Equilibrium Modeling of Combined Heat and Power Deployment

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Overview

Combined heat and power (hereafter CHP) also known as cogeneration, is the onsite production of electricity where the co-produced heat is captured and utilized for space heating, cooling, and other site specific applications, increasing the overall efficiency of the system (U.S. Environmental Protection Agency 2012). Combined heat and power has various benefits in the form of monetary savings, increased efficiency and lower CO_2 emissions. Distributed generation including CHP systems decrease the dependence on power grid and provide reliable and high quality power supply along with cost savings and emissions reduction (Zerriffi, Dowlatabadi, and Farrell 2007).

The International Energy Agency has identified CHP as a scheme to reduce GHG emissions and improve energy efficiency. Approximately two-thirds of the fuel used for global electricity generation is wasted as heat in addition to the transmission and distribution losses(International Energy Agency 2008). The average efficiency of electricity generation in the U.S has been around 35 per cent for the last few decades(U.S. Environmental Protection Agency 2012). CHP captures and reuses this waste heat. With recent development of Marcellus shale, the role of CHP as a potential consumer of natural gas is vital for the Mid-Atlantic region. A large-scale deployment of CHP will increase natural gas utilization, which will support Marcellus shale drilling activities by keeping the natural gas price from dipping.

Previous work has focused on the economic factors and optimal operation strategy that influence the decision to install a single CHP unit, or the technical potential for CHP deployment. Our approach is to assess the economic potential for CHP in an electricity-market equilibrium framework, accounting for the impact that CHP adoption will have on energy prices. We couple an econometric model of electricity prices with simulated usage of CHP in different types of buildings, using the Philadelphia area as a case study.

A large-scale deployment of CHP will decrease electricity demand and thus will also decrease location-based prices in wholesale electricity markets. The aim of this study is to estimate the equilibrium level of CHP market deployment in Philadelphia that incorporates feedbacks in electricity prices on the net present value of additional CHP installations. In other words, we estimate the level of CHP deployment such that additional investments in CHP in that region will not be beneficial or a marginal CHP investment will have a negative net present value.

Methodology

We utilize a statistical model of electricity supply and pricing in the Philadelphia region, based on Sahraei-Ardakani, Blumsack and Kleit (2012) to estimate zonal supply curves for transmission constrained electricity markets. We use this model to capture the changes in electricity prices with various levels of CHP deployment. Data on Philadelphia's commercial building stock was obtained from the CoStar database (eight building types with a total of 1,012 buildings). The Building - CHP Screening tool (BCHP), developed by Oak Ridge National Lab, was used to develop hourly electricity, heating and cooling demand profiles for the eight types of buildings under study (Oak Ridge National Lab 2005).

For each type of building, three scenarios were developed – Baseline without CHP, CHP system following thermal loads (CHP-FTL) and CHP system following electrical load (CHP-FEL) (Mago, Fumo, and Chamra 2009). We assume that the CHP units will be deployed according to the priority rankings developed by the Lawrence Berkley National Laboratory [SB1]i.e. CHP units will be installed in all the hospitals (which are ranked first) followed by large hotels and so on. Reflecting a limitation in the CoStar data, we assume that building types have homogeneous demand within type and those demand profiles are well-represented by the BCHP tool. We systematically reduce hourly demand in the Philadelphia zone of the PJM electricity markets (using demand in 2010 as a baseline) with every CHP unit deployed and estimate the zonal price change with incremental CHP units deployed.

The savings from a CHP unit is the avoided electricity costs and average cost estimates for a typical CHP unit were obtained from U.S. Environmental Protection Agency. A large-scale CHP deployment might affect both natural gas and electricity prices. However, the focus of this study is on modeling the electricity price effect and to capture uncertainty in natural gas prices we use the three gas price scenarios ($2/mm Btu, $4/ mm Btu and $8/ mm Btu). Prices for coal and oil (other fuels utilized in the Philadelphia region) are assumed to remain constant.

Results

The technical potential for CHP in Philadelphia is substantial, perhaps thousands of installations. Incremental installations of CHP reduce the demand for electricity provided by the grid, thus reducing wholesale electricity prices. The net present value from CHP (i.e., the discounted value of the energy cost savings) is modelled as a function of wholesale electricity prices, and thus decreases with each additional unit of CHP installed. The results suggests that higher natural gas prices and hence higher electricity prices, is favourable for CHP adoption.

We find that under certain operational and fuel-price scenarios, the equilibrium level of economical CHP deployment is substantially lower than the technical potential. The net present value is calculated over a 10 year period with a 10% discount rate. With each additional CHP unit deployed, the marginal savings and marginal NPV on the investment decreases. There is no conclusive point where the marginal NPV is zero for CHP-FTL for $2/mm Btu and $4/mm Btu natural gas price. In the case of CHP-FEL, for a $2 / mm Btu the marginal NPV is zero for 282nd CHP unit and for a $4/ mm Btu the marginal NPV is zero for 384th CHP unit. These points suggests that any further CHP deployment will not be economical. The marginal NPV does not cross zero with a gas price of $8/mm Btu for both CHP-FEL and CHP-FTL for the 1012 units considered.

Conclusions

Marginal savings and marginal NPV curves were developed for three gas price scenarios $2/mm Btu, $4/mm Btu and $8/mm Btu and two CHP operation strategies (i.e. CHP-FTL and CHP-FEL). The marginal savings and marginal NPV decreases as the number of CHP units increase for all three gas price scenarios and two CHP operation strategies. This study suggests that the priority rankings for CHP deployment are important considering a large-scale adoption of CHP in a region.

Under a range of operational assumptions and fuel prices, substantial CHP deployment could be achieved without reducing returns to the point where existing and incremental CHP installations would become uneconomic. The results of this study leads to a number of policy related questions such as how the natural gas demand created by a large-scale deployment of CHP might affect regional natural gas prices, assessing the importance of CHP as a source of reliable power and the associated environmental benefits, and factors affecting individual decisions to install CHP.

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