

LESSONS FROM EXTENSIVE COVERAGE OF ELECTRICITY DEMAND WITH COGENERATION IN TWO EUROPEAN COUNTRIES

by

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Abstract

Cogeneration installations currently produce 40 to 50% of the electricity in Denmark and The Netherlands. The transition from traditional central power production to extensive cogeneration took place in less than two decades. The process started with high energy prices after the oil crises in the 1970ies. Strong government support and a restructuring of the energy utilities appeared to be necessary to remove the structural, psychological and bureaucratic barriers. Subsidies were required to overcome economic hurdles resulting from existing tariff systems. Technologies were improved with respect to performance, emissions and reliability. The research laboratories of the major gas companies assisted manufacturers in this. Training, conferences, workshops and short courses helped to spread the required knowledge and experience. Unfortunately, the recently started liberalization process resulted at least temporarily in very low electricity prices while the price of gas is relatively high. Renewed networking has started to overcome the negative effects on cogeneration. Fortunately, many policy makers, especially in the European Commission, are aware that a secure and efficient energy supply is crucial for the economy.

Key words: cogeneration, barriers, government support, boundary conditions, Europe

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INTRODUCTION

In Denmark and The Netherlands, between 40 and 50% of the total electricity demand is produced in cogeneration plants, where the bulk of the heat released is utilized for heating purposes. The energy savings result in a substantial reduction in total primary energy supply (TPES) to these countries. The application of cogeneration was extensively instigated and stimulated by the national governments. Initially, after the oil crises in the 1970ies, the aim was purely to save fuel. Later, environmental concerns connected with fuel-related greenhouse-gas emissions became a major reason. Currently, increased security of supply and reduced electricity transmission costs are additional motives for promoting distributed generation with cogeneration.

A secure and low-costs energy supply is a crucial factor for the economy. The average energy intensity of the world's economies amounts to 12 MJ/US\$ (1990 US\$) (ref.1). Energy is needed for all sectors in the economy, be it commodities, products, services or experiences. With increasing wealth levels, electricity demand appears to grow stronger than linearly with Gross Domestic Product (GDP) (ref .2). In modern society, electrical and electronic equipment plays such a major role in enhancing productivity that an undisturbed electricity supply is of utmost importance. Consequently, electricity generation should not only be very efficient but also very reliable.

This paper will first show the boundary conditions that appeared to be required for a large-scale introduction of cogeneration. A first requirement is the availability of natural gas together with a coinciding demand of electricity and heat. The barriers encountered will be explained as well as the solutions. These barriers had both a social, regulatory, technical and economic background. Government intervention was necessary to remove them. It will be shown how emission legislation ultimately resulted in improvements in technology. It will also be explained why the recent liberalization of the electricity market makes it difficult to keep especially the smaller scale units financially attractive. The paper ends with a series of conclusions useful also for the situation in North America.

BOUNDARY CONDITIONS

Availability of natural gas

Both Denmark and The Netherlands depend for hard fuels (coal) and liquid fuels very much on imports. Liquid fuels are essential for transportation and coal was seen as the major fuel for electricity production. The discovery of large gas fields in the north of

The Netherlands and in the North Sea made natural gas an attractive fuel for both countries. Gas was considered as a prime fuel for cooking as well as for heating of buildings and processes. If only the production and transportation costs of gas would be considered, its price could be very low and that might give rise to wasting of the fuel. Moreover, too low a price might disrupt the economic balance on the long run. Therefore, the price of gas was officially linked to that of oil, as its first alternative, in order to take into account the real value of the fuel for the economy. Yet, the price of gas was always lower than that of fuel oil. Both Denmark and The Netherlands have extensive gas grids for already two to three decades.

