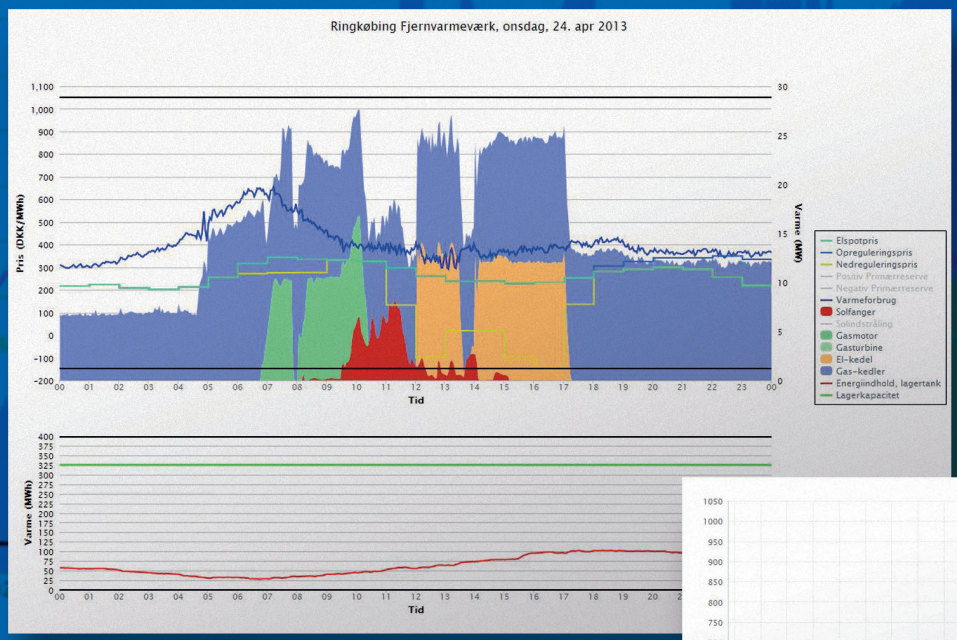
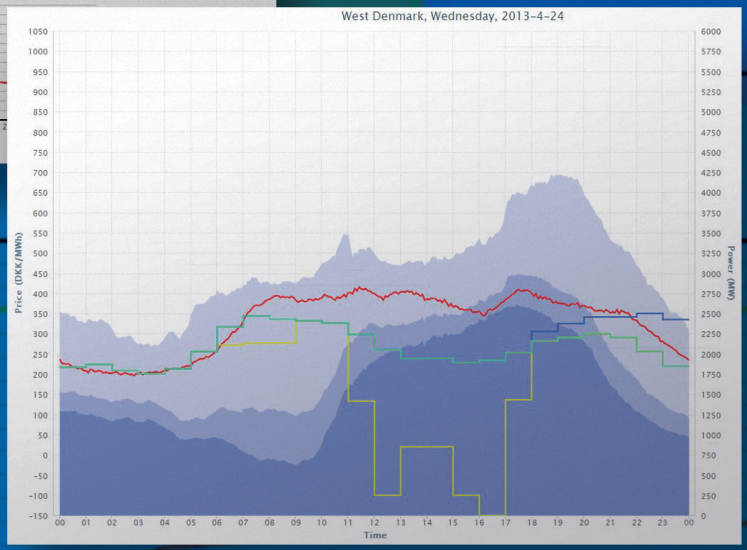
Facilitating energy storage
to allow high penetration of intermittent
Renewable Energies

stoRE
www.store-project.eu

Overview of the Danish Power system and RES integration





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Authors	Organisation	E-mail
Peter Sorknæs	EMD	ps@emd.dk
Henning Mæng	EMD	hm@emd.dk
Thomas Weiss	HSU	weiss@hsu-hh.de
Anders N. Andersen	EMD	ana@emd.dk

Graphic design: Guillaume Korompay, www.korompay.at

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In this paper is given background information to be taken into consideration when discussing bulk electricity storage for Denmark.

Background information and questions to be raised concerning bulk electricity storage for Denmark

1 Background

The European project stoRE (www.store-project.eu) aims to facilitate the realization of the ambitious objectives for high penetration of variable renewable energies in the European grid by 2020 and beyond, by unblocking the potential for energy storage technology implementation. In the stoRE project the focus of analysis and discussions is set predominantly on bulk energy storage technologies (EST), namely pumped hydro energy storage (PHES) and compressed air energy storage (CAES).

Bulk EST is expected to be amongst the key enabling technologies for the integration of large amounts of variable electricity generation from renewable energy sources (RES-E). In particular, the ability to quickly discharge large amounts of stored electricity or to reduce loads during certain points in time throughout a day can mitigate many challenges that arise from high shares of variable RES-E generation in the electricity system.

There are more reasons for Denmark to promote bulk EST in either Denmark or e.g. in Norway in the near future.

2

The Danish government and parliament have set up ambitious RE goals

The reasons for considering bulk EST for Denmark are the ambitious goals set up by the Danish government and the Danish parliament.

