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# The Impact on Wind Power Integration from Geothermal Absorption Heat Pumps and Compression Heat Pumps

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**Abstract.** Aalborg Municipality, Denmark is investigating ways of switching to 100 % renewable energy supply over the next 40 years. Analyses so far have demonstrated a potential for such a transition through energy savings, district heating (DH) and the use of locally available biomass, wind power and low-temperature geothermal resources. The analyses have also demonstrated that the municipality will still rely heavily on surrounding areas for electric load balancing assistance. With a departure in a previously elaborated 100% renewable energy scenario, this paper investigates how absorption heat pumps (AHP) and compression heat pumps (HP) for the supply of DH impact the integration of wind power. Hourly scenario-analyses made using the EnergyPLAN model reveal a boiler production and electricity excess which is higher with AHPs than with HPs whereas condensing mode power generation is increased by the application of HPs rather than AHP.

**Keywords:** Wind power integration, geothermal absorption heat pumps, compression heat pumps

## 1. Introduction

Denmark is one of the countries in the world with the highest per capita carbon dioxide emissions, but at the same time one of the countries in the world with the longest-standing policy of reducing emissions. A national carbon dioxide emission reduction target was formulated in 1990 [1], and Denmark is also a signatory to later international agreements including the Kyoto Protocol and the Copenhagen Accord from 2009. In addition to the national aims, many local communities in Denmark have embarked on ambitious goals on their own accord.

Aalborg Municipality is among the largest in Denmark and has a potential for wind power, for low-temperature geothermal heat and some potential for biomass. Much of the heat supply in the municipality comes from DH with smaller fractions from individual oil, natural gas and biomass boilers. The existence of a large DH network enables centralized solutions that are not feasible from an individual house perspective such as geothermal driven AHPs or large-scale DH HPs.

HPs are often seen as a technology apt at integrating wind power into the energy system – particularly if made dispatchable. The analysis and actual use of AHPs is more novel, but still a technology worth investigating.

## 2. Scope of the paper

This paper outlines a scenario for Aalborg Municipality based 100% on renewable energy sources. There are a number of different configurations of AHPs and HPs and two of these are analysed and compared in this paper. Using the EnergyPLAN model, the scenario is analysed in hourly steps throughout a year with particular attention to the effects on the electricity balance in order to investigate how the affect the integration of wind power.

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## 3. The EnergyPLAN model

The EnergyPLAN model is a deterministic model based on hourly demands for electricity, heat and transportation over the course of a year and hourly productions of heat, electricity and transportation fuels. Some of the hourly distributions are user-defined through the use of files containing relative values for each hour throughout the year whereas others are determined by the model subject to various restrictions. The first category include heat demands, some electricity demands, hydrogen demand, wind power production, solar thermal production, and solar electricity productions while the second group include flexible electricity demands, DH HPs, electrolytic converters and thermal power plants. Cogeneration of heat and power (CHP)-plants may fall into either group depending on choice. AHPs are combined with waste incineration CHP plants from where they acquire process steam. The model is documented in [2], used in many analyses of renewable energy integration including [3-5] and may be downloaded for free at energy.plan.aau.dk.

## 4. The 100% renewable energy scenario for Aalborg

The 100% renewable energy system for Aalborg Municipality is a holistic scenario addressing all areas of energy supply and demand. The scenario is based on

- extensive energy savings both within electricity demand and heat demand,
- substitution of fossil fuels in the industry with biomass,
- electric and hydrogen light vehicles
- heavy vehicles based on biofuels
- conversion from individual boiler-based heating of dwellings to DH or individual HPs,
- geothermal AHP pumps and compression HPs in DH supply;
- significant expansion of wind power in electricity production

Main characteristics of the scenario are listed in Table 1. The scenario is further described in [6].

