DIVISION SAFETY AND TRANSPORT
ELECTRIC POWER SYSTEMS

Sector coupling of district heating with the electricity system: profitability and operations (SeCoHeat)

Camille Hamon
Elnaz Abdollahi
Jonas Dahl
Oskar Räftegård

RISE Report 2023:89

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Abstract

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District heating systems can play key roles in the energy transition. The transition to a production mix based on renewable intermittent generation will create a larger need for ancillary services including frequency-regulation services. District heating systems typically participate in the wholesale electricity market (the so-called day-ahead market) today but do not, in general, participate in ancillary service markets. Previous studies have shown that it is technically possible to participate in these markets and that district heating systems have a role to play in these markets in the future. This requires investigating how further integration of district heating systems with the electrical grids and markets will impact operation and planning of these units. In addition, while it may be beneficial on a system level for district heating systems to participate in ancillary service markets, district heating system owners and operators will only do so if there are economic incentives to do so.

The SeCoHeat project has therefore explored topics related to the profitability for individual district heating systems to participate in other electricity markets than just the day-ahead market, such as ancillary service markets.

Studying sector coupling between the heat and electricity systems requires a thorough understanding of both sectors. This project has contributed to this by bringing together experts from both sides which has led to fruitful knowledge exchanges. Furthermore, some deliverables from the SeCoHeat project have been especially written to provide introduction about the heat sector to experts from the electricity sector, and vice versa. This includes an overview of the electricity markets in which district heating systems can participate, the technical requirements to participate in these markets and explanations about how profitability of participating in these markets can be computed. This also includes explanations about how the flexibility on the heat side can be sourced and provided to the electricity system and what limits this flexibility.

Another important contribution of this project is the development of a Python-based open model for scheduling district system units on an hourly basis to minimize heat and electricity production costs while maximising revenues from several electricity markets. This model has been used in this project to evaluate the additional profits of participating in ancillary service markets. The results show that substantial additional profits can be made by doing so, both in historical years and in scenarios for future years.

This report is a guide to the separate deliverables produced within this project. It offers an overview of the goals, methods and results from the project. The interested reader is referred to detailed descriptions in the corresponding deliverables.

The SeCoHeat project was funded by Göteborg Energi AB:s stiftelse för forskning och utveckling. The work has been performed by RISE with the support of reference group members from Göteborg Energi, Vattenfall, Svenska kraftnät, IVL Svenska Miljöinstitutet, Chalmers and Profu.

Göteborg Energi

Key words: Sector-coupling, district heating, ancillary services

RISE Research Institutes of Sweden AB

RISE Report 2023:89
ISBN: 978-91-89821-62-0
Stockholm 2023

Sammanfattning

Fjärrvärme kan spela en nyckelroll i energiomställningen. Övergången till en produktionsmix baserad på intermittent produktion från förnybara energikällor kommer att skapa ett större behov av stödtjänster, inklusive frekvensregleringstjänster. Fjärrvärmeanläggningar deltar vanligtvis i grossistmarknaden för el, den så-kallade dagen-före marknaden, men sällan i andra elmarknader. Studier har visat att det är tekniskt möjligt för fjärrvärmeanläggningar att delta i dessa marknader och att fjärrvärmesystem har en roll att spela på dessa marknader i framtiden. Detta kräver att man undersöker hur ytterligare grader av sektorkoppling mellan fjärrvärmesektorn och elsektorn kommer att påverka drift och planering av fjärrvärmesystem. Dessutom kommer fjärrvärmebolag att börja delta på ytterligare elmarknader enbart om det finns ekonomiska incitament att göra det.

SeCoHeat-projektet har därför undersökt frågor relaterade till lönsamheten för enskilda fjärrvärmesystem att delta på ytterligare elmarknader, såsom stödtjänstmarknader.

Att studera sektorkoppling mellan värme- och elsystemen kräver en grundlig förståelse av båda sektorer. Detta projekt har bidragit till detta genom att bringa samman experter från båda sidor, vilket har lett till givande kunskapsutbyten. Dessutom har vissa rapporter från SeCoHeat-projektet skrivits med speciell hänsyn tagen till att ge en enkel introduktion om värmesektorn till experter från elsektorn och vice versa. Detta inkluderar en översikt över vilka elmarknader fjärrvärmesystem kan delta i, de tekniska kraven för att delta på dessa marknader och förklaringar om hur lönsamheten för att delta på dessa marknader kan beräknas. Detta inkluderar även förklaringar om hur flexibiliteten på värmesidan kan nyttjas och tillhandahållas till elsystemet och vad som begränsar denna flexibilitet.