Goals set up by the Danish government	Goals set up by the Danish parliament
100 % renewable energy in 2050	25% reduction of fossil fuels from 2010 to 2020
100 % renewable energy for electricity and heat in 2035	50% reduction of fossil fuels for electricity and heat from 2010 to 2020
All oil boilers removed in 2030 (mainly to be substituted by heat pumps)	No oil boilers allowed in new buildings from 2013
Wind turbine shall produce 50% of electricity consumption in 2020	Wind turbine shall produce 50% of electricity consumption in 2020

These goals are to be reached amongst others with a major development of wind energy.

3

Ambitious goals have also been set up for the development of wind energy

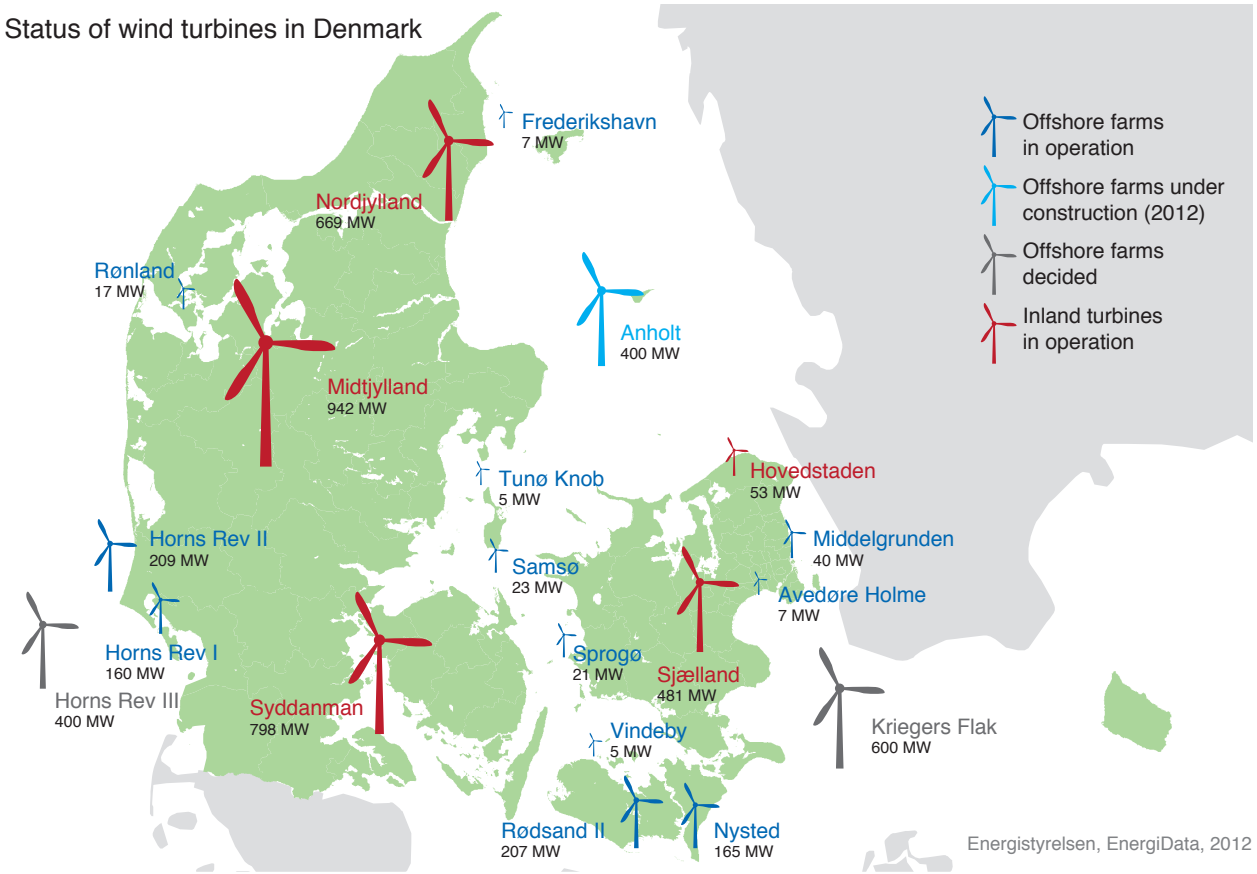


Figure 1 shows the present status of wind turbines in Denmark. As seen the wind turbines are distributed all over Denmark with a majority of capacity in Western Denmark and a majority of capacity on inland turbines. In the coming years near shore wind farms will play a more dominant role. The new large wind farms “Kriegers Flak” and “Horns Rev III” will be operating before 2020.

Figure 1:
In this figure is shown the status for wind turbines in Denmark. (source: Danish Energy Agency).

