Summary report on heat pumps in district heating systems

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Summary

The combination of district heating and heat pumps are foreseen to have a key role in the future energy systems and future district heating systems are predicted to have a larger number of heat pumps installed in the grids compared to today. Scenarios made by the project Heat Roadmap Europe shows that with an expansion of district heating, it is possible to cover up to 50% of the heating demand in Europe with district heating and around 25% of the energy to the district heating grids will come from heat pumps[1]. The project shows different scenarios, all including a larger share of district heating. The scenarios show the potential of reducing the CO_2 emissions from the European heating sector with more than 70% compared to the current situation.

The reason why heat pumps are foreseen to increase in district heating system is because heat pumps can deliver heat with high efficiency and at the same time create a link between the heating and electricity sector utilizing intermittent renewable energy sources. It enables for an overall decarbonisation of the energy system and the possibility to make district heating an integrated part of a smart energy system. To have an efficient integration of variable renewable sources, the heat pumps would have to operate in a flexible way. Most of their capacity should be used during hours when wind and solar electricity are available. When the demand is low, they can be used to fill up thermal storages with heat. This will allow for further integration of intermittent renewables[1].

The integration of large-scale heat pumps in future district heating systems are important for multiple reasons:

1. Heat pumps combined with storage systems have the potential to become a key technology since it enables for future district heating systems to balance the power grid when the production of electricity from intermittent renewable energy sources fluctuates.

2. Heat pumps makes it possible to utilize excess heat of low temperatures and reduce grid losses.

3. Heat pumps increase the flexibility of district heating systems, by utilizing multiple sources of heat, it enables higher flexibility of the energy system. Fast commissioning and low start-up costs are some of the benefits with heat pumps, as well as taking advantage of the volatility of the electricity market and the possibility to use the thermal grid and storages as thermal batteries.

4. Heat pumps play an important role in integrating more renewable energy and phase out fossil fuels from the energy systems.

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Introduction

Almost half of the total energy demand in Europe corresponds to the heating sector. Improving the overall efficiency in the sector would have a major impact on energy systems in the continent. In some European countries district heating systems have been used for many decades. One way of improving the heating efficiency in dense urban areas would be to simply integrate or expand district heating systems. Utilizing heat pumping technology in the form of large-scale heat pumps, could highly increase the overall efficiency of the grid.

Another important aspect is increasing the efficiency and decreasing the CO_2 emissions from the combined heat and power plants. This process has already started by changing from fossil fuels to biomass. But in a scenario with a 100% renewable energy system, biomass resources will not be enough to cover the heating sector. Therefor it's also important to utilize excess heat from both industry and power generation in the district heating networks. Large-scale heat pumps could help electrify the heating sector and integrate more electricity from renewable energy sources. In that way biomass will be left as a resource for the transport and industrial sector.

The Heat Roadmap Europe project showed that district heating is a cost-efficient solution for most urban areas in Europe, which can provide half of the total heat demand in the 14 countries included in the study. At the same time district heating is efficiently reducing CO_2 emissions in the heating and cooling sector. According to the Heat Roadmap Europe project[8], the share of district heating in the heating sector for Europe, should increase from today's 12% to 50% by 2050[8]. The project also shows the importance of implementing heat pumps in district heating systems to develop a flexible and supply safe system.

The decarbonisation of the heating sector can be approached with different strategies. District heating plays a key role since it is using local fuel such as local biomass and has a large potential to use available sources of excess heat that would be wasted otherwise. District heating is also a key to integrate more renewable energy sources. In urban areas, district heating systems allow the wide use of combined heat and power and waste-to-energy sources. It also enables for integration of surplus heat sources like industrial excess heat, and renewable heat sources such as both geothermal and solar thermal heat[1].

Heat pumps in combination with storage systems

A storage system makes it possible to store and save produced energy for later consumption. This increases flexibility as heat demand peaks and electricity peaks rarely occur at the same time. Load balancing in a large district heating system is challenging. Mainly because the daily capacity demand strongly fluctuates. A storage system will help balancing these changes in capacity. The maximum daily capacity can be reduced by approximately 30% if daily storage is done[9]. By integrating storage systems at the end user, it can enable the network to connect more houses with the same capacity.

It is important to examine each individual system on parameters like maximum and minimum operation temperatures on both the storage system and the district heating system. It is obvious that the heat from the storage system can only be used if the temperature is higher than the return temperature from the district heating system. Otherwise a heat pump needs to be installed. There are many kinds of thermal energy storages. For example, there are aquifer thermal energy storage, borehole thermal energy storage, tank thermal energy storage and pot thermal energy storage.