Table 1: Main energy scenario characteristics.

| Item | Size |
|---|---|
| Heat pumps – separate district heating grids | 1.3 $MW_e$ |
| Heat storage in district heating grids | 0.1 GWh |
| CHP unit - main district heating grid | 40 $MW_e$ |
| Heat pumps – main district heating grid | 24 $MW_e$ |
| District heating boilers | 310 MJ/s |
| Wind turbines | 486 MW |
| Electrolytic converter | 30 $MW_e$ |
| Hydrogen storage | 1.0 GWh |
| Individual heat pumps | 9.0 $MW_e$ |
| Individual solar collectors | 6.0 GWh/year |
| Heat savings | 44% reduction |
| Electricity savings - residential | 50% reduction |
| Electricity savings - elsewhere | 45% reduction |
| Industrial fuel savings | 261 GWh/year |
| Geothermal and absorption heat pumps | Four 200 $m^3$/h / 21 MW systems |
| District heating grid expansion | Inclusion of outlying villages |
| Biogas plant | 51 MW output |
| Gasification plant | 40 MW output |
| Waste incineration plant | 14.0 $MW_e$ |

In spite of introducing elements into the energy system that gives flexibility, the systems still exhibits a significant imbalance in the electricity system, as demonstrated in Fig. 1.

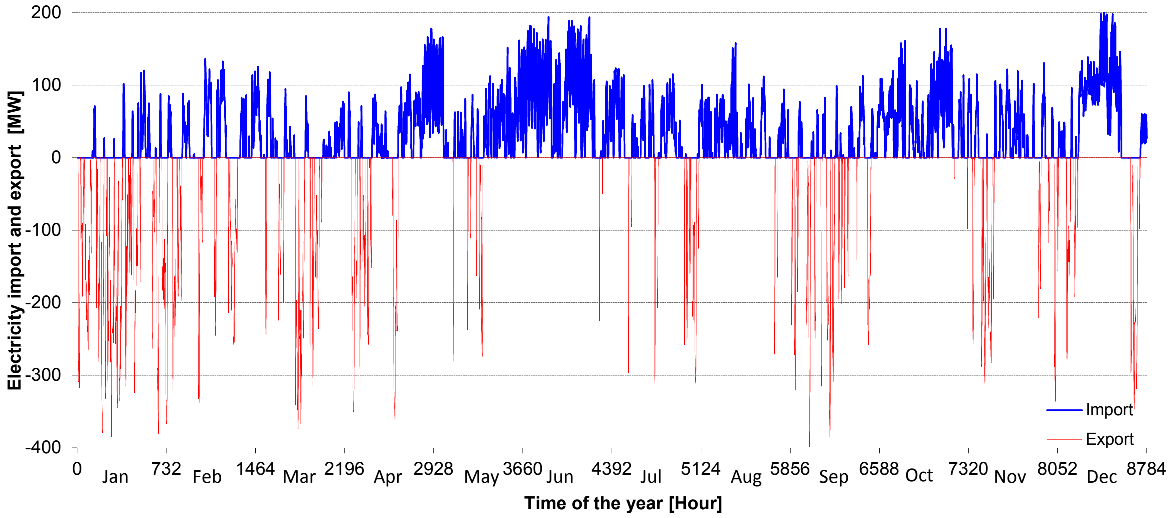


Fig. 1: Electricity imbalance in the Aalborg 100% renewable energy system over a year.

Observing Fig. 1. one sees that the systems has needs for import in the range of 0 to 200 MW while export is in the range of 0 to 400 MW with a slight tendency for export in the winter and import in the summer months.

## 5. Scenario-analyses of the impact of heat pumps in district heating

Aalborg is not an island and the electricity system is well connected to other areas in Denmark and even abroad. Therefore, the system does not need to be able to operate in island mode, however the present scenario is a future scenario and in a future situation, other municipalities and regions can be expected to go through a parallel transition.

A number of different optimization criteria are deliberated in [7], and among them are two that give indications of the system's ability to integrate wind power; on the one hand import/export and on the other hand production on condensing mode power plants. While condensing mode power generation is the typical mode of thermal power generation in most countries, it is also less efficient than CHP and in fact plays the same role as import as far as analyses like these are concerned.

In terms of heat generation, the least favourable production technology is boiler production, so this is the equivalent worst-case technology here and thus an indicator of the system's performance.

