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A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating

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ABSTRACT

The Danish city Frederikshavn is aiming at becoming a 100% renewable energy city. The city has a number of energy resources including a potential for off-shore wind power, waste and low-temperature geothermal energy usable as heat source for heat pumps producing district heating.

In this article, a technical scenario is described and developed for the transition of Frederikshavn's energy supply from being predominantly fossil fuelled to being fuelled by locally available renewable energy sources. The scenario includes all aspects of energy demand in Frederikshavn i.e. electricity demand, heat demand, industrial demand as well as the energy demand for transportation.

The locally available energy resources are deliberated and an energy system is designed and analysed with an energy systems analysis model on an aggregate annual level as well as on an hourly basis. Particular attention is given to the use of geothermal energy in the area. It is shown, that the use of geothermal energy in combination with an absorption heat pump shows promise in a situation where natural gas supply to conventional cogeneration of heat and power (CHP) plants decreases radically.

1. Introduction

At the seminar *Energy Camp 2006* in Denmark it was proposed by a number of participants that a Danish city should aim at becoming a 100% renewable energy city. The city should function as a testing site for innovative energy technologies as well as function as a beacon for other cities and regions with similar ambitions.

Through a presence of attendees from Northern Jutland at the seminar, it was decided to proceed with the suggestion that Frederikshavn – located in Northern Jutland (see Fig. 1) – should be this 100% renewable energy city. The ambition was subsequently adopted by the Frederikshavn Municipal Council.

Frederikshavn Municipal County later approved a scenario plan ([1] – described in English in [2]). The short term (2015) objective of the scenario plan is simply to match aggregate demand with 100% renewable energy sources on an annual basis. Energy may be exchanged with surrounding areas – e.g. petrol for cars against the export of electricity from wind turbines. Biomass use in the short term may exceed what would be available if nationally available biomass resources were distributed according to population and it is also noteworthy that the scenario plan includes waste as a renewable energy source.

In the long term (undefined year), the system should function in a way that does not diminish the possibilities of other areas to have a 100% renewable energy supply. This entails a reduction in the use of biomass resources and an electricity system which does not merely export hourly imbalances.

The permitted extent of electricity balancing with surrounding areas is not stated explicitly, only that the system of Frederikshavn must be able to integrate into a national system based on 100% renewable energy. Using a term from [3], this may be termed "connected island mode" which gives *"priority to the ability to operate in island mode – but also [.. includes] a certain possibility of exchange with the surroundings*". Different areas in Denmark each have a specific point of departure in their specific set of geographic, industrial and demographic circumstances, however the potential energy resource base does not vary that much within the country. Wind power and biomass are the main resources utilised presently [4] and both are likely candidates for important future roles. There are hence no significant synergies to be exploited between different areas in terms of load balancing as investigated in [5] and the Frederikshavn system should therefore be able to operate in island mode to the highest extent possible.

The Frederikshavn project has already generated a number of activities. The largest Danish utility DONG Energy has been involved in the process due to their ownership of some of the existing wind turbines in the Frederikshavn area. They have an interest in expanding off-shore wind power near Frederikshavn and have also invested in a heat pump producing district heating while

