Open district heating for Espoo city with marginal cost based pricing

Sanna Syri
Henri Mäkelä
Samuli Rinne
Department of Energy Technology
Aalto University, School of Engineering
FI-00076 Aalto, Finland
sanna.syri@aalto.fi

Niko Wirgentius
Heat, Electricity Sales and Solutions
Fortum Ltd.
FIN-00048 FORTUM, Finland
niko.wirgentius@fortum.com

***Abstract*— We present the concept for an open district heating market for cities with hourly marginal cost based pricing, using the Finnish city of Espoo (265 000 inhabitants) as example. District heating (DH) with highly efficient Combined Heat and Power (CHP) production covers about 90% of heating in larger cities in Finland. We created a model with an hourly resolution, where the power plants are dispatched in the cost optimal order according to representative fuel prices and electricity spot market prices. We explored the impacts of external producers on the system operation and possible system cost savings induced by allowing external producers to provide their waste heat to the network, simulated by 20 MW waste heat production of a large metro and shopping centre. Similarly, the impacts of a large solar heat plant (5 MW) were simulated. Our results demonstrate that open heat market could be beneficial for all parties and that significant cost and fuel savings are possible with mutually beneficial business models.**

***Index Terms*--** district heat, heat market, energy efficiency, combined heat and power, waste heat

I. INTRODUCTION

District heating (DH) with highly efficient Combined Heat and Power (CHP) production covers about 90% of heating in larger cities in Finland. In Finland, total CHP plant efficiencies are commonly around 90%, power to heat ratios varying according to the technologies and plant sizes. Heat-only boilers (HOB) are used in small communities and in peak load use in larger cities. [1], [2], [3]

The Finnish district heating concept provides a robust system against possible disturbances in fuel supply, as contrast to e.g. direct gas heating common in Central Europe. There are typically several types of power plants in the networks of larger cities. In addition, gas-fired power plants have the ability to change to an alternative fuel, typically fuel oil, in the case of a possible supply disruption.

However, DH has traditionally been a natural monopoly, and among customers in Finland, more requests are emerging for a more market-based approach instead of the traditional, rigid pricing systems and rising heat prices. Open district heating with real-time cost-based prices is one potential way to respond to this. [4], [5] Open district heat with hourly prices for buying and selling has recently been launched in Stockholm area by the network owner Fortum Ltd. Similar methodology has also been demonstrated with an industrial heat provider to the DH network. [6] These can be considered as extensions of earlier model studies of optimising DH systems and harnessing the benefits of larger, connected DH systems, see e.g. [7], [8], [9].

In this study, we developed an hourly model for the DH system in the city of Espoo in Finland, where DH has a market share of 67%. Espoo has 265 000 inhabitants and it's currently the second largest city in Finland. Our simulation shows that external waste heat primed with heat pump could provide substantial system cost savings and be economically attractive for all parties.

II. METHODOLOGY

A. *Problems of the current pricing system of DH in Finland*

In Finland, DH pricing is a natural monopoly supervised by Energy Authority. The maximum allowed profit for DH companies is specified based on invested capital and alternative risk-free investment returns. However, DH is competing with other heating forms, and especially heat pump heating is at the moment gaining market share in detached houses and in small apartment buildings in Finland.

In Finland, DH pricing usually consists of connection fee, which is paid once when a property is connected to DH network. Annual price consists of capacity fee (i.e. maximum heat delivery capacity of the connection) and energy fee (i.e.

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annual heat energy delivered), the energy fee being the major part of total annual costs. [1] In addition, some companies have lower energy fees during summer time than in winter time. However, the pricing system is quite rigid and it is not able to reflect the actual production costs in different situations: in Summer time the marginal cost of CHP heat can be very low, whereas in short peak demand times of Winter cold spells also very expensive oil-fired peak load boilers may be needed. The rigid pricing system is not transparent towards the consumer: it does not advance understanding of how the heat provision costs are formed, and what would be the effective ways of reducing the costs. It does not properly incentivize consumer saving measures during the periods when they would be most beneficial for the system and for the environment. Fig. 1 illustrates how large the heat demand variations are in reality: in Summer time heat is provided mainly for domestic hot water (DHW) use, and during the coldest winter periods the heat demand is 5-8 times higher.

