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Evaluating investments for existing District Heating networks depending on the development of buildings' heating demand applying Robust Optimization

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Overview

A main issue of planning the future investments in district heating networks is to anticipate the development of buildings' energy demand. Furthermore, investments in the extension and/or expansion for the existing district heating grid have an impact on heating related decisions (type of heating systems, thermal refurbishment of buildings) of owners of the building or owners associations. In particular, an extension of the existing network leads to lower connection costs and therefore investments in the infrastructure can cause a higher demand for connection. The future energy prices, which face a high uncertainty in their trend, are another essential influencing factor. This is particularly true if the heat production is interconnected with the electricity sector via combined heat and power plant (CHP). The current energy price situation in Europe (low coal and electricity prices and high gas prices) demonstrates this price risk for district heating companies and shows major problems for an economic feasible heat supply for district heating networks whose heat generation is based primarily on combined heat and power generation. The focus in this paper is on developing a methodological framework to answer the following research questions:

1. What are possible and robust network-plans for extension and expansion of the existing district heating grid? How can the interdependencies to the development of residential buildings' energy demand and the uncertainty of the future energy prices be modeled?
2. How does the extension and expansion of the grid influence the customers' decision of changing their heat supply system to district heating?

The methodology is formulated independently from the type of settlement areas. Thus it will be possible to apply the methodology to different settlement types and thereby extend the results on whole cities and regions. In addition, the results for different scenario frameworks regarding policy measures and investment options up to 2030 are going to be compared.

Method

To answer the research questions an integrated approach is used: A robust formulation of a mixed-integer linear optimization model (MILP) is defined to maximize the supplier's profit. This new model formulation considers the costs for heat generation and grid extension/expansion as well as capital, maintenance and reinvestment costs for the existing and future district heating grid whereby a particular focus on the uncertainty of the future fuel prices. Assuming bounded uncertainty of the future fuel costs c_{fuel} (${c^L}_{fuel} \leq c_{fuel} \leq {c^U}_{fuel}$) an additional restriction for the operation costs c_{op} has to be added to the classic optimization model (1):

$$c_{op} \leq \frac{HL}{\eta} * {c^U}_{fuel} - \delta$$

Depending on the annual Head Load HL of all buildings and the plants efficiency η, the operation costs are constricted with the difference of the upper limit of the fuel costs ${c^U}_{fuel}$ and the infeasibility tolerance δ. This restriction ensures that the solution fits best for a broad range of future energy prices.

Due to the investment decisions and the resulting connection of new buildings, the average connection costs in the area of settlement can be reduced and additional decision makers may consider a change to district heating. An iterative application will ensure the consideration of this feedback mechanism.

To respect the interaction with the buildings' energy demand, the future development is defined with the bottom-up model Invert/EE-Lab (2). The investments in new heating systems and thermal refurbishments are simulated and the applicable costs of heat for the connection to the district heating network are calculated: These costs include the fixed and variable operation costs, the investment for the installation of the heating system and the average connection costs. The average connection costs are calculated on the basis of the average distance to the existing grid and define the upper limit of the consumer's willingness to pay for the supply through district heat. According to this calculation the share of buildings in each building segment (described with age, thermal quality, used heating systems), for which a change to district heating is considered, can be determined.

Results

A methodological framework to generate robust district heating expansion plans is developed. Using the method of robust optimization also uncertainty of the energy prices can be considered. A case study for a representative area in a central European city is performed to illustrate the results of the model. The outcome of this paper should also highlights the impacts for different policy measures or presumptions relating to the general framework. One example for a change in the framework is the composition of the power plant facilities up to 2030.

Conclusions

The methodological framework developed in this paper is suitable to depict the investments in an existing district heating grid considering the development of heat demand and different scenarios from an economic point of view. The classical approach of MILP can't handle the uncertainty in the trend of parameters and can result in wrong decisions. Thus, the robust formulation of the optimization problem reduces the risk of bad investments as the consequences of various input parameters are considered.

Moreover, an analysis of the effects of different scenario assumptions allow to derive conclusions and recommendations about the total costs for the district heating grid, the environmental impacts of an extension/expansion and the key measures to achieve a specified share of district heating.

References

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