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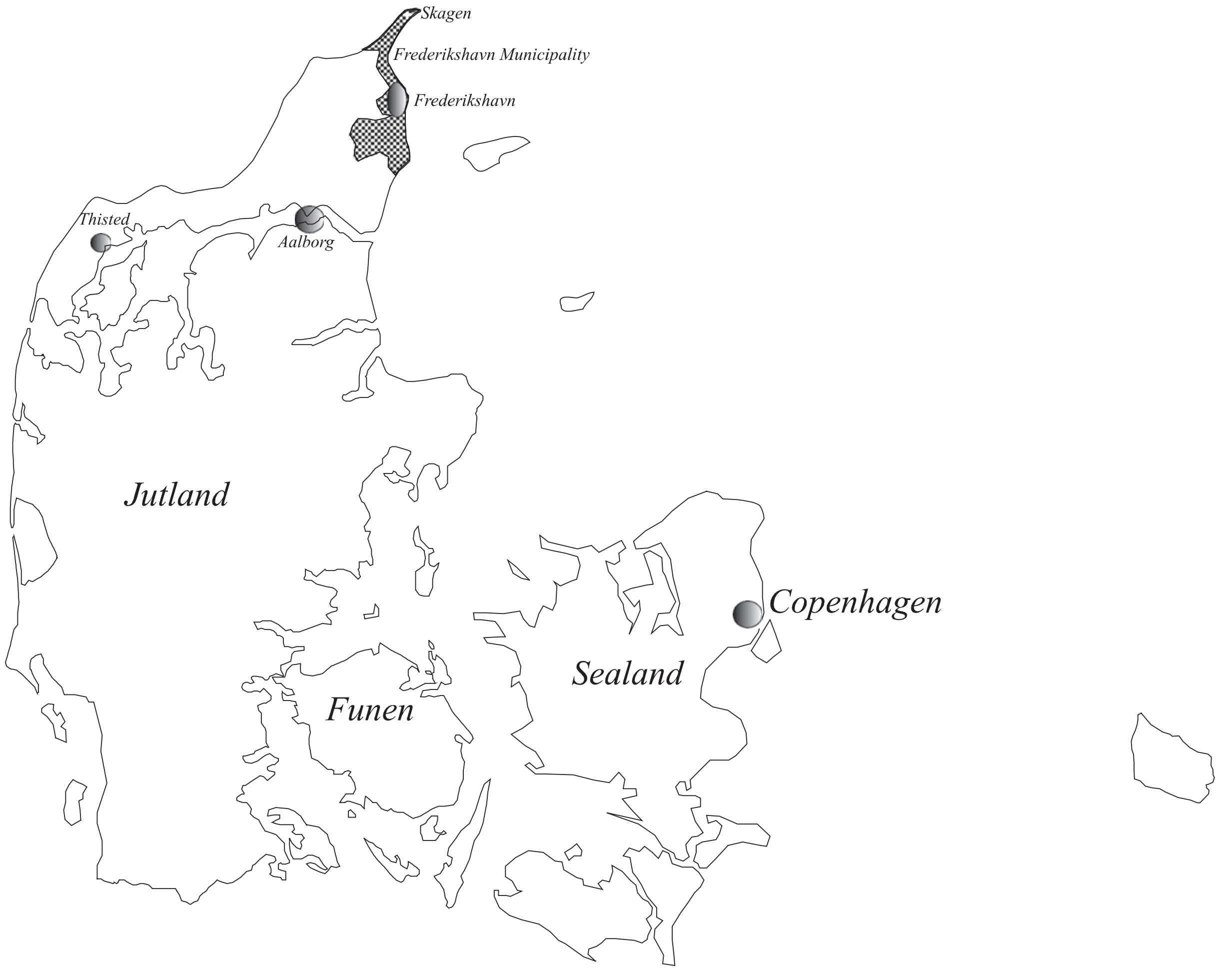

Fig. 1. Denmark with Frederikshavn located in the very North.

helping integrating wind power. An additional 25 MW of off-shore wind power is planned of which 12 MW was planned to be erected in 2009 but encountered delays.

The northern suburb of Strandby has already established a large-scale solar collector for the Strandby district heating system in combination with an absorption heat pump, and plans are underway for the expansion of the local waste incineration plant as a consequence of lacking capacity and plans for shutting down a smaller installation in the city Skagen 35 km to the North (see Fig. 1). A biogas to natural gas upgrading facility has also been proposed.

Potential energy resources are in limited supply however. Regions in the world with high penetrations of renewable energy typically rely on single resources such as ample biomass resources, good wind resources or good potentials for hydro power – all combined with modest populations. There are limited biomass resources in the case of Frederikshavn, wind potentials are also limited, and there is no potential for hydro electricity. There is however an unrealised potential for geothermal heat which may be combined with other sources to form a multi-tier renewable energy system.

Investigating the scientific work on renewable energy systems reveals a large focus on single-technology systems e.g. wind power [5–8], photo voltaic cells [9], biomass [10], biogas [11] and waste resources [12,13]. All of the resources may serve as important factors in 100% renewable energy systems, but energy systems may also benefit from synergies between the resources. Likewise, there is focus on many of the potential technologies that may facilitate 100% renewable energy systems – compressed air energy storages as deliberated by Lund and coworkers [14–16], hydrogen for transportation [17], electricity for transportation [18,19], hydrogen as a storage option [20] and conversion of individual heat systems to district heating systems [21]. In addition, renewable energy sources may also be investigated from a spatial perspective [22,23] or even from an institutional or policy perspective [24–27]. Again, synergies may be exploited if a more integrative approach is applied.

From an even more technical point are the issues of ancillary services, impacts on transmission grids and the electro-technical design of electricity systems [5,28–33]. Such analyses are also relevant when designing future energy systems though beyond the scope of this article.

While much of the work referenced above investigates single technologies, most of the technologies are in a specified context – either a renewable energy context or a more traditional fossil fuel context. As noted in this article, as well as by e.g. Lund in [34], a single-technology perspective does not suffice. Future 100% renewable energy systems require a more integrated approach found in national analyses in [35–37] or local analyses as found in [38]. However, of these examples, only [36] includes transportation in the analyses.

Geothermal energy is widely utilised in many countries, however most of the heating applications are using near-ground level heat sources in combination with compression heat pumps [39]. There is some research on using absorption heat pumps in combination with geothermal energy, however most relate to cooling