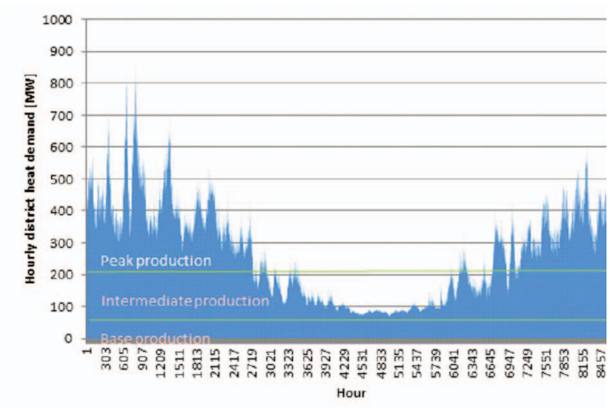

Figure 1. Hourly heat demand in the DH network of the city of Espoo during a typical year (MW). This demand profile was used in the simulations. Also the shares of different types of production are indicated.

B. Hourly marginal costs based model for the Espoo DH system

We developed a Matlab-based hourly model for the Espoo DH system and simulated the system during the years 2012 and 2013 with realistic weather and heat demand data. Real electricity market price time series for the Finnish market area during these years were used in the simulation.[10]

We used realistic fuel prices and taxes during the periods simulated. In Finland, heat delivered to the network is taxed, whereas electricity is not, as the latter is traded on the multinational electricity market. Table I shows the ranges of the fuel and electricity prices during the simulations. The values used are actual taxes and electricity spot market prices and average fuel prices reported in official statistics. The fuel prices paid by individual companies can be different from the reported average prices.

Table II shows the power and heating plants in the network. Also one confidential source of waste heat, which currently exists in the network, is indicated. We also included Fortum's currently planned new plants in the simulation. Our external heat provider simulations are noted with footnote b.

Our basic modelling principle is to minimize for each hour of the year the total cost of delivering the required amount of heat. For this, the calculation of heat-only boilers (HOB) marginal costs is quite straightforward based on the fuel price and the boiler efficiency. CHP operation is more complex. We simulated the CHP plants operation in the following way: the cost function takes into account the fuel cost for generating heat and electricity, and they are generated with the specific power to heat ratio of each plant. The generated electricity is assumed to be sold at the market price of each hour, and this income is deducted from the total variable cost of the plant. The remainder is then the marginal heat production cost. Taxes were calculated according to the Finnish legislation: 90% of the fuel used for the heat part of CHP is subject to tax [11]. Suomenoja 1 (Table II) is also able to run in heat-only mode, and this is also allowed in our simulation, if electricity prices are so low that this is more profitable. More details of the modelling are given in [12]

C. External heat providers: waste heat from a metro centre and a solar heat plant

We simulated two kinds of possible external heat providers: waste heat primed by a heat pump and a solar heat plant. The waste heat would originate from a large metro and shopping centre, which is currently under construction in Espoo. We simulated this with a capacity of 20 MW and a COP of 2.8.

TABLE I. FUEL, ELECTRICITY AND TAX VALUE RANGES USED IN THE SIMULATIONS. VAT IS EXCLUDED [11], [10], [13], [14], [15] .