In the analyses, AHPs and compression HPs are varied in the range from 0 to 84 MJ/s. The conventional heat pumps are modelled having a coefficient of performance (COP) of 3.6. The AHPs have a COP of 2.34 based on steam from the waste incineration CHP plant. Bleeding steam on the other hand, also reduces the waste incineration CHP plant's electric and direct DH production efficiencies from 25% & 76% respectively down to 19% & 19% combined with 63% steam.

Fig. 2. shows how heat production varies with the level of heat production on AHP and HP. Both AHP and HP production naturally increases with installed capacity, but AHP increase more at higher installed capacities. Direct DH from the waste incineration CHP plant remains stable in the HP scenario but drops in the AHP scenarios as the DH efficiency decreases as more steam is bled to the AHP. CHP production is slightly lower for high AHP values as there is less room for the CHP plant, while constant for the HP scenario as HP units typically are run when there is a high wind production – and not when there is a high CHP production. Boiler production drops in both scenarios though significantly more in the HP scenario than in the AHP scenario.

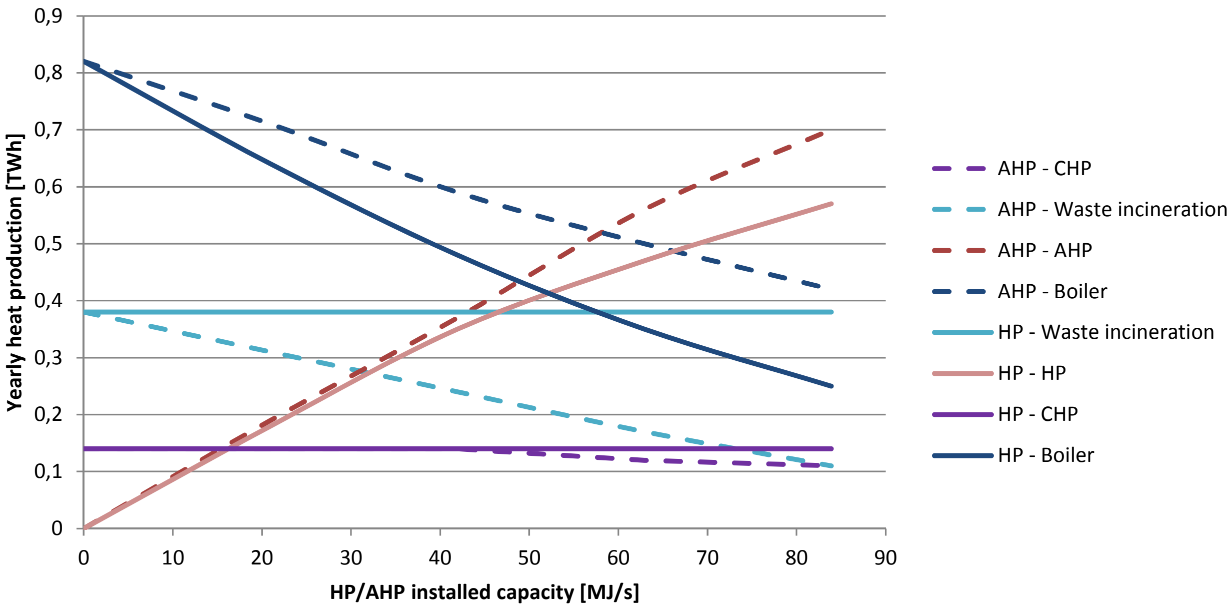


Fig. 2: Yearly heat production to the district heating network with varying degree of HP/AHP capacity.