Simultaneous demand for electricity and heat

For cogeneration, satisfying a local heat demand must be leading for achieving the desired combined energy efficiency of close to 90%. This heat demand should be present during a substantial time frame over the year for creating sufficient running hours to justify the capital investment in a cogeneration installation. Such conditions are often present in process industries running around the clock for long periods of time. In parallel, much electricity in Denmark and The Netherlands goes to lighting of homes and commercial buildings; those are also the major applications for low-temperature heat. In Western Europe, close to the sea, the climate is moderate but heating is required during a large part of the year. The mean ambient temperature in Denmark is 16 °C in summer and 0 °C in winter. In the Netherlands, it is about the same. Such a climate is rather suitable for cogeneration. At least statistically, there is a good correlation between heat demand and electricity consumption. Locally, the situation can require the exchange and distribution of electricity. As an example, the many greenhouses in both countries require a lot of heating but their electricity demand, especially in the daytime, is relatively low. Therefore, cogeneration installations of greenhouses are often equipped with heat storage tanks and their excess electricity can be transferred to the local grid.

Table 1: The amount of fossil fuel used for electricity generation and for heating purposes (unit: PJ = 10¹⁵ joule; data mid 1990ies, ref 3).

Country	I	SF	CH	NL	UK	DK	S	D	J
Electricity	1428	285	10	540	2178	136	100	3726	4970
Heat	2234	525	365	1100	3236	473	632	5746	10258

Table 1 gives the fossil fuel input for electricity generation and for heating purposes for some countries. In The Netherlands, the amount of fossil required for heating purposes is close to double that for electricity production. In Denmark, this factor is close to three. That means that at least in theory, sufficient application for the heat released by electricity production can be found. In countries with a hotter climate, the need for heating is much smaller and therefore it will be more difficult to find a useful application for the heat. In that case, the electricity demand can be relatively high because of cooling requirement. The United Kingdom is an example where electricity finds much application for space heating; hence the relatively high fuel input for electricity

production. Sweden and Switzerland use much nuclear power and hydropower. Because of the large differences in climate over the country, the USA are too large for analyzing possibilities for cogeneration with simple data such as in table 1; an approach per state would be more appropriate.

Suitable technology

For cogeneration, smaller generation equipment is required than for large power plants. For larger process plants, special industrial combustion turbines are used. For intermediate-size process plants where much steam is required, aero-derivative combustion turbines are a suitable solution. For district heating, commercials (hospitals, offices, hotels) and smaller process plants (bakeries, agricultural drying, dairy industries), reciprocating engines are the prime movers of choice. Currently, gas engines are available in the power range between 1 kW and 17 MW per unit. The reciprocating engines are primarily automotive and marine diesel derivatives. To justify the investments in cogeneration, often a high electrical efficiency is required, also at reduced loads. Currently, the investment in a complete cogeneration installation is around 500 US\$ per kW of electric power. Standardization in design of the installations has helped to keep costs down. Next to a good reliability and availability, a good predictability of the maintenance intervals is desired. Moreover, the exhaust emissions and noise level should comply with the ruling legislation. Both engine and turbine technologies have been subject of a learning curve in the past decades. Some installations have accumulated up to 170000 running hours. Figure 1 summarizes the different aspects of importance for a cogeneration installation.