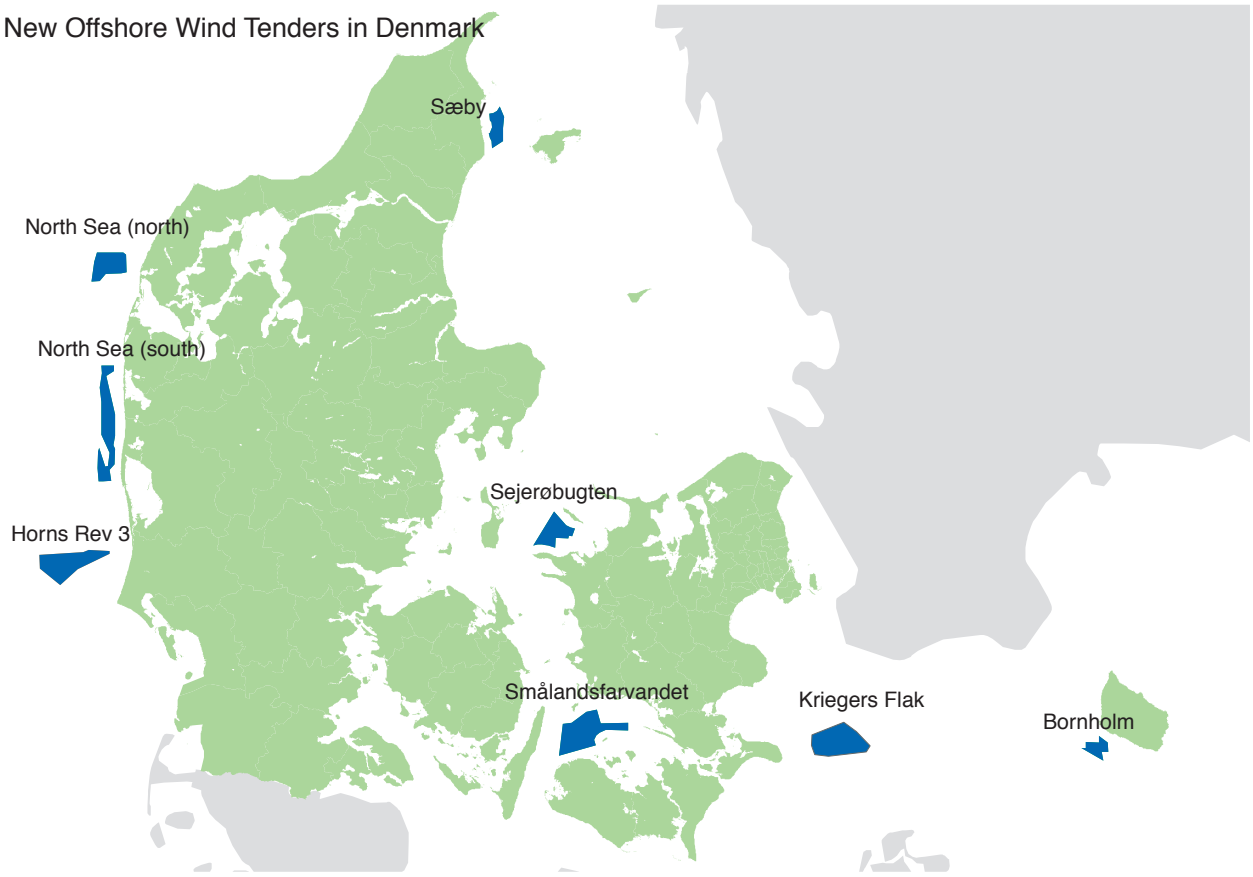


Figure 2:
Near shore wind sites considered (source: Danish Energy Agency)

During the last years a planning process for new near shore wind farms has taken place and six sites have been chosen. As Figure 2 indicates a desired geographical distribution has been taken into account. These new farms are not expected to be in operation before 2020.