Ett annat viktigt bidrag från detta projekt är utvecklingen av en Python-baserad öppen modell för schemaläggning av distriktssystemenheter på timbasis för att minimera värme- och elproduktionskostnader och samtidigt maximera intäkterna från flera elmarknader. Denna modell har använts i detta projekt för att utvärdera de extra vinsterna av att delta i stödtjänstmarknader. Resultaten visar att vinster från elsektorn då kan öka betydligt, både under historiska år och i scenarier för kommande år.

Denna rapport är en guide till de separata resultat som producerats inom detta projekt. Den ger en översikt över projektets mål, metoder och resultat. Den intresserade läsaren hänvisas till detaljerade beskrivningar i motsvarande leveranser.

Projektet SeCoHeat finansierades av Göteborg Energi AB:s stiftelse för forskning och utveckling. Arbetet har utförts av RISE med stöd av referensgruppsmedlemmar från Göteborg Energi, Vattenfall, Svenska kraftnät, IVL Svenska Miljöinstitutet, Chalmers och Profu.

Göteborg Energi

Content

1 Background

The Paris agreement [1], the European Green Deal [2] and the national Swedish climate targets [3] call for an ambitious energy transition in the coming decades. Sweden is to have zero net emissions by 2045 at the latest and 100 % fossil-free electricity production by 2040 [4]. Electrification of industries and transport will play an essential role at achieving the climate targets. For Sweden alone domestic electricity use is forecasted to increase significantly from today's 140 TWh to up to 350 TWh in some scenarios for 2050 [5], [6], [7].

District heating can play key roles in meeting the challenges associated with the energy transition.

First, the massive electrification will lead to additional local grid and production capacity challenges where the existing electric grids do not have enough capacity to transfer the required amount of electricity. This is already happening in several Swedish metropolitan areas [8] and can have large consequences on employment, housing, infrastructure, and economic growth [9]. In this respect, district heating systems can remedy the issue by both decreasing the need for electricity for heating and providing local electricity generation in combined heat and power (CHP) plants. Furthermore, sector coupling units in district heating systems such as CHP plants, heat pumps and electric boilers can contribute with flexibility in heat and local electricity networks [10]. Therefore, there is a need to investigate how further integration of district heating systems with the electrical grids and markets will impact operation and planning of such systems.

Second, the transition to a production mix based on intermittent renewable generation will create a larger need for ancillary services including frequency-regulation services. While sector coupling units do not typically participate in ancillary service markets today, studies have shown that it is technically possible to do so and these units can play a role in these markets in the future [11], [12]. Once again, this requires investigating how further integration of district heating systems with the electrical grids and markets will impact operation and planning of these units.

The European, Nordic and Swedish electricity and ancillary service markets will undergo large changes in the coming years. In the day-ahead market, the flow-based capacity allocation method will be introduced in place of the current net transmission capacity method. Intraday auctions will be introduced to complement the current continuous intraday market. The settlement period will change from 1 hour to 15 minutes [13]. A new Nordic balancing model will be introduced and entail many changes to the current Nordic balancing setup [14]. New markets have recently been introduced (such as the market for fast-frequency reserves introduced in 2020) and more will come (such new products for frequency-containment and frequency-restoration reserves). Therefore, a deeper coupling between the district heating and electricity systems entails a need for district heating companies to better understand the current and future markets on the electricity side in which they can participate.

It is in many cases not profitable to invest in sector coupling units instead of heat-only units [10]. If district heating systems are to play a role in the future electricity and ancillary service markets, there needs to be stronger economic incitement to drive investments in these sector coupling units, for example by diversifying the participation in different electricity markets. Hence, in addition to the impact on operation and planning of the units themselves, there is a need to evaluate the profitability of participating in electricity and ancillary service markets.

The SeCoHeat project was created to explore these topics. Section 2 presents the project objectives. Section 3 presents the project results related to each specific objective. Section 4 presents conclusions from the project. Future work ideas are identified in Section 5. Finally, all deliverables from the project referred throughout this report are listed in Section 6 and can be found attached to this report.

2 Project objectives

The overall objective of the project is to study how sector coupling between heat and electricity systems will impact district heating companies (DHC) in terms of operations of their units and whether it is profitable for them to participate in electricity markets and ancillary service markets.

The specific objectives of the project are as follows.

