Will Denmark phase out CHP?

District heating (DH) and combined heat and power have played a steadily increasing role in space heating in Denmark for nearly 100 years, but now the tide seems to be turning, see fig 1. The total Danish CHP heat production reached a peak during the late 1990s and has subsequently been decreasing.

This note describes the background and the driving forces behind the CHP development.

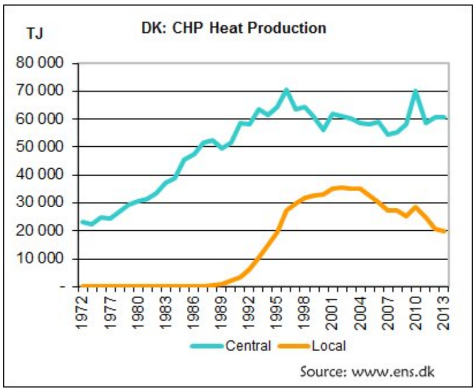

Fig. 1 Declining local CHP heat production during the last ten years

Early History

There are considerable thermal losses from electricity production in steam and diesel power plants. It is a natural idea to utilize these losses for space heating in urban areas. The first CHP system in Denmark was established in Copenhagen in 1925 distributing steam in pipes to areas close to the power station.

At the beginning of World War 2, the western part of Denmark (Jutland and Funen) had 433 small power stations for public supply. There were an even larger number of private power plants. This structure was inefficient, and in 1946 a commission recommended locations for six new regional power stations[1]. Five of the six power plants were located close to city centres in order to facilitate heat supply, and as they were developed after the war so heat production increased, see fig 3.

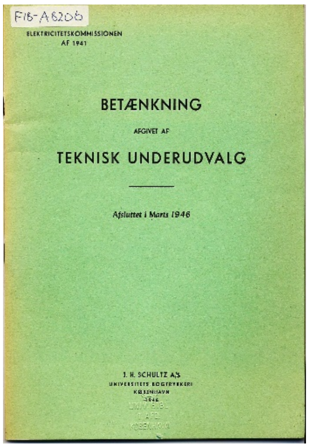

Fig. 2 "Report from technical subcommittee" 1946

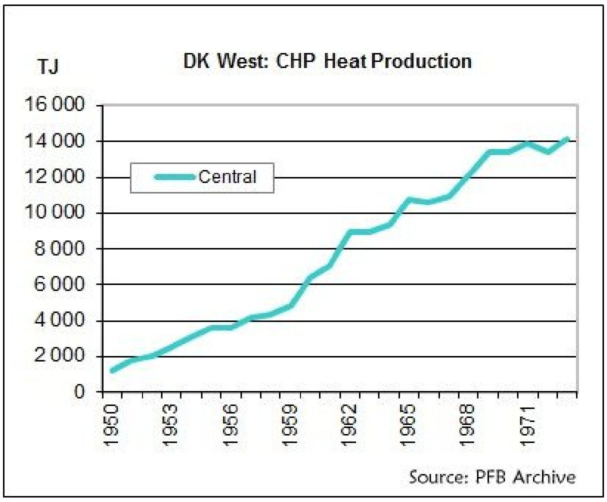

Fig. 3 Post war CHP development in West Denmark

East Denmark already had two large power plants in Copenhagen and two regional power stations, Kyndbyværket and Masnedøværket but only Copenhagen used CHP for district heating.

[1] Electricitetskommissionen af 1941: Betænkning afgivet af Teknisk Underudvalg, København 1946.

The demand for electricity rapidly increased during the 1960s. A new power plant had to be added every year. The sites of the existing regional power plants were not ideal for large, modern units and for fuel import on large tankers, and it was debatable whether the CHP concept was still profitable. New power plant sites without heat distribution were established at Asnæsværket and Stigsnæsværket in East Denmark and Vendsysselværket, Studstrupværket and Enstedværket in West Denmark. In 1972, the total Danish heat production from CHP was 23,000 TJ, of which 14,000 TJ were from the five central heating systems in West Denmark and the remaining 9,000 TJ at the CHP systems in the capital.

The result of the developments was a Danish portfolio of "**central power plants**" some of which were CHP systems and some were purely electricity generators.

Oil crises in the 1970s

The price leaps of oil in 1973 and 1979 changed the economic conditions dramatically. Now it was more important to save energy, and CHP was a very efficient method of achieving that objective.