4

Overview of the transmission network in Denmark

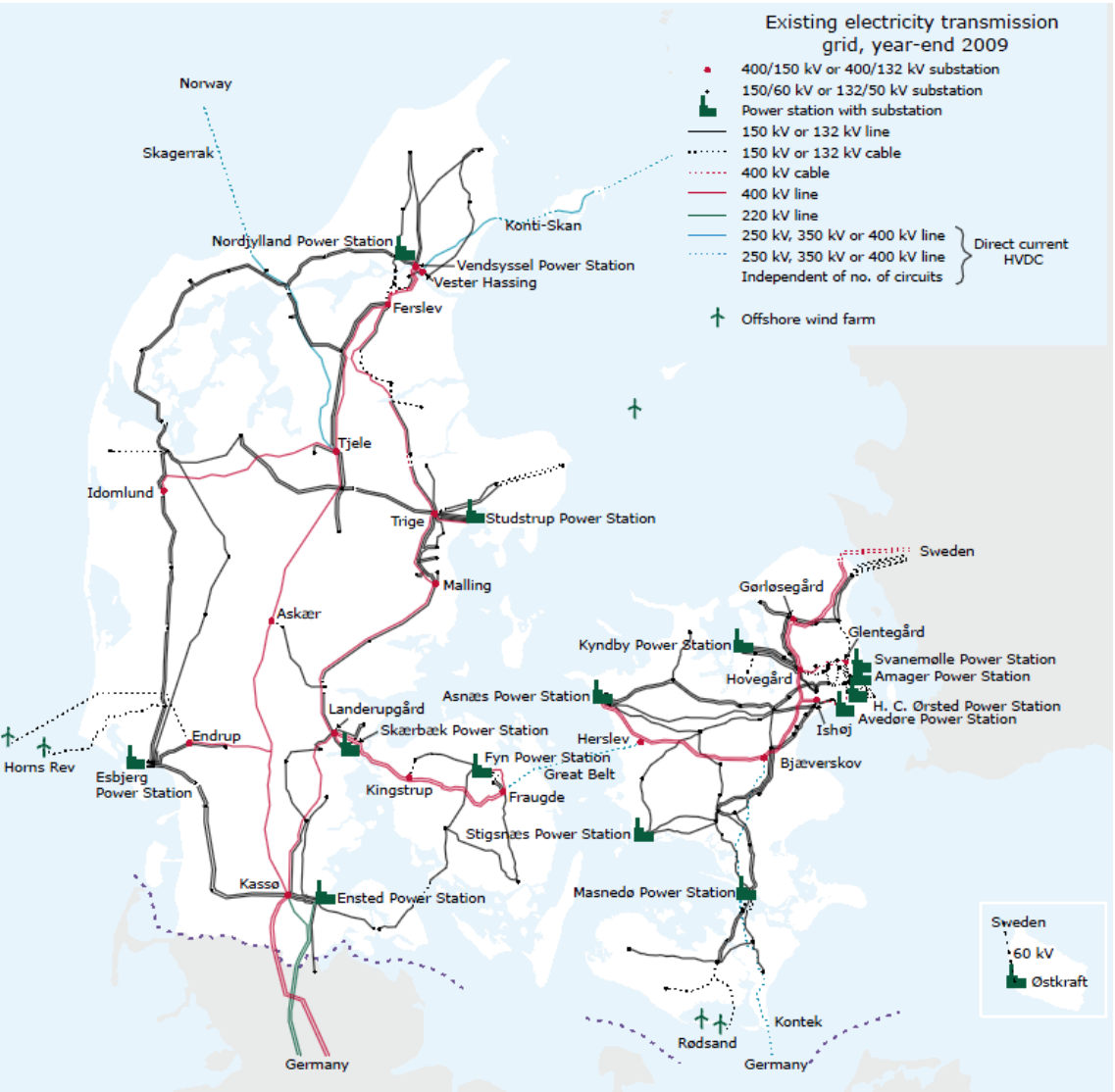


Figure 3:
Overview of the transmission network in Denmark.
(source: energinet.dk)

The transmission network in Denmark is divided into two separate transmissions grids; Western and Eastern. The West Danish grid is connected to the European continental grid, whereas the East Danish grid is connected to the Nordic grid. The two areas have since autumn 2010 been connected through a 600 MW DC connection across the Great Belt. The Danish transmission grid can be seen in Figure 3, with the interconnectors to Germany, Norway and Sweden.

Denmark is part of the Nordic electricity spot market Nord Pool Spot, which besides Denmark covers Estonia, Finland, Norway and Sweden. Due to bottlenecks in the electrical grid in the Nord Pool Spot area the electricity market is divided into several price areas, where Denmark is divided into the two price areas; West Denmark and East Denmark.

East Denmark is connected to Sweden by four AC interconnections with a total transmission capacity of 1,900 MW, and to Germany by a DC interconnection with a total transmission capacity of 600 MW.

West Denmark is connected to Germany by AC connections where the total transmission capacity is determined by congestion in the surrounding grids and is normally 1,500 MW in the southbound direction and 950 MW in the northbound direction. West Denmark is connected to Sweden with a DC connection with a total capacity of 740 MW, and is connected to Norway with a DC connection of 1,040 MW.

New offshore grids are being planned. In Figure 4 is seen the proposed new grid connecting the coming Kriegers Flak wind farm. The new grid is laid out so it can both feed wind power into the onshore grids and exchange electricity between Germany and Denmark and may be later on to Sweden.

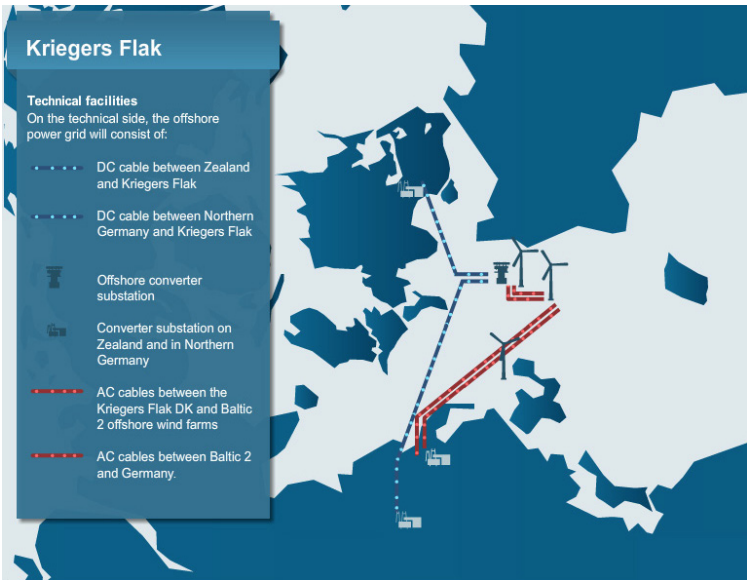


Figure 4:
New offshore grids being planned connecting the coming Kriegers Flak wind farm. (source: energinet.dk)

5

The Danish TSO has made a list of priorities for integrating wind

The Danish Transmission System Operator (TSO), Energinet.dk, has made a clear list of priorities for integrating the fluctuating productions from wind turbines.