- Specific objective 1 (SO1): an overview of the electricity markets and ancillary service markets of relevance for DHC will be performed to identify ways for DHC to diversify their revenue streams from the electricity system.
- Specific objective 2 (SO2): scheduling and operation strategies for the production and heat storage units will be devised to enable participation of DHC in these markets and services.
- Specific objective 3 (SO3): incomes from these markets and services will be estimated to investigate whether it is economically profitable to start participating in these markets.
- Specific objective 4 (SO4): an inventory of production units relevant for DHC that couple heat and electricity systems will be performed.
- Specific objective 5 (SO5): investment studies will be performed to study the profitability of strengthening the coupling between the heat and electricity systems by investing in these units.
- Specific objective 6 (SO6): the project will promote knowledge exchange both between DHC and between DHC and grid owners by organizing workshops.

In addition to the above-mentioned workshops, industry partners will be involved continuously throughout the project in an agile way. This will allow us to focus on the aspects that matter the most for the project partners.

3 Results

This section reports on the project results and deliverable of the projects as related to the specific goals in the previous section. All deliverables are also listed in Section 6.

3.1 Specific objective 1 (SO1): Overview of electricity markets and ancillary service markets

Specific objective 1 (SO1): an overview of the electricity markets and ancillary service markets of relevance for district heating companies will be performed to identify ways for district heating companies to diversify their revenue streams from the electricity system.

The deliverable in attachment 1[1] introduces the project by presenting an overview of the district heating sectors in Sweden, Denmark and Finland. In particular, it was noted that CHP plants have participated in ancillary service markets in Denmark. Furthermore, an overview of the electricity and ancillary service markets in Sweden, including the day-ahead and intraday markets, all ancillary service markets, disturbance and strategic reserves is provided giving details about both technical requirements to participate in these markets and historical price levels in recent years. A review of local flexibility markets recently set up in Sweden in Stockholm, Uppsala, Skåne, Gotland and Gothenburg is also presented. Finally, a literature review about sector coupling aspects between the heat and electricity sectors is performed. For more detail about these topics, the reader is referred to the deliverable in attachment 1.

3.2 Specific objective 2 (SO2): Scheduling and operation model for participation of district heating systems in ancillary services

Specific objective 2 (SO2): scheduling and operation strategies for the production and heat storage units will be devised to enable participation of district heating companies in these markets and services.

Within the SeCoHeat project and building upon the literature review performed in attachment 1, a model has been developed to optimally schedule and operate units in district heating systems to participate in the day-ahead market and some ancillary service market. The model is an optimization-based model that schedules units on an hourly basis for a horizon of one week, minimizing the heat and electricity production costs and maximizing revenues from the electricity markets. The model is fully specified in attachment 2[2] and an overview of the model can be found in attachment 3[3]. The model itself is a Python package that is available in attachment 4[4]. Within the SeCoHeat project,

[1] Camille Hamon, Yelena Vardanyan, Elnaz Abdollahi, "Review of current and future heat- and electricity-related products and their relevance for district heating companies", RISE Research Institutes of Sweden, 2023.
[2] Camille Hamon, Elnaz Abdollahi, Meng Song, Akshaya Tammanur Ravi, "Formulation of the district heating scheduler", RISE Research Institute of Sweden, 2023.
[3] Camille Hamon, Elnaz Abdollahi, "Profit estimation for district heating systems when participating in electricity and ancillary service markets", RISE Research Institutes of Sweden, 2023.
[4] Camille Hamon, Elnaz Abdollahi, Meng Song, Akshaya Tammanur Ravi, "District Heating Optimization", Python model available at https://github.com/CamilleHamon/DistrictHeatingOptimization.

investigations were performed to include district heating temperature effects in the scheduling model. Being able to model district heating temperatures has been shown in past studies to lead to more accurate scheduling decisions, for example by considering the output temperature when discharging a thermal storage. While these aspects have not been included in the main model, a literature review of research works on this topic as well as some recommendations are given in attachment 5[5]. The actual implementation of these recommendations is left as future work.

3.3 Specific objective 3 (SO3): Estimation of incomes from electricity and ancillary service markets

Specific objective 3 (SO3): incomes from these markets and services will be estimated to investigate whether it is economically profitable to start participating in these markets

The specific objective 3 was met in two steps. First, statistical analyses of historical prices on ancillary service markets were performed in attachment 6[6] to estimate the potential profitability of each ancillary service market for district heating owners. Second, the model presented in Section 3.2 was used in two district heating systems, one in Nyköping and one in Gothenburg, to estimate the additional profits that could have been made in 2020 and 2021 if these district heating systems had participated in ancillary service markets. The case studies and results are reported in detail in attachment 3[7]. The analyses show that it is profitable to participate in ancillary service markets which can bring up to 9% of additional yearly profits. The results vary from year to year and from ancillary service market to ancillary service market. The actual additional profits depend on electricity price variations, the underlying heat demand that must be met by the district heating systems and the amount of flexibility that can be provided to the electricity system. Overall, the aFRR down market has been shown to be the most profitable market in most cases.