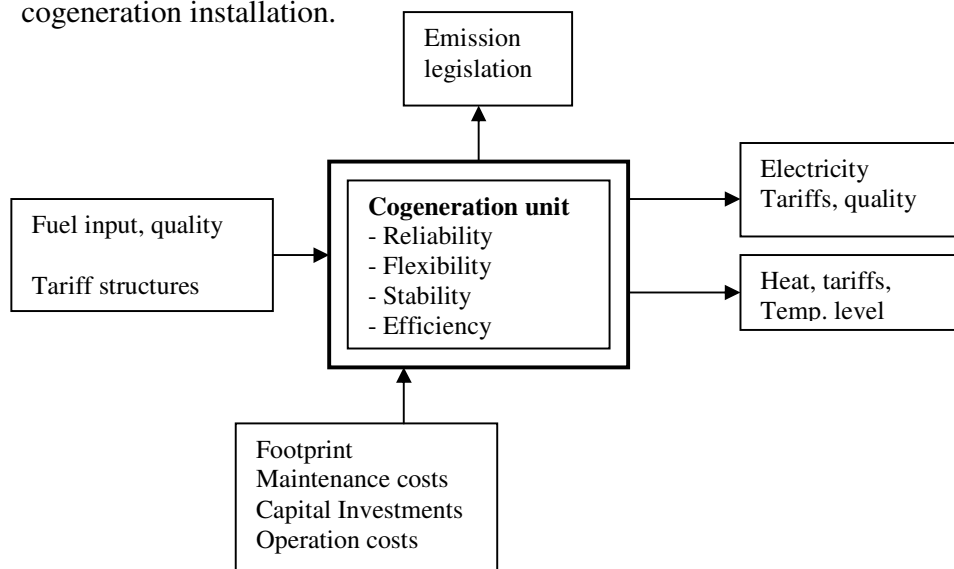


Figure 1: The many aspects around a cogeneration unit.

Accessible electricity distribution grids

From a national point of view, fully exploiting each heat demand with cogeneration would save the maximum amount of fuel. In many cases, that would mean a much higher electricity production than needed at the site. For large process plants, the cogeneration unit has sometimes been laid out in such a way that it covers all electricity need while flexibility in heat production is created by burning extra fuel, often with so-called duct burners in the exhaust of turbines. For optimum fuel efficiency, 'exporting' of any excess electricity to outside the premises would be the best option. This also applies for interesting heat sinks such as greenhouses. However, in the beginning, most electricity companies could block private generators from their grid or refuse to pay any realistic compensation per kWh sent into the grid. Figure 2 shows a traditional energy supply structure where production and distribution were united in one utility company. Gas, electricity and water were strictly separated. Government interference was necessary to open up the grids and guarantee sufficient compensation for the electricity delivered.

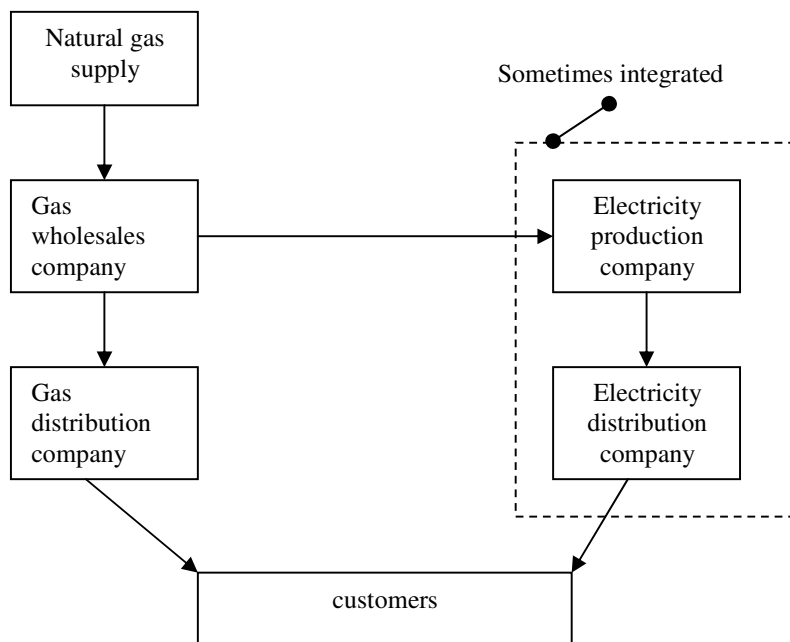


Figure 2: The traditional separated energy supply structure

HISTORICAL OVERVIEW

Structural measures

In the early 1980ies, an increasing price of electricity made large industries and some private companies to install their own generating equipment, often just for running in non-export mode. Some integrated (= gas and electricity from the same utility) energy distribution companies in Denmark and The Netherlands installed their own engine-driven cogeneration plants, especially for district heating and for the supply of heat to

greenhouses. The large gas-pipeline companies stimulated this since they saw it as an opportunity to sell extra gas. The European Commission tried to reduce the use of natural gas in central power plants; the relatively low fuel efficiency of such power plants was seen as wasting the high value of the gas. However, natural gas for cogeneration was stated to be a prime application. The traditional electricity companies considered this development as an infringement on their monopoly and resisted local generation as much as possible. Their major objections were related with security of supply, safety and stability of the grid. Basically, a traditional bureaucratic system and fear of change were the reasons that electricity companies were against cogeneration.