	Short term	Medium term	Long term
Primary focus: Power system balancing	• Expansion of interconnections • Reinforcement and expansion of existing power grid • Downward regulation of generation aided by negative spot prices • Market coupling • Better wind power forecasting	• Geographic distribution of offshore wind farms • Offshore grid • Demand response • Flexible electricity generation • Smart Grid	• Electricity storage in the gas system • Compressed Air Energy storage • Electricity storage in batteries
Primary focus: Integration of RE electricity into other sectors	• Heat pumps at CHP plants • Electric boilers at CHP plants • Heat pumps in households	• Plug-In hybrid vehicles • Electric vehicles	• Use of (electrolysis-based) hydrogen in the transport sector • Use of (electrolysis-based) hydrogen in the gas network

Energinet.dk does not specify what is meant by Short term, Medium term and Long term, and it is assumed that the list is only priorities rather than a time schedule.

From the list it is clear that the Danish TSO sees the implementation of electricity storage in Denmark after the initiatives listed in the Short term and Medium term have been carried out. For this reason there are currently no concrete plans for electricity storage in Denmark. In the Long Term the Danish TSO sees CAES, batteries and the production of fuels using electricity as viable electricity storage technologies in Denmark.

Expansion of the interconnections is related to bulk EST, because Norway has pumped hydro storage potential. Using bulk EST in Norway is closely related to developing the transmission network in Denmark and in the Scandinavian electricity markets.

A quantification of some of the means that the Danish TSO (Energinet.dk) expects to be taken into action in the period until 2030 for integrating the fluctuating productions from wind turbines is shown in Figure 5.

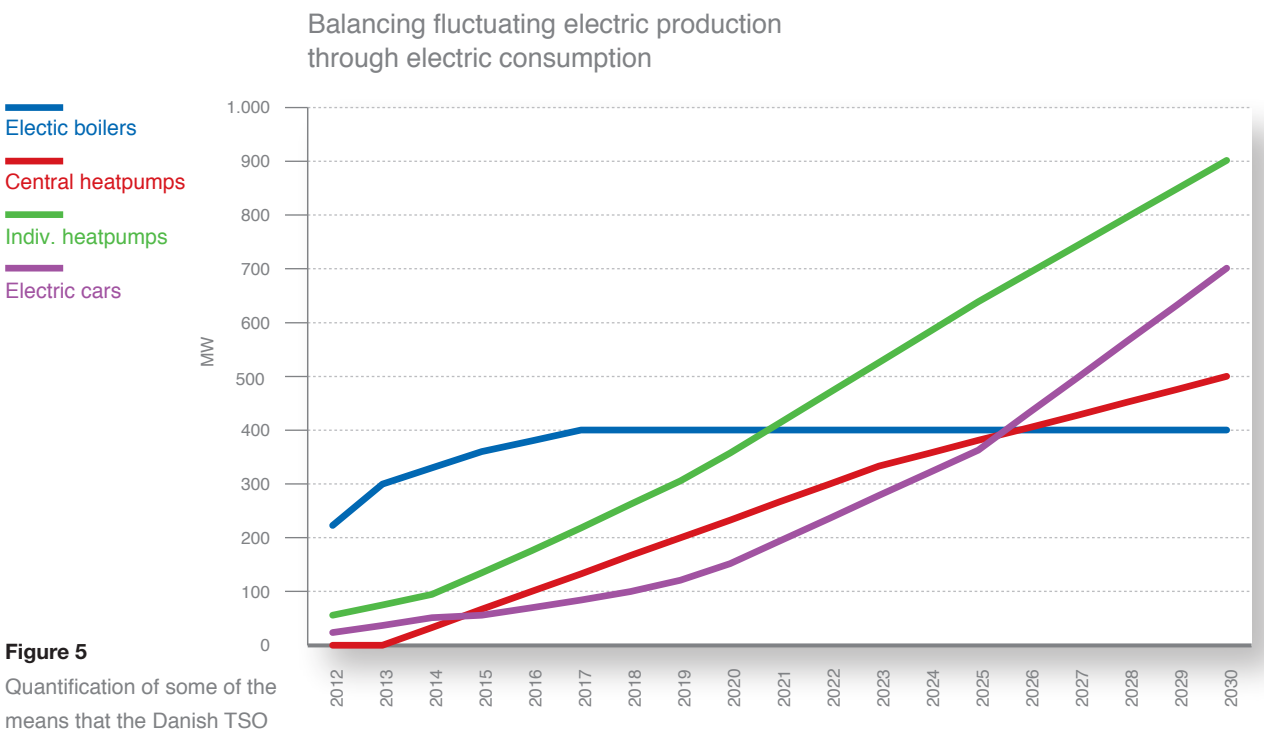


Figure 5
Quantification of some of the means that the Danish TSO (Energinet.dk) expects to be taken into action in the period until 2030 for integrating the fluctuating productions from wind turbines

The four means are each considered to be able to swallow several hundred MW when 2030 is reached.
The electric boilers and the central heat pumps are considered to be integrated at the CHP plants (central and de-central), where heat production can be stored in the existing thermal stores.
The individual heat pumps are mainly considered as an option in rural areas, where district heating is not an option.
The fourth mean is electric cars.