During the 1980s there was a strong movement "Small is beautiful" along with a vision to spread DH and CHP at village level. The political establishment supported the idea. Natural gas was introduced to Denmark in the 1980s. One purpose for creating small CHP systems was to provide customers for the natural gas project.

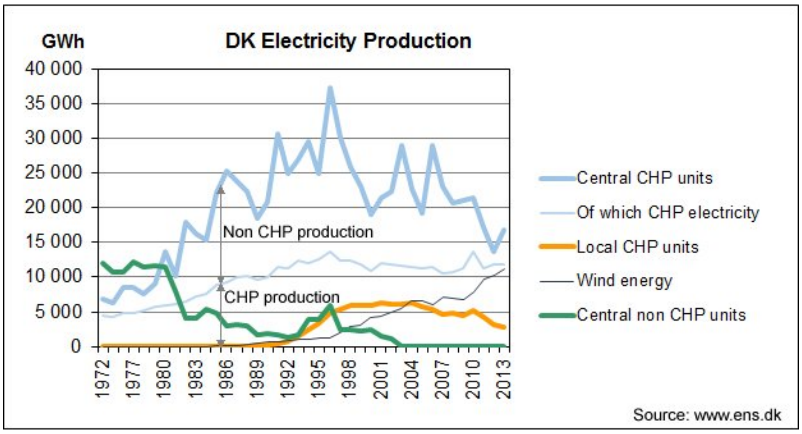

Fig. 4 Non-CHP units were phased out after the oil crises

Subsidies were necessary to persuade local communities to enter into binding agreements with the gas companies. The main subsidy ("grundbeløbet" or "the basic amount") would last until 2018. The experts forecast steadily increasing energy prices, so by 2018 the projects were expected to be viable without subsidies. Consultants made promising feasibility analyses, which were not always borne out in practice[2].

[2] Some of the smallest CHP systems were established in rural areas with long distances and without DH distribution facilities. These CHP systems are known in Denmark as "Wilderness Projects". The fuel contracts are a major problem. The local CHP units are liable for the debt of the local gas supplier and must purchase rather expensive natural gas, consequently heating is very expensive in these areas and the houses are difficult to sell. Special subsidies have been introduced, and in a few cases permission was given to replace CHP by the use of wood pellets in the backup boiler.

The Wilderness projects were results of poor consulting. Nobody accepts responsibility, but the significant liabilities remain with local consumers.

The new power plants are the "**local**" or "**decentralized** CHP units". By 1 January 2011, there were 686 such units with a total capacity of 2,632 MW with an average capacity at 3.8 MW[3]. (Sixteen units are smaller than one MW).

Increasing Share of District Heating

Over the period 1972 to the present, although new and better houses were built so the heated area is probably much larger than before, demand for space heating has remained much the same, but the composition of heat sources has changed radically. District heating has become dominant, see fig 5.

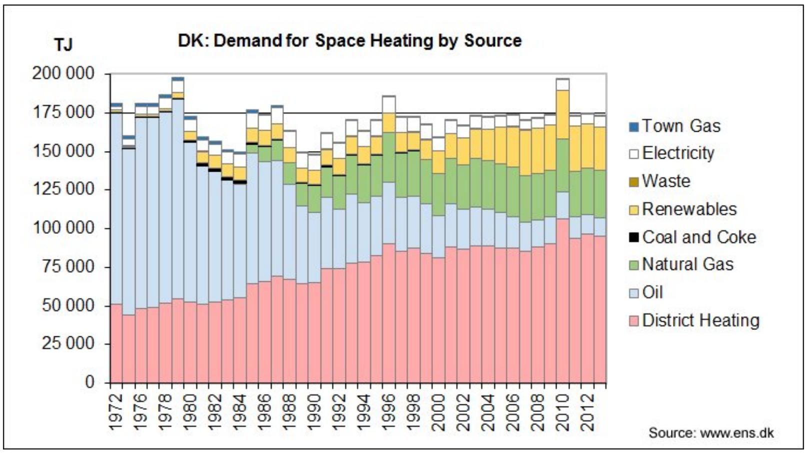

Fig. 5 DH supplied 55% of Danish space heating in 2013

The CHP share of district heating increased from 28% in 1972 to a peak of about 76% in 2001, see fig. 6.

Fig. 6 includes both heat demand and distribution losses. Therefore the data in fig. 6 are different from the corresponding data in fig. 5.