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Creating a link between the heating and electricity sector is what makes it possible to absorb low-price electricity as soon as it is produced and to use other types of fuels in a flexible and efficient way. This link is created by combining large-scale heat pumps and thermal storage systems with combined heat and power plants. When there is a power surplus in the electrical system from renewable energy sources like wind and solar power, the excess electricity produced can be stored and used in different ways. A temporarily yet efficient way to utilize the energy is by using large-scale heat pumps to convert the excess electricity to heat. The heat can then be distributed to the district heating grid or stored in a thermal storage system for later use. In this way heat pumps, district heating and thermal storage systems represent short term solutions for energy storage. Gas grids and liquid fuels can then be excluded to a greater extent and will only be used as secondary priority for the heating sector, as an option for long term energy storage.

In a smart energy system, the large-scale heat pumps are mostly used when there is a surplus of electricity, i.e. when prices are low. This means that the heat pumps would not be used continuously and there might be an over installed capacity in the smart energy system. During the hours of the day where there are high levels of excess electricity from intermittent renewable energy sources, this electricity can be used to supply the large-scale heat pumps, which can supply thermal storage and the district heating demand.

Large-scale heat pumps can also play a role in a future cooling system. Cooling systems today usually consists of individual electric heat pumps and chillers. In a smart energy system, district cooling is the way to go. In Europe today, district cooling only covers about 1% of the total cooling demand. If central chillers and large-scale heat pumps are implemented, some of the heat pumps used for heating could deliver cooling at the same time. This would create more of a synergy between the heating and cooling sector and the electricity sector.

Studies have shown that district heating together with thermal storage and large-scale heat pumps are more feasible, fuel efficient and cheaper than individual solutions in areas with high urban density. Large-scale heat pumps with electrically driven compressor are an important technology to increase the efficiency of district heating and make it more renewable.

Heat pumps makes it possible to utilize excess heat of low temperatures and reduce grid losses

When the temperatures from the heating sources are not high enough to be used for district heating directly, heat pumps can be used to increase these temperatures. This increases the efficiency compared to electric boilers and makes it possible to use less expensive sources of heat that might be available close to the grid[2]. In this way large-scale heat pumps improve existing district heating systems, by making use of low temperature heat sources available naturally or from surplus heat. Heat pumps are essential to develop a 4th generation district heating. But at the same time, it is useful to improve 3rd generation district heating systems. Heat pumps increases the temperature of heat sources with a lower temperature to utilize it in the district heating grid.

4th generation district heating is characterised by integration of thermal and electricity systems with low supply and return temperatures. To increase the use of renewable energy sources, combined heat and power plants, large-scale heat pumps and thermal energy storage systems will work together in synergy. In this way, district heating systems won't just be a solution for distributing heat, it will be a very important system for increasing renewable energy[2]. 4th generation district heating

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systems are also characterised by interacting with the district cooling systems. In the future district heating systems, large-scale heat pumps will be an essential element.

Since a lower supply temperature increases the heat pumps coefficient of performance (COP), a low temperature district heating system with a supply temperature around 50-60℃ makes it possible for large scale heat pumps to operate with high COP. The difference in temperature between the heat source and the district heating would be lower, which means that the heat pump would need less electricity to lift the temperature to desired level. This would make large-scale heat pumps in district heating systems even more profitable. The implementation of large-scale heat pumps in today's district heating systems puts a limitation to the heat pumps COP value because of the high system temperatures. This low-temperature network of district heating will help overcome the barrier of implementing heat pumps and at the same time reduce grid losses.

Thermal grids are defined as grids where energy is transported and exchanged between different consumers/prosumers. The challenge in a thermal grid is to balance the loads because some buildings are extracting heat from the system while others extract cooling from the grid.

Low temperature district heating has advantages on both the demand- and the generation side. Especially in connection with buildings that only require low temperatures for space heating. A well-designed low temperature heating system that operates with supply temperatures around 35-40℃ makes it possible to use both VLT (very low temperature, with a typical supply temperature around 60℃) and ULT-systems (ultra-low temperatures, which operates with a supply temperature around 45℃ or sometimes even lower) for space heating. Thanks to this it is possible to increase the use of other energy sources such as solar thermal collectors, heat pumps or excess heat.

For production of domestic hot water (DHW) by a heat exchanger, a district heating temperature of approximately 60℃ or higher is needed. For this reason, the lowest temperature system that can be utilized is the VLT-system. To utilize a temperature system like the ULT-system, a booster heat pump needs to be installed at the end consumer for production of DHW.

Depending on needs and possibilities in the thermal network, heat pumps can be integrated to the district heating system in different ways. A heat pump can be installed both centralized and decentralized. Usually if there are only one or a few main heat production sites with a large capacity, then central integration is the way to go. But if there is a smaller heat pump at a separate location or the heat production are distributed over multiple locations in the network, decentralized integration may be worth considering. In thermal grids with low temperatures, decentralized heat pumps are often installed at each building for DHW purposes. Studies has shown that supply temperatures at 40-45℃ is sufficient for space heating 80 % of the year, which means that grid losses can be reduced with 25% on a yearly base[4].