Besides these means, the list also includes storing surplus electricity as fuel by using electrolysis, which then will function as energy storage for seasonal adjustments.

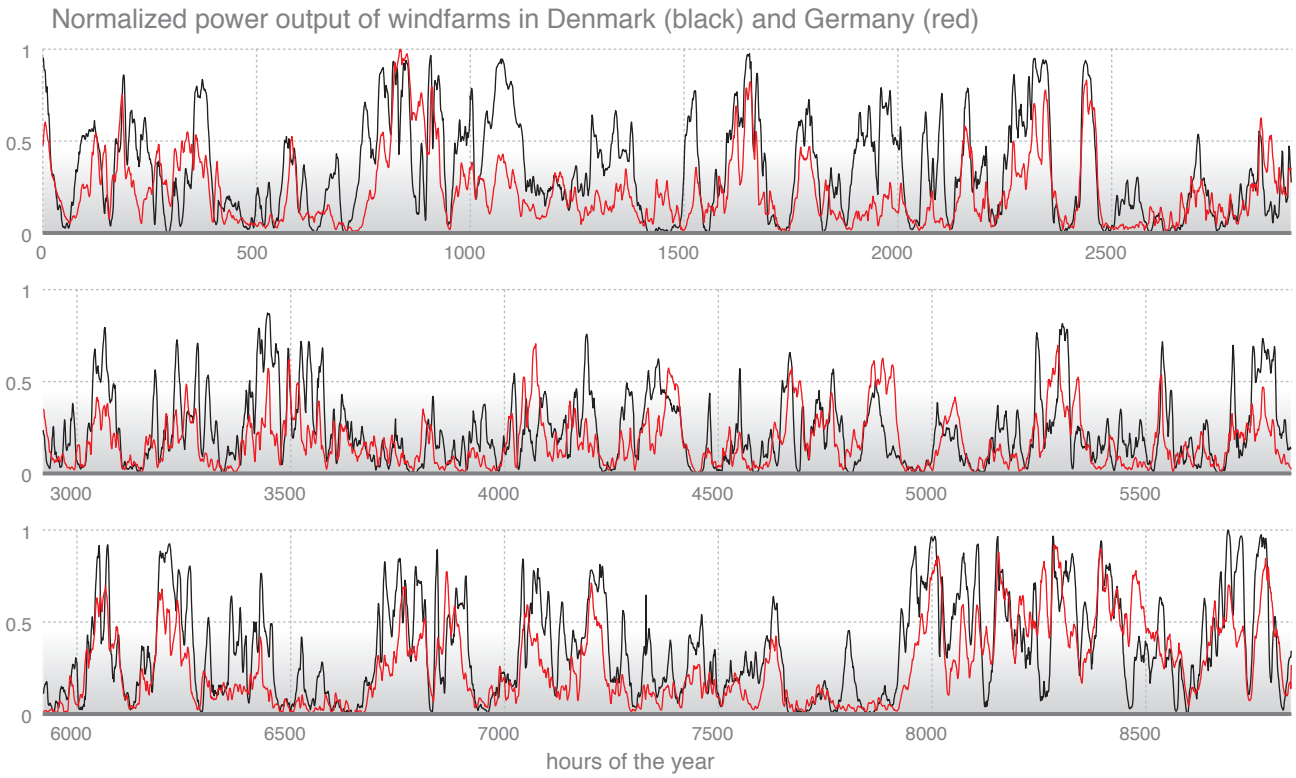
6

Is connecting to Germany a major possibility for integrating wind?

One main idea for integrating the fluctuating productions from wind turbines is to connect to Germany. But looking into the correlation between wind power in Denmark and Germany, you will see that this is a limited possibility. In the figure below the data is based on the real feed-in curves from wind in both countries in the year 2011.

This indicates that it could be difficult to export wind energy to Germany during times of strong wind energy production. It can already be stated that when there is a surplus of renewable energy (negative residual load) in Denmark there is often also a surplus in Germany.

Figure 6:
Normalized wind energy production in West Denmark (black) and Germany (red) for the year 2011



7

Is district heating a major possibility for integrating wind?

When discussing the need for bulk EST, it is to be kept in mind that Denmark has a large amount of CHP-units at distributed district heating companies.