3.4 Specific objective 4 (SO4): Investment options to strengthen the sector coupling between the electricity and heat systems

Specific objective 4 (SO4): an inventory of production units relevant for district heating companies that couple heat and electricity systems will be performed.

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[5] Camille Hamon, “Considering temperatures in operational planning of district heating systems”, RISE Research Institutes of Sweden, 2023.
[6] Camille Hamon, Elnaz Abdollahi, “Potential profits from ancillary service markets”, RISE Research Institutes of Sweden, 2023.
[7] Camille Hamon, Elnaz Abdollahi, “Profit estimation for district heating systems when participating in electricity and ancillary service markets”, RISE Research Institutes of Sweden, 2023.

In attachment 7[8], the potential flexibility from district heating systems that can be used in the electricity system is analysed, starting with some introduction to CHP plants, continuing with the flexibility potential from these plants and finally the flexibility potential of the district heating supply mix. Furthermore, limitations to this flexibility potential are identified and investment suggestions to improve the flexibility that can be provied to ancillary services are given.

3.5 Specific objective 5 (SO5): Investment studies for increased flexibility provision to the electricity system

Specific objective 5 (SO5): investment studies will be performed to study the profitability of strengthening the coupling between the heat and electricity systems by investing in these units.

Two types of investment studies have been performed within the scope of the project. They are fully specified and reported on in attachment 3[9].

First, the existing system in Nyköping has been simulated for future electricity price scenarios to investigate the profitability of participating in day-ahead and ancillary service markets in the future. As was the case when investigating historical years (see Section 3.2), aFRR down is still the most profitable market in the future scenarios. However, FCR-D up comes close to be as profitable as aFRR down in some scenarios. Participating in aFRR down bring up to 11 % of additional total profits in future years.

Second, two types of flexibility enhancements have been tested in this system: (1) double as high ramp rates in CHP plants for ancillary service provisions and (2) double as large heat storage. In both cases, the additional profits of these flexibility investments are about 1% of total yearly profits (or about 3 to 4 Mkr). These additional profits need to be weighed against the investment costs. This is very system specific and is left as future work.

In both case studies, the mentioned profits are additional profits compared to the total yearly profits, including revenues from selling heat. Excluding this revenue from the profits (because it does not depend on which electricity markets the system participates in) highlights additional profits from participating in ancillary service markets in a better way. In the first case study, additional profits of participating in ancillary service markets excluding heat revenues can be up to 90%. In the second case study, the additional profits made by having more flexibility to provide to the ancillary service markets can be up to 6%.

[8] Oskar Räftegård, Jonas Dahl, "Flexibility opportunities in a CHP and district heating system", RISE Research Institutes of Sweden, 2023.
[9] Camille Hamon, Elnaz Abdollahi, "Profit estimation for district heating systems when participating in electricity and ancillary service markets", RISE Research Institutes of Sweden, 2023.

3.6 Specific objective 6 (SO6): Knowledge exchange between district heating companies and grid owners.

Specific objective 6 (SO6): the project will promote knowledge exchange both between district heating companies and between district heating companies and grid owners by organizing workshops.

A reference group was formed including representatives from:

- two simulated district heating systems from Vattenfall in Nyköping and from Göteborg Energy in Gothenburg.
- Svenska kraftnät
- Chalmers
- Profu
- IVL Svenska Miljöinstitutet

A total of 5 reference group meetings were organized in additional to add-hoc meetings. These reference group meetings have been the opportunity to share knowledge between grid owners, district heating companies, academia and research centers on a number of topics included in the project. These topics have included discussions and knowledge exchanges on the electricity markets and ancillary service markets, system-specifics about heat production in the two studied systems, temperature quality issues and its importance in modelling, long-term storage and feasibility of different alternatives, among other topics. The project has also been the opportunity to gather experts with a background in heat production and district heating systems and experts with a background in electricity markets and ancillary service markets, both within and across the participating organizations. This has led to fruitful understanding of and exchanges between both sectors.

4 Discussion and conclusion

Traditionally, district heating companies participate in the day-ahead market and, sometimes, in the intraday market but only in rare instances do they participate in additional markets in the electricity system. While there is an expressed need for more actors to participate in ancillary services, these actors will only do so if the economic conditions are right. The SeCoHeat project has therefore explored topics related to the profitability for individual district heating systems to participate in additional electricity markets, such as ancillary service markets.