The potential for use of large-scale heat pumps in Europe is high. Heat pumps can be used to increase the temperatures of low-temperature excess heat and thereby make it usable for district heating. Low-temperature excess heat sources are for example excess heat from services, industry, or buildings, with temperatures between 5℃ and 40℃. In today's district heating systems, the supply temperature is on average 80℃ or above. This is where the heat pumps come in the picture and lifts the temperature to what's necessary. In the Heat Roadmap Europe project, only common low-temperature heat sources were used. However, there is a high potential to recover heat from unconventional heat sources in urban areas, such as data centres and metro stations. Expanding the heat recovery with heat pumps could replace further fuel boilers and some of the cogeneration capacity. This would reduce even more the primary energy consumption of the system.

Heat pumps increase the flexibility of district heating systems.

One of the most efficient solutions for utilizing excess electricity in energy systems with a high level of intermittent renewable energy sources (RES), is to install heat pumps. For the system to work optimally, large-scale heat pumps should be designed to operate during periods where the electricity production from RES is high and reduce operation during periods where production from RES is low[3].

During hours with high electrical production from RES, instead of only supplying the electrical storage, the excess electricity can be used by large-scale heat pumps that can supply heat for thermal storage systems and the district heating system. Large-scale heat pumps have an important role in future energy systems. It enables recovery of low temperature heat sources and creates a connection between the electricity and heating and cooling sector.

One way to balance variations in the electricity production is through demand response. It can lower the power consumption, reduce the power peaks, and increase the energy efficiency[5]. This might lead to both lower and more stable electricity prices. Also, better control of the market forces and benefits for the customers[5,6]. A combination of district heating and heat pumps could possibly play an important role for increased flexibility in future electricity grids.

A new important field for heat pumps in district heating systems could be to support the power grids. Due to the rapid development of renewable electricity from intermittent sources, massive challenges in the power grids due to stochastic production characteristics will follow. That is why flexibility options will play an important part in the electricity markets. Increased flexibility comes with the possibility to alternate between usage of heat pumps or other heat sources, like fuel-based combined heat and power plants for production of district heating. The heat pump can either be large-scale located centrally in the district heating grid or multiple decentralized heat pumps located at the end users. The flexibility can possibly help to avoid high costs for expanding the electricity grids, since investments in the electricity grids is foreseen to be a must to be able to handle variations in supply and demand of electricity in the grid. At the same time, the efficiency of the district heating grid will increase.

When there is a high share of renewable energy sources in the electricity grid, it will lead to a peak of electricity which correlates to a low power price. In this situation the combined heat and power plant (CHP) can be turned down since there is anyhow enough electricity to supply the grid. However, turning down the CHP means that the heat production goes down as well. In this way, the excess electricity produced by e.g. wind turbines can be used by the heat pumps to deliver heat to the thermal grid and the excess heat will be stored in storage systems.

When there is a low share of electrical production from renewable energy sources in the grid, the operation of the CHP will increase to produce the electricity needed to cover the demand. The CHP will also produce more heat but there is no need to utilize electricity with a higher price in the heat pumps. If the heat produced by the CHP is not enough the heat in the thermal storage can also be used as this point. Electricity from intermittent renewable energy sources like wind and solar is not always available and for that reason it is very important to develop a flexible system that can absorb electricity and use it as soon as its produced.

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Heat pumps play an important role in integrating more renewable energy and phase out fossil fuels from energy systems.

In the project Heat Roadmap Europe[8], they modelled an energy efficiency scenario for 2050. In this scenario district heating is supplied mostly by decarbonised energy sources and 25% of the total district heating demand is met by large-scale heat pumps. The 2050 scenario would bring a higher variety of energy supply to the district heating system. This will increase flexibility and the security of supply. The scenario also show that it would be possible to reach a more decarbonized district heating system with reduced CO_2 emissions above 70%. The district heating supply for the 2050 scenario is designed to avoid direct use of fossil fuel, but excess heat from industries and cogeneration might be of fossil fuel origin. This is accounted for to make use of existing heat sources and improve the overall system efficiency[7].

In today's district heating systems, large-scale heat pumps operate with full capacity almost all the time. This is not the case in the scenario for 2050. Heat pumps in the 2050 scenario are estimated to only operate 33% of the time on a yearly basis. This means that in a smart energy system there is always an installed overcapacity of heat pumps to increase flexibility. However, the 2050 scenario where heat pumps operate with only 33% of their capacity might not be the optimal way to model this technology in the energy system[9]. But there is a potential to increase these levels further, as large-scale heat pumps are recommended to operate on full load hours for about half of the time during a year. Without increasing the installed capacity in the 2050 scenario, large-scale heat pumps could have a much higher share in the market and still be able to operate in a flexible way. In the 2050 scenario, the heat market share for heat pumps could increase from 25% to 38% of the district heating production if large-scale heat pumps can operate in full load capacity half of the time during a year.

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