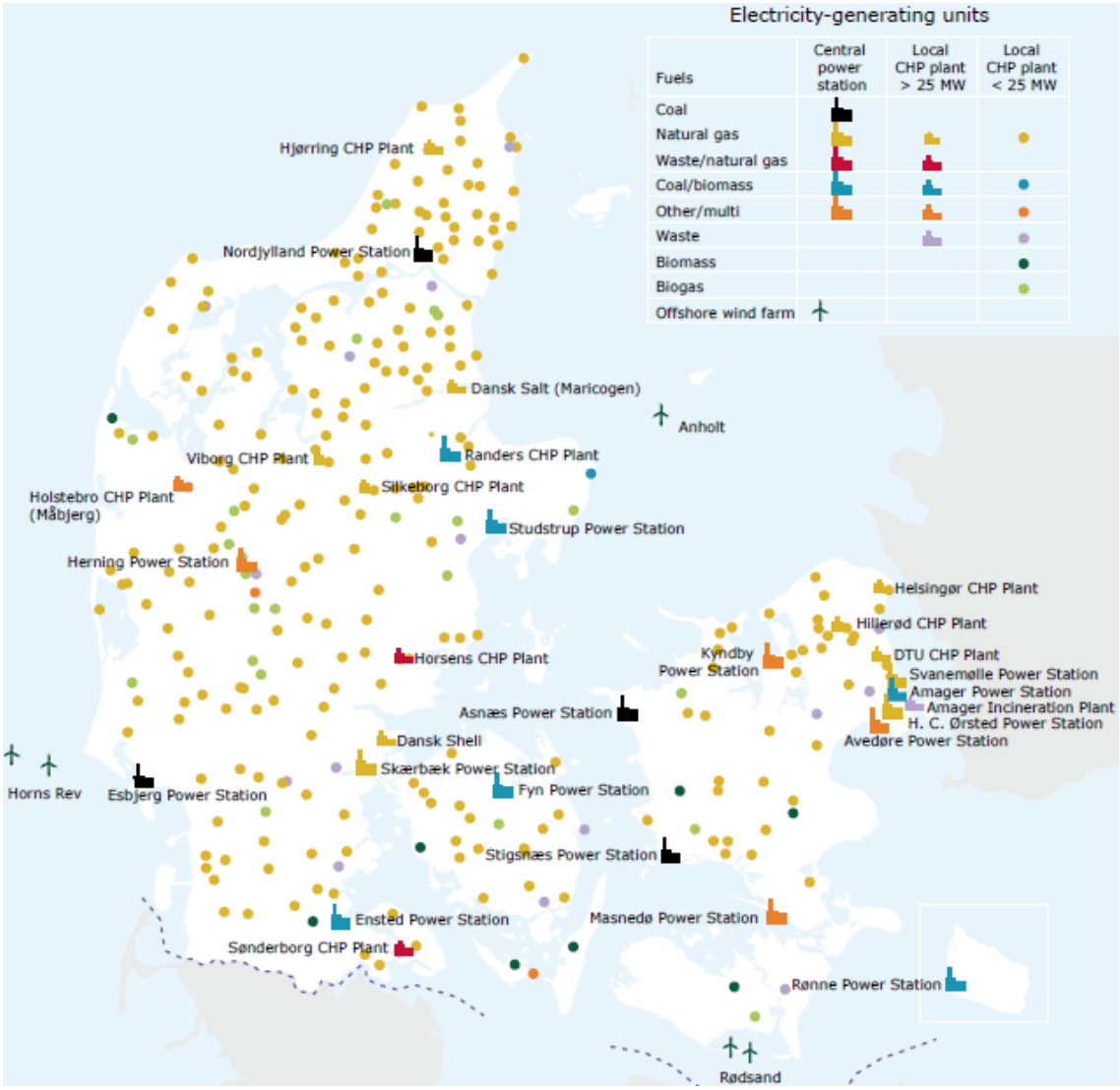


Figure 7:
The Figure shows there are many smaller natural gas fired CHP plants throughout Denmark.
(source: energinet.dk)

These distributed plants can do a similar job as bulk EST, about integrating the large amounts of fluctuating productions from wind turbines. An example of how this is already realised in actual daily operation is shown below in figure 8 and figure 9.