Studying sector coupling between the heat and electricity systems require a thorough understanding of both sectors. This project has contributed to this by bringing together experts from both sides which has led to beneficial knowledge exchanges. Within the scope of this project, the discussions have focused on identifying sources of flexibility on the heat side that can be used to offer flexibility on the electricity side. Of particular importance is the understanding of what limits the volume of flexibility. While the project has made some contributions in this area, it has also become clear that further investigations are needed to identify the exact technical limits on the heat side for providing flexibility on the electricity side.

Although the emphasis has been on understanding the profitability in participating in additional markets in the electricity system, the model developed within this project also allows for studying the impact of this participation on the scheduling and operation of the units. Indeed, the model computes hourly schedules and actual real-time activations from ancillary services. Therefore, the model can be used by district heating operators as a tool to understand changes in operational planning and operations practices due to the participation in ancillary services. Some operational changes proposed by the model, although technically possible, may not be acceptable for the district heating operators.

Several profitability analyses have been performed in the project. They include estimation of additional incomes if district heating systems had participated in ancillary services in historical years, in scenarios for future years and if extra investments in flexibility were made. All these analyses show that profits from the electricity sector can increase substantially when the revenue streams are diversified by participating in new electricity markets.

5 Future work

During the course of the project, a number of topics have been identified as needing further investigation.

First, the model developed in this project could be expanded to include seasonal storage. This would open new possibilities for providing flexibility to the electricity sector and, therefore, possible additional profits. This would put more requirements on the model in terms of simulation horizon and proper consideration of district heating temperatures in the system. Recommendations have been made in this area, in particular in attachment 5, but more work is needed to see how these recommendations can be implemented in practice.

Second, the project has focused on utilizing the production-side flexibility in the district heating system, including the ability of CHP units to ramp up and down the electricity production and of thermal storage to compensate for variations due to activation of ancillary services. Other flexibility sources in the district heating system, such as demand-side flexibility and the heat stored in district heating networks, could be investigated to get a broader and more complete picture of the flexibility potential.

Third, there is a need to understand more in detail what the actual technical limits are for providing flexibility to the electricity system. These limits are very much unit specific. They have been investigated partly in attachment 7 where it was recognized that the quantification of the flexibility volumes that can be provided as ancillary services requires detailed simulations of the district heating systems and their pressure and temperature dynamics. This quantification is important in order to, on the one hand, ensure a safe operation of the units and, on the other hand, utilize the available flexibility to its full potential.

Fourth, the quantification and management of uncertainties in the scheduling process needs to be further explored. The economic analyses performed in this project have used historical prices or scenarios for future prices, which in both cases entail perfect price information. Price forecasts of the different electricity markets, together with heat demand forecasts, need to be further investigated to implement actual bidding strategies for choosing between the different electricity markets.

6 List of attachments

- Attachment 1: Camille Hamon, Yelena Vardanyan, Elnaz Abdollahi, "Review of current and future heat- and electricity-related products and their relevance for district heating companies", RISE Research Institutes of Sweden, 2023.
- Attachment 2: Camille Hamon, Elnaz Abdollahi, Meng Song, Akshaya Tammanur Ravi, "Formulation of the district heating scheduler", RISE Research Institute of Sweden, 2023.
- Attachment 3: Camille Hamon, Elnaz Abdollahi, "Profit estimation for district heating systems when participating in electricity and ancillary service markets", RISE Research Institutes of Sweden, 2023.
- Attachment 4: Camille Hamon, Elnaz Abdollahi, Meng Song, Akshaya Tammanur Ravi, "District Heating Optimization", Python model available at https://github.com/CamilleHamon/DistrictHeatingOptimization
- Attachment 5: Camille Hamon, "Considering temperatures in operational planning of district heating systems", RISE Research Institutes of Sweden, 2023.
- Attachment 6: Camille Hamon, Elnaz Abdollahi, "Potential profits from ancillary service markets", RISE Research Institutes of Sweden, 2023.
- Attachment 7: Oskar Räftegård, Jonas Dahl, "Flexibility opportunities in a CHP and district heating system", RISE Research Institutes of Sweden, 2023.
- Attachment 8: Camille Hamon, Elnaz Abdollahi, Akshaya Tammanur Ravi, Meng Song, "A Generic Planning and Operation Model for Participation of Sector Coupling Units in Ancillary Service Markets", 2023. Not included because under preparation for submission to the PSCC 2023 conference on October 1st.

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RISE Research Institutes of Sweden AB
Box 857, 501 15 BORÅS, SWEDEN
Telephone: +46 10-516 50 00
E-mail: info@ri.se, Internet: www.ri.se

Electric Power Systems
RISE Report 2023:89
ISBN: