Excess Heat as a Sustainable Energy Source for District Heating: A Multi-Stakeholder Perspective

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Abstract

Excess heat can be utilized for energy purposes, reducing primary energy consumption and CO_2 emissions. District heating enables the utilization of excess heat. However, excess heat utilization in district heating faces several challenges, such as the lack of awareness and misalignment among different stakeholders' perspectives. In this study, we address these gaps. We quantify the impact of different ownership structures on the business models of different actors involved in excess heat utilization in district heating. We use a comprehensive modeling framework that is used for green field development of district heating in our case study town in Denmark. In addition to optimizing the heating grid and selecting the least-cost technologies for excess heat-based district heating, the modeling framework can quantify the financial profitability of each stakeholder under different scenarios of technology ownership and grid ownership. Thus, we consider the multi-stakeholder perspective in this study. We find that a combination of technology ownership and grid ownership can create a win-win situation for all the stakeholders. The grid cost is the major cost contributor, and the levelized heat cost can be lower compared to individual heating technology as long as it is bear by the municipality or industry with excess heat. This case is very favorable for the industry with excess heat, with a payback period of 1.2 years. However, when grid and technology costs are all bears by this industry, the business model is no longer feasible, highlighting the need for efficient cost sharing among the stakeholders.

1. Introduction

Excess heat (EH) is referred to as a by-product that is often generated due to some industrial process and is unavoidable (Garay-Martinez and Meir, 2022). Mostly the EH is managed passively by releasing into the atmosphere via air or water. However, active management of EH is also common, where a cooling system is used to get rid of EH quickly. For example, data centers and supermarkets often use active cooling systems to prevent overheating (State of Green, 2016). Using EH for energy purposes offers a sustainable solution by reducing primary energy consumption and overall CO2 emissions (Broberg Viklund and Johansson, 2014).

District Heating (DH) enables the utilization of EH. The potential sources of EH also increase with reducing the DH supply temperature (Sandvall et al., 2021). DH in Denmark has contributed to making the Danish energy sector among the most efficient in the world (Danish Energy Agency, 2016). According to (Turns, 2023), EH produced across Europe could meet the heating and cooling demand of the whole continent. The benefits of EH utilization in DH are manifold: it reduces greenhouse gas emissions and local air pollution by replacing fossil fuels in boilers; it promotes the local economy and security of supply by using local sources of energy; it provides additional revenues to industries that sell their EH; and it is often renewable and cheap. Energy system-level studies have recognized the crucial role of EH in achieving a decarbonized energy sector (Sandvall et al., 2021).

However, the uptake of EH in DH faces several challenges that hinder its widespread adoption. The most relevant ones are the lack of awareness among industries about the potential and benefits of EH (Fritz et al., 2022) and diverging perspectives among stakeholders, such as DH utility, industries with EH, and consumers, about different expectations and preferences regarding the price and quality of EH (Fritz et al., 2022). Therefore, there is a lack of sufficient literature on the impact of different ownership structures on the business model of different actors involved in the utilization of EH in DH.

In this study, we quantify the impact of different ownership structures on the business model of different actors/stakeholders involved in the EH utilization project. We consider a multi-stakeholder perspective by calculating the financial profitability of each stakeholder. This will help to create awareness among different stakeholders and to create a win-win situation by understanding and distributing the burden and benefits of each stakeholder.

Most literature discusses ownership structures by examining whether the DH utility is publicly or privately owned or some partnership (Okkonen and Suhonen, 2010). However, in this study, we dive deeper into project finances and redefine ownership structure. In our study, the ownership structure refers to which stakeholder will invest the capital cost (CAPEX) needed to utilize EH in DH? And what are the impacts of such investment on the actors' profitability? For each stakeholder's profitability, we calculate financial metrics, Net Present Value (NPV), Internal Rate of Return (IRR), Payback period, and Levelized Cost of Heat (LCOH).

We define two kinds of ownership: grid ownership and technology ownership. Technology ownership refers to which stakeholders will invest in the technologies needed to utilize the EH in DH. For example, if a heat pump is needed to extract EH from an industry, technology ownership will determine which stakeholder will bear the cost of that heat pump. Similarly, grid ownership determines how the cost of the heating network/grid will be shared among stakeholders.