In Denmark, legislation was used to force utilities to use cogeneration in combination with district heating systems as the first choice. In The Netherlands, production and distribution of electricity were separated resulting in a sudden interest of distribution companies to participate in cogeneration installations ('the generating blood was thicker than water'). Many gas and electricity companies were integrated into larger enterprises with special departments for stimulating cogeneration. The government together with the energy distribution companies started a small independent Project Bureau (PWK) for the stimulation of cogeneration. This bureau had to pinpoint the bureaucratic, cultural and economic barriers for combined heat and power and indicate directions for solutions. Next to that, they had to make the connected stakeholders enthusiastic for the concept of cogeneration. Ultimately, PWK is the forerunner of Cogen Europe and the International CHP Association.

Economic measures

Notwithstanding the positive attitude of the governments towards cogeneration, investing in the installations was not always attractive. A major aspect was that the traditional generating utilities never applied the economic concept of amortization and interest on capital. Any capital required was raised via the tariffs paid by the customers. Indirectly, the customers paid the capital costs via prepayment. Consequently, if a power station came close to the end of its technical life after e.g. 30 years, money was available for new investments. For private investments, the situation is completely different. Private investors often require a payback time of less than 5 years; the interest rate considered can be up to 10%. Also, for cogeneration providing heat during the colder seasons, the number of operating hours is considerable lower than when running around the clock. Table 2 illustrates the effect of the different approaches on the 'capital' costs.

Table 2: The effect of load duration, amortization method and interest rate on the capital costs (presumed investment: 500 US\$/kW).

		Utility approach		Private approach	
		30	30	5	5
Required pay-back time	year	30	30	5	5
Interest rate	%	0	0	8	8
Running hours/year		3000	8000	3000	8000
Specific capital costs	\$cts/kWh	0.55	0.21	3.99	1.91

Although table 2 gives a somewhat simplified picture, it clearly shows the mechanisms involved. In order for cogeneration to overcome this hurdle, the governments in both Denmark and The Netherlands introduced a compensation package. In Denmark, electricity from cogeneration received a subsidy exceeding 1 \$ct/kWh. In The Netherlands, a subsidy of 30% on the investment capital was given. That equals 1 \$ct/kWh in case of 3000 running hours during the first 5 years (presumed amortization time 5 years). A subsidy on the investment is probably a better answer to the basic hurdle for private investors, which is the required short payback time. Some parties argued that it was not fair to use tax money to subsidize cogeneration. However, the general public had always subsidized the traditional energy sector via the tariff system.

Another economic problem was the differentiated tariff system for natural gas. The tariff for large-scale users is linked to heavy-fuel-oil prices and the tariff system for smaller users to the price of light fuel oil. Next to that, the tariff system had a set-up that more had to be paid for the first blocks of quantities of gas. That means that large users on the average pay much less than smaller users. This barrier is amplified if the number of running hours of the small plant is reduced. In The Netherlands, a special gas tariff for cogeneration was introduced. This removed at least part of the disadvantage in fuel price compared with large central power plants.

Technology developments

In the 1980ies, much effort was put into the development of the prime movers, i.e. the combustion turbines and reciprocating engines. The reliability and controllability had to be improved drastically. This required a multi-disciplinary approach, with input from engine-part designers, lubrication oil suppliers and providers of control and monitoring equipment. Also the proper matching of the installations with the existing energy infrastructure and with heat demand had to be learned. In many cases, when the cogeneration installation had to run in parallel with a boiler in cold situations, a high return temperature prevented the operation of the cogeneration unit. Sometimes the combination of different heat-exchanger materials created severe corrosion problems resulting in damage to the installation. With the help of the engine industry and the research laboratories of the major gas companies in Denmark and The Netherlands, these problems could be solved. Currently, cogeneration plants can be installed for around US\$ 500/kW with very short lead times compared to large central stations.