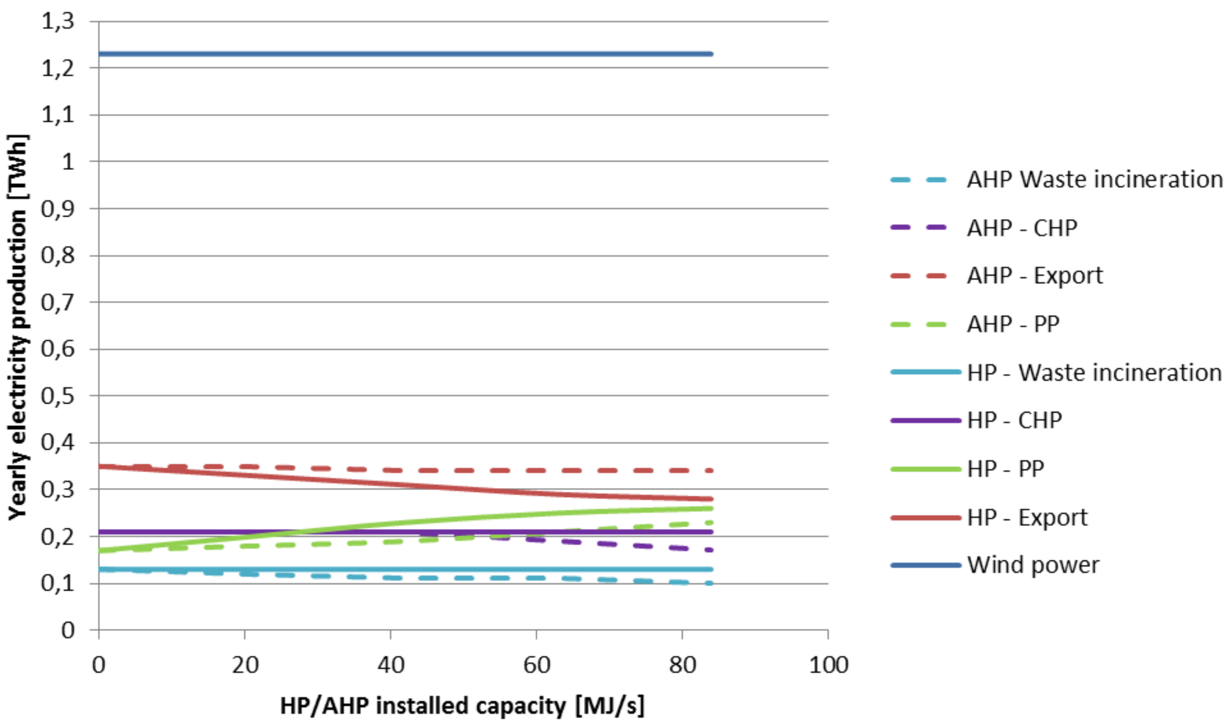


Fig. 3: Yearly electricity production with varying degree of HP/AHP capacity

Electricity production as shown in Fig. 3 is also affected by the AHP and HP penetrations. Some are directly related to the heat productions shown in Fig. 2 such as the CHP production and the electricity production on the waste incineration CHP plan. CHP production thus decrease at higher AHP levels as there is no room for the heat production. Likewise, electricity production on the waste incineration CHP plant decreases as more and more steam is being bled for the AHP unit. Condensing mode power (PP) generation is lower for the AHP scenario than for the HP scenario, while export is lower for the HP scenario than for the AHP scenario. A main reason for this is found in the added electricity demand in the HP scenario.

Both condensing mode power generation and export are indications of the systems inability to function in in island mode and an indication that the fluctuating sources of electricity are not fully integrated. Here there is the interesting situation, AHPs are preferable from a condensing mode power generation perspective – but HPs are preferable from an export perspective.

## 6. Conclusions

This paper has investigated the system impact of adding either HPs or AHP to the energy system with the perspective of good system integration of the fluctuating power output from wind turbines.

The results have demonstrated how boilers, CHP units, waste incineration plants condensing mode power generation as well as export is affected by the choice of HP or AHP technology as well as the level of penetration of the technology.

For the present system, boiler production is reduced more by the application of HPs than the application of AHPs. Likewise, export is reduced more through HPs than through AHPs. On the other hand, condensing mode power generation is increased by the application of HPs rather than AHP due to increased demand of electricity in the HP scenario.

It should be noted though, that in the original scenario, wind power penetration was calibrated to ensure a balance between annual electricity demand and production. This has not been done here. The additional electricity demand from the HPs as well as the lowered electricity production from the waste incineration CHP plant has generated an imbalance, which has not been taken into consideration

## 7. Acknowledgements

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