2. Methodology

2.1. Modeling Framework

We use a modeling framework developed under Horizon 2020 project EMB3Rs (EU Horizon 2020, n.d.). The EMB3Rs platform is open source and easy to use due to its drag-and-drop interface. The platform matches excess heating or cooling with demand and is a one-stop shop for the feasibility analysis of excess heat/cool utilization.

The platform has different modules, each performing a crucial function. These modules characterize sinks and sources (Core Functionalities module), find the shortest and optimized route for the heating network (Geographical Information System), invest in least-cost technologies to meet the heat demand based on the (Techno-economic optimization), simulate different markets to get a price for the heat (Market module), and calculates the financial profitability of the project along with the impact of technology and grid ownership structure on the financial profitability of each stakeholder (Business model module). Thus, the EMB3Rs platform can consider the multi-stakeholder perspective. More information on these modules can be found here (EMBERs, n.d.). We use the EMB3Rs platform for our study due to its comprehensive modeling framework. The EMB3Rs modeling framework provides all the necessary optimization and simulations under one platform.

The different stakeholders consider in this study are sources and sinks. Sources represent the industry with EH that can be utilized. Each source is considered a different stakeholder or commercial entity in our study. Similarly, sinks represent the end customers of DH having a heat demand. We calculated IRR and Payback period for sources as commercial industries widely use such metrics to make investment decisions. We calculate LCOH for sinks, allowing them to compare DH with other individual heating technologies. Finally, we don't consider DH utility directly, but we calculate the IRR and Payback for the whole project and calculate all the above metrics twice, first by considering the grid cost and second by ignoring the grid costs. Thus, DH utility perspective is passively taken into account as the impact of grid cost tells us the role DH utility can play.

2.2. Case Study

We model the case of Regstrup town in Denmark. Regstrup is a small rural town with a population of 2,000 inhabitants. The town mainly consists of single-family houses with individual heating systems, mostly consisting of gas boilers. The town doesn't have any prior DH network. The total annual heat demand of the town is approximately 23 GWh.

The town has two industrial units that produce excess heat. The first source (Super Frost) of excess heat is cold storage for food products, where the cooling compressor produces excess heat. The second source (Schoeller Plast) manufactures transport boxes and other plastic-based packaging. They also require cooling with a total cooling capacity of 730 kW, which a heat pump can replace. We model this case in the EMB3Rs platform and compare options for excess heat utilization. In the modeling platform, this town's houses and apartments are grouped into 43 sinks. This reduces the time of modeling every single house or apartment.

Furthermore, as there is no existing DH grid in our case study town, we consider a green field development of DH grid. We consider a 4% discount rate when we calculate the financial profitability of the whole project. Thus, representing a socio-economic discount rate. For the calculation of an individual actor's financial profitability, we consider the 5% discount rate. We consider project lifetime to be 20 years.

2.3. SCENARIOS

As mentioned in the modeling framework, the EMB3Rs platform calculates the optimal network/grid route and cost and the optimal technologies needed to utilize the excess heat. Once the optimal heating network/grid is calculated, we consider several different ownership structures for both grid and technologies and their impact on the financial feasibility of each stakeholder. We consider three ownership structures, which are described below:

1. Source: Under this ownership structure, the sources own all the technologies and the grid. In other words, when calculating financial feasibility for sources in our case study, we include the CAPEXes of optimal technologies and optimized grid in the cash flows of sources.
2. Sink: Similar to the above ownership structure, the sink owns all the technologies and grid in this case. As there are a lot of sinks in our case, we divide all the CPAEXes equally among the sinks.
3. Shared: In this ownership structure, each stakeholder owns its technologies. For example, if a heat pump or a boiler is installed at a source, then this source will own or invest in that technology. Similarly, if a heat exchanger is installed at a sink, then it will invest or own that heat exchanger. The grid cost is equally divided among all stakeholders (sources and sinks).