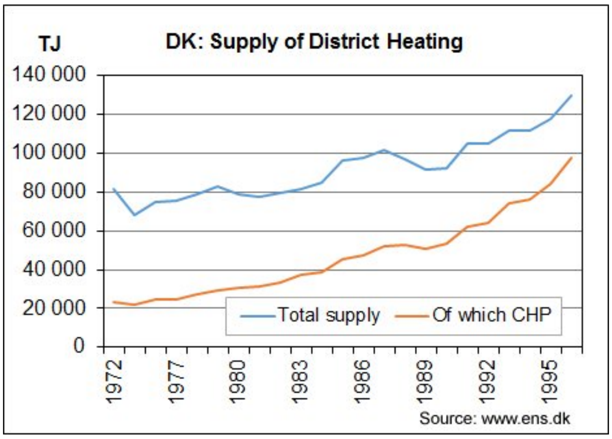

Fig. 6 CHP share of DH increasing from 28% in 1972 to 76% in 2001

The Flexibility of CHP Systems

Heat and electricity have very different annual and diurnal demand variations; the electricity demand is a little lower in summer than in winter but the heat demand is much lower. In fig 7, the light blue area is the CHP electricity production, which is proportional with the heat demand.

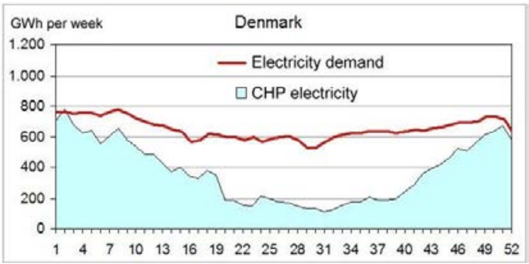

Fig. 7 The heat demand is very low during the summer season

[3] Energinet.dk: Analyseforudsætninger 2011-2030

During the cold season, the CHP production is of the same magnitude as the electricity demand. The supply of wind energy on top of the CHP production creates an energy surplus during winter. Both CHP electricity and wind power have low marginal costs. Contrariwise the marginal cost of electricity production during the summer season is high. Therefore, Denmark usually exports electricity during the winter and imports it during the summer, see fig 8.

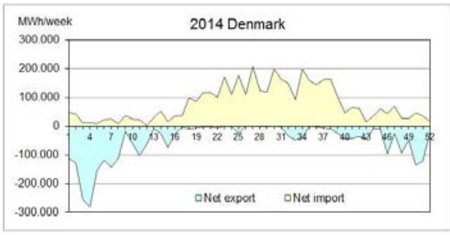

Fig. 8 Danish imports/exports of electricity in 2014

CHP systems can be designed in different ways and with different characteristics. The central power plants in Denmark are situated by the sea.

Due to their seawater cooling the central power plants can be operated partly independent of the heat demand. Steam for heat production is extracted in an appropriate quantity from the turbine hence these units are called **extraction units**. The extraction of steam for heating causes a slight reduction of electricity output and reduces the need for cooling by seawater.

Fig. 9 shows the possible combinations of electricity and heat production for an extraction unit. In **counter pressure operation,** the total thermal efficiency is about 90%. The chart shows a case of combined operation with 250 MW electricity and 150 MW heat. The first 102 MW electricity are in counter pressure mode with 90% efficiency. The additional 148 MW require cooling by seawater (**condensing operation**). The thermal efficiency of the additional 148 MW is about 45%.

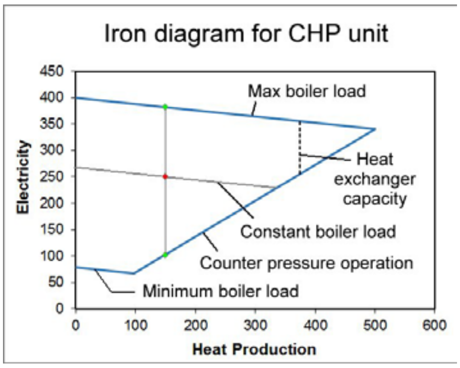

Fig. 9 Operating limits for an extraction unit

The local CHP units do not have cooling by seawater, but by the district heating system. Therefore electricity production is directly proportional to the heat load. This constraint is normally alleviated by hot water storage and in some cases also electric heaters. The hot water storage can usually keep enough to meet the maximum heat production for some hours, and allows electricity production to be shifted to periods when the market price of electricity is high. This type of flexibility is extremely useful for balancing the variations of wind and solar power.

