The 15th International Symposium on District Heating and Cooling
September 4-7, 2016, Seoul, Republic of Korea (South Korea).

HEAT COLLABORATION FOR INCREASED RESOURCE EFFICIENCY
- A CASE STUDY OF A REGIONAL DISTRICT HEATING SYSTEM AND A MINE

Louise Trygg[1], Curt Björk[2] Peter Karlsson[2], Mats Rönnelid[3] and Danica Djuric Ilic[1]

[1] Linköping University, SE-581 83 Linköping, Sweden

[2]IndLast, SE-590 34 Tjällmo, Sweden

[3]Dalarna University, SE-791 88 Falun, Sweden

Corresponding: author:louise.trygg@liu.se

***Keywords:* District heating, mine, collaboration, system perspective**

ABSTRACT

To rapidly develop sustainable energy systems is crucial for the whole society's transition towards sustainability. System efficiency and reduced climate impact are important parts of this. Swedish district heating systems are fairly well developed, mainly based on non-fossil fuels, and includes energy-efficient technologies (such as combined heat and power production and fuel gas condensation). Increased use of district heating is therefore considered as a way to increase energy-efficiency, to phase out fossil energy for heating purposes, and subsequently to a reduction of global CO2 emissions.

The aim of this paper is to study system impact of increased demand of district heating by analysing a collaboration on heat supply between the local energy supplier of Ludvika in Sweden and a nearby mine. The paper analyses economic potential, as well as the potential for more efficient operation of district heating production plants in the local district heating system. The heat demand in the mine is presently supplied from a small-scale biomass-fuelled heat-only boiler located near to the mine. The system consists of two biomass-fuelled heat-only boilers with fuel gas condensers. The consequences of connecting the heat demand of the mine with the municipal district heating system is analyzed using the cost optimization model MODEST.

The connection of the mine to the local district heating system is shown to be an energy-efficient and cost-effective measure. The results show that when the heating demand of the mine is integrated with the local district heating production in the city of Ludvika, the overall energy system cost of the combined system of the energy utility and the mine is reduced with about 120 000 euro per year. The higher energy efficiency indicates a reduction of global CO2 emissions. The collaboration results also in an increased utilization of plants in the local district heating system, which opens up possibilities for investment in more efficient district heating technologies (such as combined and heat production).

INTRODUCTION

Energy systems of today significantly contribute to society's unsustainable situation. Fossil fuel use related to the energy systems is continuously increasing, as well as greenhouse and toxic gases which are released during the fossil fuel incineration. Other problems related to the energy systems are degradation of the biosphere due to extraction of fossil fuels from the Earth's crust and due to overuse of biomass [1], [2].

Development of sustainable energy systems, which should be characterise above all with 100% of renewable energy supply and high energy-efficiency, require cooperation between different types of energy systems. District heating have been recognised as a technology with many opportunities for cooperation with other energy systems: power sector (trough combined heat and power production in the district heating systems, or electricity use for district heating production), transport sector (by introducing transport biofuel production in the district heating systems), industry sector (by delivering industrial waste heat into the district heating system or by converting industrial processes to district heating). A number of previous studies have analysed economic and environmental impacts of cooperation between a district heating company and industry [3], [4].