3. Results

3.1. Modeling overview

First, we present the results of optimized network/grid and least-cost technologies to meet the demand with excess heat. Table 1 depicts these results. The total length of the grid is 31 km, and its installed capacity is 2.7 MW. Similarly, techno-economic optimization installs a heat pump and natural gas recovery boiler at Super Frost. The second source is disregarded and not being used. Thus, the second source (Schoeller Plast) is not utilized. Table 1 also represents the size and costs of these technologies. The techno-economic optimization only installs heat exchangers at each sink. As is evident from Table 1, the major cost comes from the grid deployment.

Table 1: Results of the optimized heating grid and least cost technologies for EH recovery.

TECHNOLOGY	**Installed capacity (MW)**	**CAPEX (Million €)**	**Annual heat generation (GWh)**	**Length (km)**	**Total thermal loss (kW)**
Grid	2.7	16.5		31.32	519.8
Super Frost Heat Pump	0.08	0.02	0.032	--	--
Super Frost Natural Gas Heat Recovery Boiler	2.6	1.36	22.1	--	--

Before looking into the impact of different ownership structures on the profitability of each stakeholder, we first calculate the financial profitability of the project as a whole (table 2). This represents the socio-economic outcome. Based on Table 1, we observe that grid cost has a major impact on the whole project. Without grid cost, the investment into such a project generates investment returns in 0.3 years. However, the payback period jumps to 9.4 years when considering grid cost.

Table 2: Socio-economic feasibility of the project.

IRR - with grid cost	IRR - without grid cost	Payback period (years) - with grid cost	Payback period (years) - without grid cost
0.08	3.1	9.4	0.3

3.2. Ownership impact on stakeholders

Finally, we look into the impact of different ownership structures described in section 2.3 on the stakeholders. Table 3 represents the impact of different ownership structures on the financial profitability of the source (Super Frost). The best case for source is when sinks invest in all the technologies and grid. In this case, the payback for the source is zero years with infinity IRR, as the source only earns money by selling its EH. Under the ownership structure where the source invests in all the technologies and grids, the impact of grid cost is again visible. Including grid cost led to a payback period of less than one year and/or IRR greater than one. However, when grid cost is considered, the payback period is 22 years, higher than the project's lifetime. Thus, IRR is negative. The shared ownership structure is beneficial for the source with or without the inclusion of grid cost.

It is important to discuss the implication when no grid cost is considered. As mentioned before, the municipality's role through DH utility is passively taken into account. Therefore, when no grid cost is considered, it implies that this cost is bear by the DH utility. Such municipality-owned utilities have less stringent requirements on payback period than commercial actors (like Super Frost source in our case), which allow DH utilities to invest in projects with a high payback period.

Table 3: Impact of different ownership structures on the financial profitability of source.

Ownership structure	IRR - with grid	IRR - without grid	Payback - with grid	Payback - without grid
Source	-0.0096	1.3183	22.16	0.759
Sinks	--	--	0	0
Shared	0.8082	1.3307	1.237	0.751

The impact of different ownership structures on the sinks or end customers is depicted in Figure 1. The figure represents the LCOH for each sink modeled in the EMB3Rs platform. The figure compares the LCOH for sinks for whether or not grid cost is considered and also compares these with other individual heating technologies.

It is evident from Figure 1 that LCOH is lowest for the sinks when either no grid cost is considered or it is bear by the source. Thus, if sinks must bear the grid cost, it becomes more attractive for them to invest in individual heating technologies. This also highlights the role that the DH utility or municipality needs to play in setting up the heating grid.