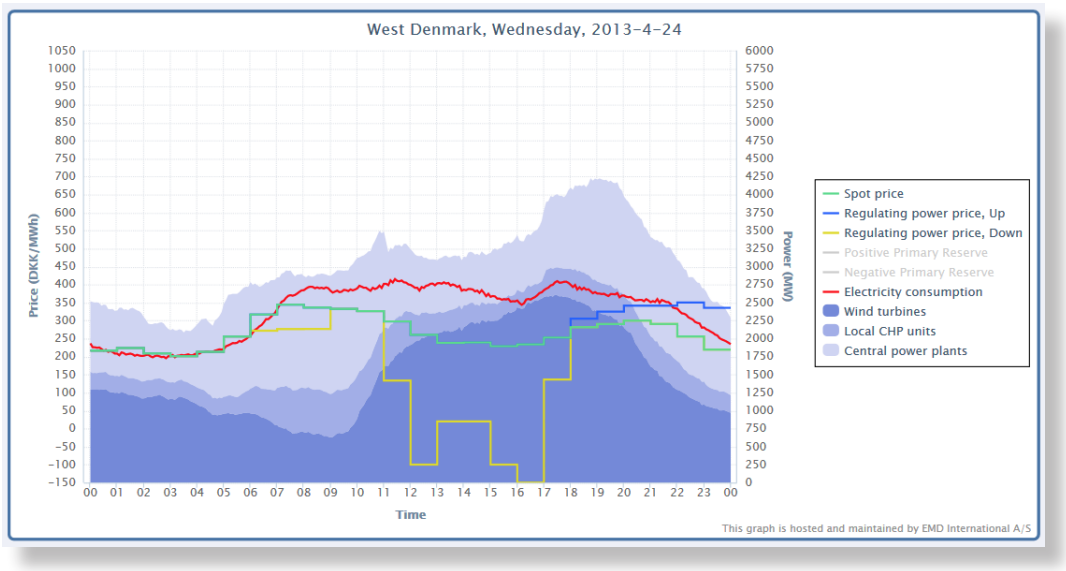


Figure 8:
At http://emd.dk/el/ is seen the challenge of integrating large amounts of fluctuating productions from wind turbines.

At http://emd.dk/el/ the challenge of integrating large amounts of fluctuating productions from wind turbines is shown online. As an example, see Figure 8. On Wednesday, 24. April 2013, wind was blowing heavily, making the price in the regulating power market negative for several hours.

But if you look into online operation of one of the West Danish CHP-plants, see Figure 9 – their CHP´s and electrical boilers reacted properly on this.

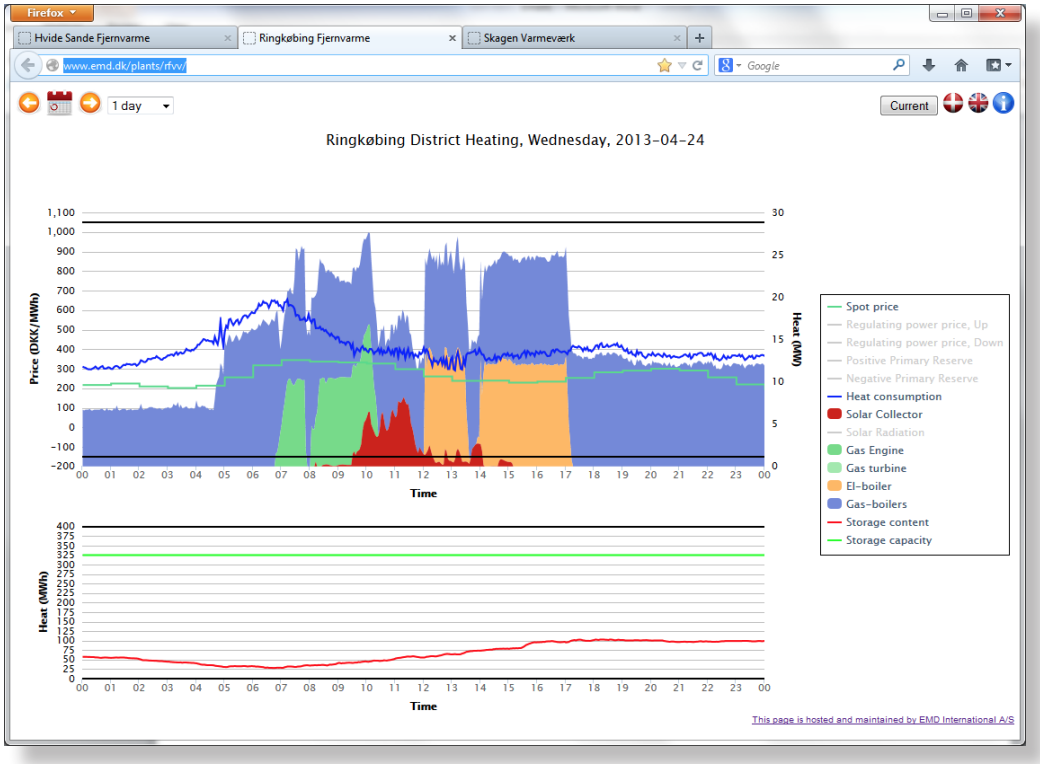


Figure 9:
At http://www.emd.dk/plants/rfvv/ the operation of a West Danish CHP-plant is shown online.

8

Is CAES in the long term a viable EST in Denmark?

In the long term the Danish TSO sees CAES situated in Denmark as a viable electricity storage technology in Denmark. It is to be expected that when implementing a sustainable energy system in Denmark based on renewable energy, the gas to the CAES plant will to a higher extent become RE gases, and what is even more challenging is that the existing coal fired power plants will not be replaced by new coal fired power plants. The electricity system needs inertia to be stable. When the existing coal fired power plants are taken out of operation, this inertia needs to be delivered by e.g. synchronous generators (inertia wheels) or it might be delivered by the CAES plants.

This consultation paper has been produced as part of the project "Facilitating energy storage to allow high penetration of intermittent renewable energy", stoRE. The logos of the partners cooperating in this project are shown above and more information about them and the project is available on www.store-project.eu