Electricity distribution	21 €/MWh
Electricity tax	18 €/MWh
Coal price	10 - 13 €/MWh
Natural Gas price	31 €/MWh
Light Fuel Oil price	62 - 72 €/MWh
Heavy Fuel Oil price	46 - 54 €/MWh
Biodiesel price	62 - 72 €/MWh
Wood Pellet price	41 €/MWh
Electricity prices 2012	4 - 300 €/MWh
Electricity prices 2013	1 - 210 €/MWh
Coal tax	22 €/MWh
Natural Gas tax	15 €/MWh
Light Fuel Oil tax	19 €/MWh
Heavy Fuel Oil tax	20 €/MWh
Biodiesel tax	48 €/MWh
Wood Pellet tax	0 €/MWh

The approximate investment cost for the heat pump was estimated to be 200 €/kW, i.e. in total 4 M€. In addition, a hypothetical solar heat plant of 5 MW was simulated to study its impacts on the system. This would correspond to an area of 8000 m^2, production depending on the solar radiation available.

TABLE II. POWER AND HEATING PLANTS IN THE DH NETWORK OF ESPOO [1].

Plant	Boilers	Heat output (MW)	Electricity output (MW)	Main fuel
Suomenoja 1	1	162	75	Coal
Suomenoja 2	1	213	234	Natural Gas
Suomenoja 6	1	80	49	Natural Gas
Suomenoja 3	1	70	-	Coal
Suomenoja 7	1	35	-	Natural Gas
Kivenlahti	2	130	-	Heavy Fuel Oil
Tapiola	2	160	-	Natural Gas
Vermo	2	80	-	Natural Gas
Kaupungin-kallio	2	80	-	Light Fuel Oil
Otaniemi	3	120	-	Natural Gas
Auroranportti	1	15	-	Light Fuel Oil
Juvanmalmi	1	15	-	Natural Gas
Kalajärvi	2	5	-	Light Fuel Oil
Vermo	2	90	-	Natural Gas
Masala	2	5	-	Natural Gas
Kirkkonummi	4	31	-	Natural Gas
Confidential external heat	-	12	-	-
Suomenoja heat pumps	-	40	-	Electricity
Vermo[a]	1	35	-	Bio oil
Kivenlahti[a]	1	40	-	Wood pellets
Third party[b]	-	20	-	Electricity
Solar heat[b]	-	5	-	-

a. Under planning

b. Our simulated external producers.

The current DH system of Espoo has a versatile combination of both coal and gas fired CHP plants and HOB's running on different fuels. The system includes also 40 MW heat pumps at Suomenoja wastewater treatment facility, which utilize the heat content of the municipal waste water and prime it with heat pumps.

When simulating the possibilities of the external heat providers, first the hourly simulation with cost minimization was performed for the current system (including Fortum's near-future plans, Table II). Then, the simulation was repeated with the hypothetical external heat producers, i.e. the heat pump of 20 MW and the solar heat plant of 5 MW. The third party, i.e. the heat pump owner at the metro centre, is assumed to provide heat always when the electricity price (including distribution fee and electricity consumption tax) is so low that heat provision would reduce the total system cost. Solar heat would be provided to the heating network according to the radiation available. These external heat providers always replace the most expensive required production forms in the system. The difference between these cases shows the total cost savings.

III. RESULTS

A. *Hourly system operation with the external producers*

We found that during the simulated years, electricity prices have during most of the hours remained so low that external heat primed by the assumed heat pump would provide system savings. It would reduce the operation of the most expensive heat production forms. Fig. 2 shows the results of our modelling for the first two weeks of January 2012, including the simulated external heat provider and solar heat plant. During this period, external heat would replace mostly the use of wood pellet and natural gas fired HOB's in the system. During 2012, heat demand was not so high that the most expensive HOB's, i.e. oil-fired ones, would have been needed.

Fig. 2 also shows that in winter time, the cost-optimal use of CHP's with different fuels and HOB's would change rapidly according to the electricity prices. During periods with low electricity prices, the use of Suomenoja 3 coal-fired heat-only plant would be attractive, whereas during periods of higher electricity prices (about 40-60 €/MWh), the use of Suomenoja 2, the gas-fired large CHP with a high power to heat ratio, would become profitable even with the high natural gas prices on the Finnish market during 2012-2013. However, it should be noted that in reality the power plants are not able to perform as rapid ramp-ups and ramp-downs as assumed in this simulation, and the start-ups of large CHP plants are decided on the basis of, for example, weekly forecasting.