Resistance heaters and large heat pumps can add further to the flexibility of both local and central CHP systems. Analyses have shown that the need for foreign balancing services can be reduced significantly by an optimal interaction between district heating systems and the power system.

Hot water stores have also been installed at some of the central CHP units.

Declining CHP production

Fuel prices are still volatile, but not as high as forecast. Under the present conditions, most of the 686 local units would be unprofitable without subsidies. Therefore, owners of local CHP units have responded by saving operating hours. Gas turbines and diesel engines need a thorough and expensive overhaul after a certain number of operating hours. If the continued operation of a unit is uncertain after 2018 some owners prefer to save remaining operating hours for periods with very high prices in the electricity market and use gas fired backup boilers for the remaining heat production. This is the background of the declining local CHP heat production, see fig 1.

The CHP heat production from the central units has been stable for the last 20 years, but the electricity condensing production (non-CHP) has been decreasing from about 10-20 TWh per year to about 5 TWh per year, see fig 4. The revenue from sale of electricity and heat is insufficient to keep all units in operation, and consequently the available capacity of central power plants has been reduced from 7,069 MW on 1 January 2006 to 4,150 MW by 1 January 2014[4]. Some units have been mothballed and others are decommissioned. A consequence of the reduced capacity is that Denmark is no longer self-sufficient with dispatchable power in all situations.

The CHP fraction of DH has decreased from 76% in 2001 to 60% in 2013, see fig 10.

Other targets for the energy policy have replaced the wish for a high CHP share. By 2020, wind energy must provide 50% of the electricity consumption, and Denmark must be free of fossil fuel by 2050. Officially, the energy policy still includes CHP, but the conditions are less favourable. It is uncertain what will happen to “the basic amount” after the subsidies finish in 2018. In addition, the economics are hit by the fall of average prices in the electricity market due to the increasing supply of wind energy.

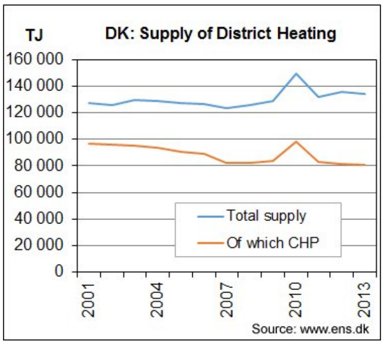

Fig. 10 CHP share decreasing to 60% of DH in 2013

Comments

It is difficult to predict the capacity of local and central units by 2020, but the available capacity is likely to decrease further. Therefore, a further reduction of the CHP heat and electricity production is also probable.

The paradox is that the power system can be efficient and flexible with a carefully balanced capacity of CHP, wind power and solar power. However, when the target is wind energy beyond 50% of the electricity demand, then thermal power including CHP must reduce. The district heating systems must find other ways of meeting their load and the power system must find the necessary flexibility elsewhere.

Denmark is a part of an international electricity market, and the development of wind and solar power in Germany has a strong impact on the market prices in Denmark. Therefore the power system in Denmark cannot be designed without considering the development in neighbouring countries and it can be expensive to set national targets too much more ambitious than the neighbours do.

It should be kept in mind that a power system must meet different requirements such as security of supply, economy, pollution control and climate policy. Stable operation requires a

[4] Energinet.dk: Analyseforudsætninger 2006-2015 and Analyseforudsætninger 2014-2035

certain level of local system services (or ancillary services) to be available and online at any time. Typical large power plant units provide a wide range of these services. Wind parks and photovoltaic systems can be equipped for supply of some ancillary services, but not for the full range. Under the present circumstances, it is necessary to have a certain spinning capacity of large units for the maintenance of stable system operation. Both Germany and Denmark are considering alternative measures in order to reduce the necessary spinning thermal capacity.

During the 1980s a comprehensive development effort in Denmark resulted in a generation of outstanding thermal power plants, which were 10-20 years ahead of comparable concepts in other countries. Now the design departments have been closed. Very little has been done to specify and develop a fossil-free and dispatchable CHP plant, which must be profitable even with a low capacity factor. Nobody has presented a vision for the perfect power and heating system for the future.

The future is not far away. The lifetime of the thermal power plants in Denmark is running out. We will need successors within a few years.