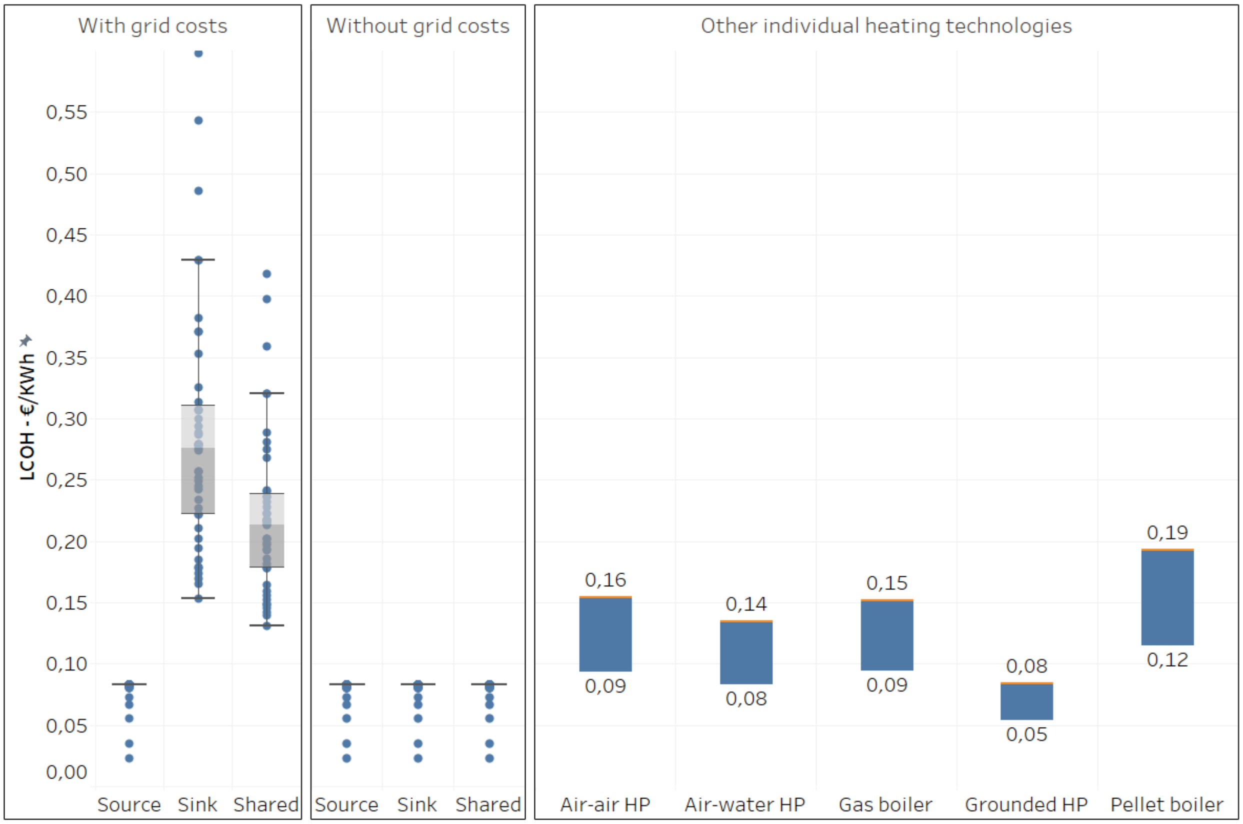

Figure 1: LCOH comparison for sinks; with and without grid costs and with other individual heat technologies (IEA, 2021).

4. Conclusion

Excess heat provides an important opportunity to decarbonize the heat supply sustainably. The modeling framework discussed in this paper provides a comprehensive overview from the perspective of different stakeholders, which is crucial for most excess heat projects.

Our results indicate that excess heat from cold storage can be a feasible option for district heating in Regstrup. The network cost is the most significant cost component, which might require an active engagement from the local municipality. We quantify the impact of grid cost and find that the project is feasible from a socio-economic perspective without grid cost. Even when grid cost is considered, from a socio-economic perspective, the project has nine years of payback which is quite acceptable.

For the source, the payback period is zero when sinks own both the grid and technologies. Even with a shared ownership structure where the stakeholders equally share all the costs, the source has a favorable payback period of 1.2 years, including the grid costs. This is acceptable as commercial actors often have lower investment payback requirements. However, the shared ownership structures are not favorable for end consumers, who pay more than other heating technologies. Thus, another ownership structure can be considered where more capital investments are allocated to the source.

For sinks or end consumers, the excess heat utilization via district heating has the lowest levelized cost than other individual heating technologies when the sinks do not bear grid cost. This also calls for a more active role of the municipality.

This study gives insight into the impact of different ownership structures on finances for each stakeholder. The combination of technology ownership and the grid can create a win-win situation for all the stakeholders. This can also make excess heat price negotiations more effective by understanding the burden carried by each stakeholder, thereby providing more leverage for a favorable price.

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