In Europe electricity use has a distinct connection to high CO_2 emissions [5]. Energy efficiency measures (EEMs) to lower the use of electricity are therefore particularly interesting. The potential of reducing electricity use is especially high within industry [6]. In Sweden, per-capita use of electricity is among the highest in the world and a large part is used for processes that are not electricity specific, such as heating and drying. A likely explanation for such a high use is the historically low price of electricity [7]. Thus, both from a climate point of view and a more short-term economic point of view, there are good reasons for Swedish industries to make their use of electricity more efficient and, in some cases, to also convert from electricity to other types of energy carriers. There are also wider sustainability potentials from a systems perspective. Electricity-related EEMs in industry can free up electricity for vehicles, allowing for reductions of fossil fuels in the transportation sector. And most importantly, EEMs can pave the way for more renewable energy. With a more efficient use of energy, the total volume of renewables needed to replace current energy sources will be smaller and therefore easier to accomplish within sustainability constraints. Furthermore, the economic savings resulting from EEMs can be invested in development of renewables. Identification and implementation of EEMs should consequently be of great importance for Swedish industry in order to maintain its competitiveness as well as for society to promote sustainability in general. In the view of the high use of electricity in Swedish industries, energy audits have been performed in, e.g., industrial Small- and Medium-Sized Enterprises (SMEs). Generally, these studies show that there is a great potential for improved energy efficiency and that many of the identified measures would in fact be profitable (e.g. [8], [5], [9], [10]). For example, to study if and how Swedish industries can reduce their use of electricity and thereby change the relation between electricity and fuel, over 50 industrial SMEs in the Swedish municipalities of Oskarshamn, Örnsköldsvik, Ulricehamn, Borås and Vingåker were analysed. In the municipality of Oskarshamn, ten industrial energy audits were carried out in 2001 [8]. The municipalities of Örnsköldsvik, Ulricehamn, Borås and Vingåker were part of a pilot project of the programme “Sustainable Municipality”, financed by the Swedish Energy Agency. The energy audits were carried out during 2003-2004 in about ten industrial SMEs in each of these municipalities [11], [12], [13]. The result of the study showed an average possibility to reduce the use of electricity within the range from 20% to 58%.

The aim of this paper is to study system impact of increased demand of district heating by analysing a collaboration on heat supply between the local energy supplier of Ludvika in Sweden and a nearby mine. After analysis of the economic potential, in the article it is also discussed how this collaboration would affect the heat load duration curves in the local district heating systems and operation of district heating production plants.

METHOD

The method used in this study consists of 2 different scenario calculations using the linear optimization program MODEST.

MODEST is an abbreviation of "Model for Dynamic Optimization of energy systems Time-dependent components and boundary conditions”. MODEST is used to optimize the production of electricity, steam, heat and cold. The model calculates how the demand of energy should be met at the lowest cost taking into account variations in the short and long term when considering for example electricity prices and heating use. Other measures that can be modelled and studied with the MODEST model are consequences of more efficient use of electricity and conversion between electricity and heat.

The figure 1 below shows schematically how MODEST is constructed by input, optimization and performance.

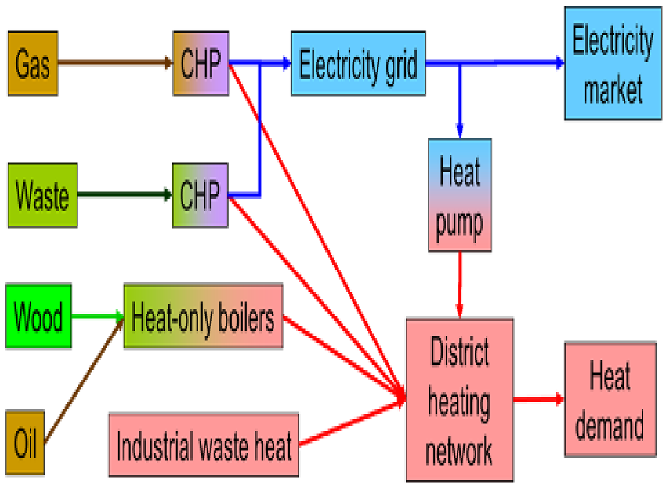

Figure 1 Schematic picture of the MODEST model [12]

The optimisations aim to minimise the total system cost of supplying the demand for heat and steam by finding the most optimal types and sizes of new investments and the best operation of existing and future plants. The total system cost is calculated as the present value of all capital costs of new installations, operation and maintenance costs, fuel costs, taxes and fees. In this study the system is optimised over a period of 10 years and the capital costs are based on a discount rate of 6%. Each year in the optimisation model is divided into seasons, which are then divided into daily periods to give a total of 88 different periods during one year [14].