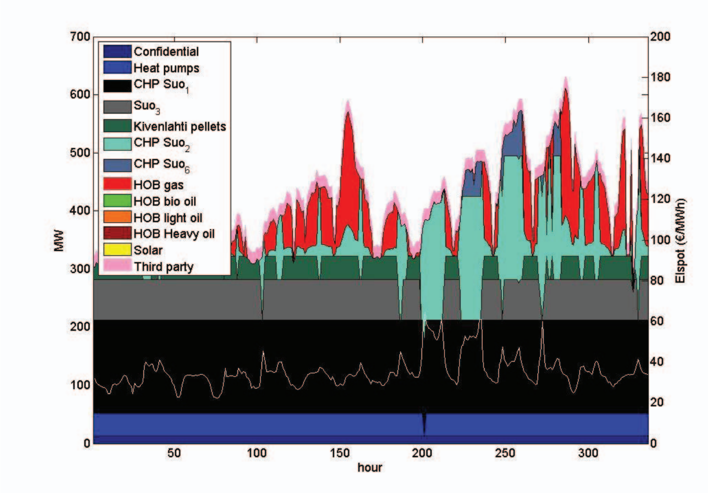

Figure 2. Hourly simulation of the DH system with external heat providers during two first weeks of January. Nordpool electricity prices for the Finnish area are shown with white line (right axis).

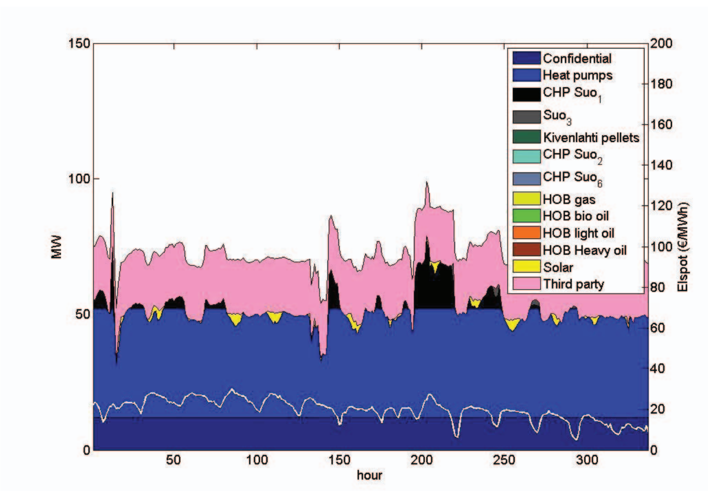

Figure 3. Hourly simulation of the DH system with external heat providers during two first weeks of July. Nordpool electricity prices for the Finnish area are shown with white line (right axis).

Fig. 3 shows the system behaviour during the two first weeks of July in 2012, when district heat use is at minimum, being a small fraction of the winter time and mainly used for domestic hot water (DHW). In summer time, also the assumed solar heat plant would provide heat to the network in day time, reducing always the most expensive generation. In Summer time, electricity spot market prices were lower than in winter time, making the use of heat pump of the external party even more attractive than in winter time. In fact, during this period the total heat pump and external heat capacities assumed would almost completely be able to cover the heat demand.

B. *Fuel and system cost savings*

In summer, district heat use is a small fraction of the winter time, mainly used for domestic hot water (DHW). One CHP plant running at partial load is for most of the summer period enough for providing the heat needed, and with the current energy and CO_2 prices the most economic option is coal-fired CHP. Thus, the fuel savings induced by external heat providers would be mostly coal in Summer time, and then also the relative fuel saving is at largest (Fig. 4).