The rapid rise in cogeneration power gave rise to concern about the NO_x emissions. Denmark and The Netherlands emitted much acidifying components, SO_x from coal-fired power stations, NH₃ from agriculture and NO_x primarily from increasing road traffic. The total NO_x emission averaged over all energy use in The Netherlands was close to 210 g/GJ. The specific NO_x emissions of both reciprocating engines and gas turbines was generally much higher since up till then, NO_x was never considered a problem from an emissions point of view. Lean-burn combustion techniques appeared to provide the solution. With fuel-air mixtures much leaner than stoichiometric, the peak temperatures in the combustion processes could be reduced to such an extent that the

NOx production became sufficiently low. An interesting side effect was that cooler combustion reduced the temperature load of the engine parts resulting in a longer part life. Moreover, for reciprocating engines, it resulted in a much higher specific power per engine and in an improved efficiency. Currently, reciprocating gas engines are available with a shaft efficiency of close to 47% based on the lower heating value of the fuel (ref. 4). Without additional exhaust-gas treatment, the specific NOx emissions of gas engines can be below 70 g/GJ (ref. 1).

The use of distributed generation connected with cogeneration did not have negative effects of the grid as was initially feared by the traditional energy companies. In practice, the reliability and voltage stability of the grid were even improved. In many cases, expansion of the grid could be avoided because of the local supply of electricity (ref. 4). Moreover, substantial transmission losses could be avoided.

The learning curve

The relatively rapid transition to reliable and efficient cogeneration was greatly helped by an extensive learning process. Frequently, conferences were held addressing the technical, economic and structural issues. Many workshops and short courses were held to train the necessary workforce. Annually, one-year postgraduate courses were given for educating personnel at a higher level. Many pioneers from the industry as well as university lecturers co-operated in this process. Magazines regularly published articles on the subject. Moreover, user groups per engine brand or type were started for optimizing the feedback of operating and maintenance experience to the manufacturers. All these actions helped in quickly making cogeneration into a mature industry.

THE CURRENT SITUATION

Recently in The Netherlands, the government has rapidly followed the recommendations from the European Commission for liberalization of the electricity sector. That means that free competition exists now in the electricity production market. As a result, electricity producers are selling their kilowatt-hours at prices close to the fuel costs in order to push out the competition. The liberalization also required a full restructuring of the energy distribution companies from utility-type operation to companies owned by private shareholders. As a result, many jobs disappeared and many individuals involved in promoting cogeneration were transferred to other positions. Moreover, the market for fuel gas is not yet fully liberalized resulting in relatively high fuel costs for the smaller-scale cogeneration plants. Currently, the larger cogeneration plants in industry are still running with the necessary profit. The smaller, mainly reciprocating-engine-driven units suffer at the moment from negative boundary conditions. Private cogenerators do not have the means to participate in the energy trading business; they are generally too small for that. And basically, they need the benefits of higher electricity prices during peak hours because of their general inability to run over 8000 hours a year. However, the cogeneration industry combined in Cogen Nederland, users as well as suppliers, has started renewed promotion activities towards

the policy makers. This is stimulated by the strong urge from the European Commission to the European countries to use cogeneration as much as possible in order to reduce the imports of fossil fuel.

THE LESSONS LEARNED

1. Cogeneration of heat and electricity helps to save fuel. Translated to USA situation: if 40% of the electricity demand is generated by cogeneration, a 10% reduction in total national fuel consumption will be achieved (ref. 1). Also, much less CO₂ will be emitted.
2. Government assistance was required in Denmark and The Netherlands to remove the barriers for cogeneration created by the original players.
3. Information and knowledge exchange between stakeholders was essential for cogeneration to rapidly become a mature technology.
4. Extensive cogeneration needs the use of many smaller heat loads. Regulators should safeguard at least the smaller cogenerators (< 50 MW) from extensive trading efforts and negative effects from tariff systems and from temporarily negative competition effects resulting from a free energy market
5. The exhaust emissions of cogeneration units are low enough to allow an operation at locations where a heat application can be found.
6. The distribution grid for electricity generally benefits from cogeneration: the voltage stability and reliability in both Denmark and The Netherlands were only positively affected. Moreover, investments in grid expansion could often be avoided.
7. The prices of cogeneration systems are quite competitive compared to central power plants while their lead-time is very short.

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