The method assumes perfect conditions where the capacity of the plants is available and the demand for district heating and electricity is known. It is vital to stress that MODEST is not primarily a tool for operational optimisation, even if such an optimisation can be done in an approximate manner. MODEST has also no other aim than total minimisation of cost such It is also vital to stress that the MODEST model has its limitations as for example:

- Hourly and daily operations are not the aim of the model, although every hour of the year could be reflected. Even faster or continuous fluctuations can, however, not be treated at all.
- Binary variable and mixed-integer linear programming included in the model. This means that start-up costs cannot be represented and minimum operation capacity consequently must be modelled manually.
- Investment costs are stated per output unit (SEK/MW). This is important to point out since smaller installations are characterized by higher cost per capacity than larger installations.

Further limitations within the MODEST model are described in [14].

CASE STUDY

In this study the energy utility in Ludvika and a nearby situated mine, Blötberget are included. The energy utility in Ludvik, VB Energi (Västerberslagens Energi AB), is owned by Vattenfall together with the municipalities of Ludvika and Fagersta in Sweden. The Ludvika district heating system is characterise by an annual district heating production of approximately 100 GWh.

District heating load duration curve in the system is highly dependent on outdoor temperature since the district heating is currently used only for space heating and hot tap water production in multi-family residential buildings, service sector and private houses. The system consists of two biomass-fuelled heat-only boilers with fuel gas condensers, and a thermal storage (see Table 1). Fuel gas condensation is a technology of recovering energy for district heating production by condensing the water in flue gases.

Tabel 1 District heating production units in Ludvika energy system

Production unit	Installed capacity
Boiler 1, pellets	10 MW
Boiler 2, pellets	10 MW
Flue gas condenser	5 MW
Thermal storage	2 000 m^3

The heating demand curve of the mine Blötberget is characterized with low outdoor temperature dependence. The annual heat demand has been estimated to 6,4 GWh. This demand is currently supplied from a biomass heat-only boiler which is located near the mine [13].

Two different scenarios were analysed: (1) scenario called business-as-usual (denoted as BAU in Table 2), and (2) scenario called cooperation (denoted as COOP in Table 2).

Tabel 2. Description of the scenarios

Scenario BAU	BAU scenario describes the existing energy system where the Ludvika district heating system is not connected to the mine.
Scenario COOP	COOP scenario describes the consequences of cooperation on heat supply between the mine and Ludvika district heating system.

RESULT

Analyzing the result from the two modeled scenarios gives possibilities to compare the system cost for the existing system and the combined system. Analyses show that when the two systems are not connected (scenario BAU) the total system cost for satisfying the heat demand of the mine and of the municipality of Ludvika is about 26 MEUR for the studied period of ten years. When modelling the cooperation between the district heating company and the mine (scenario COOP) the corresponding system cost is about 25 MEUR for the studied period of ten years. The system cost savings related to the cooperation are approximately 120 000 EUR per year.

Furthermore, building a pipeline that connects the mine to the district heating system leads to a more resource efficient use of energy, and subsequently to a reduction of global CO2 emissions. The reason for the increased energy efficiency is that heat production in a small-size biomass-fuelled boiler owned by the mine company is replaced by the heat production in the medium-size biomass boiler from the district heating system, which are characterised by a higher efficiency mostly due to the flue gas condensation (see section case study).

CONLUDING DISCUSSIONS

In a future sustainable energy system with high percentage of renewable energy sources it will be of even greater importance to find measures that will support a fully balanced energy supply.

In this study the effects of collaboration between a municipal energy system and a nearby situated mine are analyzed. The results showed that the collaboration will lead to a district heating demand curve which is less dependent on outdoor temperature. As a result, the utilization period for the power plants will be prolonged, the energy-efficiency of the system will increase, and the total system cost will be reduced. The increased use of district heating will also open up possibilities to invest in a combined heat and power plant for the municipal energy system. This concludes that the suggested cooperation on heat will not only reduce the total energy system cost but also led to possibilities to produce electricity and subsequently to reduce the global CO2 emissions.