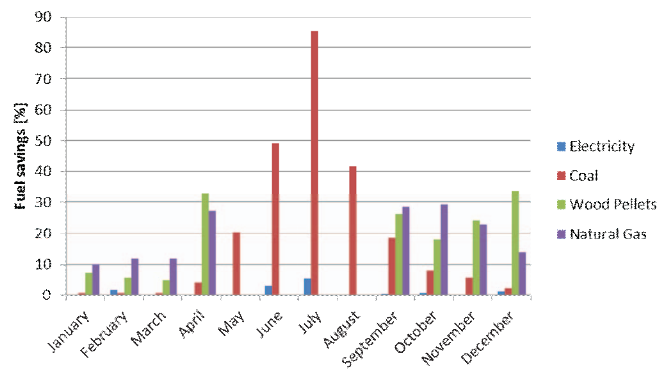

Figure 4. Monthly relative fuel savings by the external heat provider and solar heat in 2012.

Table III shows the total system savings achieved during the simulated years, calculated for either external technology individually and for the situation, when they would both be in the system. (The numbers don't add up, as the most attractive savings are only available once.) In this initial study, we did not include the impacts of EU ETS in the simulations, since the prices during 2012-2013 were far too low to change the merit order of the plants. However, the avoided ETS allowances would bring minor additional benefit to the power plant operator, in 2012 this additional benefit would have been in total 0.19 M€.

TABLE III. SAVINGS IN TOTAL SYSTEM COSTS WITH THE EXTERNAL HEAT PRODUCTION WITH 2012 AND 2013 ELECTRICITY PRICES.

	2012	2013
Only solar heat	0.082 M€	0.067 M€
Only third party	2.82 M€	2.60 M€
Both	2.85 M€	2.63 M€

C. *Profitability of the external party's heat pump investment*

Table III shows that the total annual system cost saving can be quite substantial compared to the estimated investment cost of the heat pump (about 4 M€). The investment payback time would be in the order of a few years, depending on the business model (pricing of heat purchase from the external provider) and the desired return on investment.

IV. DISCUSSION AND CONCLUSIONS

Our simulations on the possibilities of external heat producers in the DH network of Espoo indicate that significant savings would be possible with the simulated external heat providers. During the simulation years 2012-2013 electricity market prices have been so low that for most of the hours, waste heat primed with a heat pump could replace the most expensive heat production modes. Monetary savings would be the largest in winter time, when also expensive HOB's are needed to cover the heat demand. In summer time, external heat would replace mostly coal-fired CHP with the current coal, CO_2 and electricity prices. Solar heat would provide heat in summer time, when mostly only DHW is needed and produced by one CHP plant in operation. The marginal heat production costs of coal fired CHP are low, thus economic savings would not be substantial.

However, a large amount of heat pump operators on the electricity market would also change the electricity consumption profile and prices, and extrapolation to wider future applications should be done with care. Similarly, the future operation of the DH system is heavily dependent on the fuel prices and taxes applied, on the CO_2 price levels and electricity market prices. However, the combination of heat pumps and CHP's would make the system more versatile also for the probable near-term future situation, when there will be significantly more wind power in the Nordic and Finnish electricity systems and consequently more fluctuating electricity prices.[16], [17]

In the simulation, we assumed that perfect power plant ramping on hourly scale would be possible. Especially for large CHP plants this is not true, in reality significant power changes are possible on a time scale of 4-12 hours. In reality, the start-up and continuous use of CHP plants would be decided for example one week beforehand, and then only minor power adjustments would be made.

The results indicate also that demand side management (DSM) in district heat could be attractive to reduce the most expensive peak production forms, given that Finnish apartment houses can typically be cut off from heating for 4-8 hours without notable reduction in room temperatures. Taking the possible power plant ramping rates into account would emphasize the need for DSM and heat storages. With DSM and heat storages, the short-term demand peaks could be handled cost-efficiently to avoid the most expensive peak production modes. However, this would be a topic of a separate study.

As the scope of this study was the economic modelling of the possibilities of open DH concept, we did not consider the heat distribution issues within the network. In reality, this should also be taken into account, as the geographical area is rather large. For instance, some local HOB's could probably not be fully replaced by external producers in some other parts of the network during the coldest periods.

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