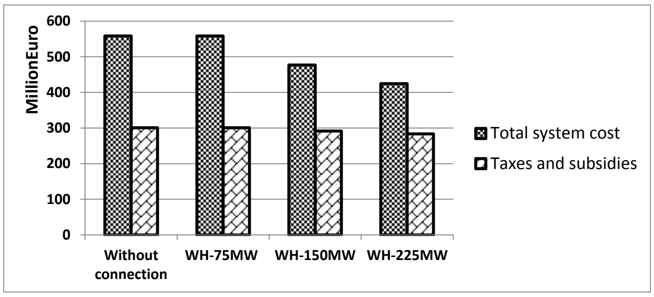

Figure 5- Total cost of DH production (net of taxes) and sum of CO_2 taxes in the region

4. DISCUSSION AND CONCLUSION

In this study, the economic and environmental sustainability of cooperation between a regional DH system and industries is assessed. It is investigated how different levels of WH capacities from industries effects total system costs, technology choices and environmental parameters including CO_2 emissions and fuel use.

In the modeling results, integration of local DH systems and introduction of WH, in excess of 150MW from the chemical industries in the municipality of Stenungsund, reduces the total system cost, which suggests that such actions can improve the cost-competitiveness of DH in comparison with other heating technologies. Additionally, the investment in DH transmission pipelines and the increased use of WH decreases the use of fossil fuels in the DH production of the region significantly. The Swedish DH sector, which is strongly dependent on biomass as fuel, can substitute biomass with WH and benefit economically and environmentally from DH grid connections. However, the utilization of more WH in DH systems also leads to a reduction of electricity generation from biomass-based and NG CHP plants which of course is of importance in a more general energy supply perspective.

The existence of large low-cost heat sources, such as industrial WH, is an important requirement for investments in new integration pipelines between local DH systems to show cost-effectiveness. In this study, by introducing one WH source to the system, two new integration pipelines were added to the system to transfer DH to areas with larger heat demand. Additionally, more WH sources make local DH systems more resilient against economic cycles because local systems can choose between different WH sources.

Through integration of local DH systems into larger regional ones, WH can be used to supply both local and regional heat demand. That is, a regional DH system assists full utilization of available WH as a low cost energy source within the system. In this study, the investment cost of integration pipelines plays an important role in building of a regionally integrated DH system. In several previous studies, this parameter has not been accounted for when the total cost of a regional DH is calculated. One factor in calculation of the investment cost is the distance between local DH systems, which is subject to uncertainties in the sense that the actual best localization of a pipeline will be subject to local conditions. Additionally, in this study the investment cost of the pipelines is constant, independent on their capacity level. In future studies, the investment cost of pipelines might be modeled with better accuracy.

The presented study is using a specific, today only partly utilized, waste heat resource and the region of Västra Götaland as our case. The same method can be applied to other waste heat resources and regions but the outcomes of the study are obviously highly case dependent.

ACKNOWLEDGEMENTS

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