FURTHER WORK

An interesting extension of this work would be to analyze

- investment in new district heating technologies such as small-scale combined heat and power plants or heating pumps
- sensitivity analysis on different energy market conditions i.e. energy prices, energy policies and assumptions regarding alternative electricity production.
- biomass availability and how the reduce biomass use in the analysed system would affect the global CO2 emissions considering different alternative users of biomass.

ACKNOWLEDGEMENT

The authors would like to thank Vinnova for financing this work. The authors also would like to thank Kathrine Abrahamsen and Lars Lindblom at High Voltage Valley for valuable support.

REFERENCES

[1] Steffen, W., A. Sanderson, J. Jäger, P. D. Tyson, B. Moore III, P. A. Matson, K. Richardson, F. Oldfield, H.-J. Schellnhuber, B. L. Turner II, and R. J. Wasson, eds. (2004). Global Change and the Earth System: A Planet Under Pressure, IGBP Book Series. Heidelberg, Germany: Springer-Verlag.

[2] IPCC. (2014.) “Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change”, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

[3] Djuric Ilic, D., Dotzauer, E., Trygg L., Broman G. Introduction of large-scale biofuel production in a district heating system - An opportunity for reduction of global greenhouse gas. Journal of Cleaner Production, 64 (1) 2014, pp. 552-561

[4] Djuric Ilic, D., Dotzauer, E., Trygg L., Broman G. Integration of biofuel production into district heating - Part I: An evaluation of the biofuel production costs. Journal of Cleaner Production, 69, 2014, pp. 176-187

[5] Trygg, L., Karlsson, B. (2005). “Industrial DSM in a European electricity market - a case study of 11 industries in Sweden” Energy Policy, 33:1445-1459 Elsevier.

[6] EC. (2005) Green Paper on Energy Efficiency or Doing More With Less. COM(2005) 265 final

[7] Stenqvist, C., (2014). Industrial energy efficiency improvement – the role of policy and evaluation. Dissertation. Lund University. Download at: http://lup.lub.lu.se/record/4220512

[8] Trygg., L. (2004). “Generalized method for analysing industrial DSM towards sustainability in a deregulated European electricity market - method verification by applying it in 22 Swedish industries.” Proceeding of the 2nd International Conference on Critical Infrastructures, Ed. J-C Sabonnadiere, s10-a2, Grenoble, France.

[9] Thollander, P., Rohdin, P., Danestig, M. (2007). “Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs”, Energy Policy; 35(11): 5774-83.

[10] Backlund, S., Thollander, P., (2015). Impact after three years of the Swedish energy audit program. Accepted for publication in Energy.

[11] Henning D, Hrelja R, Trygg L. (2004). ”Energianalys Örnsköldsvik”. (Energy analysis of Örnsköldsvik, in Swedish) ER 15:2004, Swedish Energy Agency, Eskilstuna, Sweden.

[12] Bohlin H, Henning D, Trygg L. (2004). ”Energianalys Ulricehamn” (Energy analysis of Ulricehamn, in Swedish) ER 17:2004, Swedish Energy Agency, Eskilstuna, Sweden.

[13] Gebremedhin A, Palm J. (2005). “Energianalys Borås” (Energy analysis of Borås, in Swedish, ER 28:2005, Swedish Energy Agency, Eskilstuna, Sweden.

[14] Henning D. ‘Optimisation of Local and National Energy Systems: Development and Use of the MODEST Model’1999, Dissertations No. 559, Linköping university, SE-581 83 Linköping, Sweden.

[15] Björk C, Karlsson P, Jonson M (2015) ‘Testbed efficient energy supply mines‘ report Vinnova