LOCAL ELECTRICITY GENERATION: AN EVALUATION OF ITS VALUES FOR THE DISTRIBUTION OF ELECTRICITY

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ABSTRACT

The current energy efficiency of the global electricity sector is only 32.5%, which negatively affects the security of energy supply, the global emissions and the costs. Major reasons for the low efficiency are high distribution losses, the use of outdated technologies and running at low loads. These results are based on an analysis of electricity production and distribution in five different European countries (data 2004). A much better energy efficiency can be obtained with extensive use of high-quality local electricity production and cogeneration, resulting in about 20% reduction in primary energy supply to a country.

INTRODUCTION

A reliable supply of electricity is essential for modern life. Currently, the world uses almost 14.5 PWh of electric energy per year. The mean net energy efficiency of the electricity sector is just 32.5 %. In 2005, the energy needed for electricity generation amounted to 34% of the total primary energy supply (TPES) to the world. This makes the electricity sector the single largest energy user by far. Electricity has therefore a major impact on the security of fuel supply and the price development of fuels as well as on emissions. The International Energy Agency expects that the net efficiency of the sector will increase slightly to reach only 36% by the year 2030. Then, almost 40% of the world's TPES goes into electricity production.
This paper will first analyse the background of the low energy efficiency of the electricity sector. This analysis finds its base partly on work done for the ELEP project carried out with support from the European Commission. ELEP is short for European Local Electricity Production. The generation performance in five member countries of the European Union, each being different in generation methodology and wealth level, served to determine and illustrate the background of the low energy efficiency.
Next, this paper will show how an extensive use of local generation helps to improve the energy performance of the electricity sector. Local generation is of value since it enables the application of cogeneration, where the bulk of heat released during the process of energy conversion can be used. Moreover, local generation can supply electricity with a high net efficiency when and where it is needed during times of peak demand. In addition, certain technologies for local generation have a high flexibility for fuel types, ranging from natural gas to most liquid fuels.

ENERGY USE IN 5 EU COUNTRIES

The five member countries of the European Union chosen for analysing the performance of the electricity sector are Denmark, Germany, Italy, Poland and Portugal. Denmark has the highest wealth level and uses much wind power and gas-fuelled cogeneration. Nuclear energy, lignite and coal dominate the German power system, while that country derives its wealth primarily from industries. Italy is a larger southern country with much capacity from natural-gas-fuelled generators as well as hydro power. Poland only recently joined the EU and has an aged electricity production capacity running on coal and lignite. Portugal is a small southern country with diverse generation methods. The TPES per capita (GJ/cap) does not differ much in the five countries selected (see table 1). However, the Energy Intensity of the economy shows large variation. In Poland, almost a factor 5 more energy is needed for the same amount of Euros (2004 value) in GDP as in Denmark. It is true that the general purchase power parity (PPP) of a Euro is a factor 2.4 higher in Poland than in Denmark, but fuels and electricity are considered as global commodities in this paper. The electricity supply per capita shows the same tendencies as TPES. The electricity use per € of GDP is lower in the richer countries than in the poorer countries. System use and distribution loss cause the difference between gross and net electricity supply/capita.

Table 1: Key energy related economic data of the 5 selected EU countries (year 2004) [1].

Property	Unit	Denmark	Germany	Italy	Poland	Portugal
Gross Domestic Product/capita	k€/cap	40.1	34.6	22.0	5.3	13.6
Total Primary Energy Supply/cap	GJ/cap	155	176	134	101	104
Energy intensity TPES/GDP	MJ/€	3.87	5.09	6.09	19.06	7.64
Gross Electricity Supply/capita	MWh/cap	6.97	7.24	5.90	3.75	4.91
Gross Electricity Supply/GDP	kWh/€	0.174	0.209	0.268	0.708	0.360
Net Electricity Supply/capita	MWh/cap	6.10	6.23	5.09	2.61	4.28
Net Electricity Supply/GDP	kWh/€	0.152	0.179	0.231	0.492	0.314

Table 2: The economic impact of fuel costs for electricity.

country	Fuel costs/GDP (%)	Fuel costs/imports (%)
Denmark	0.7	1.9
Germany	0.5	2.0
Italy	1.0	5.3
Poland	2.7	9.1
Portugal	1.1	3.2

This paper presumes commodity prices for fuel of 3.5 €/GJ for hard coal, 3.0 €/GJ for lignite, 7 €/GL for natural gas and 10 €/GJ for oil. In reality, these prices will vary, but the average price ratio will stay rather constant. Based on these prices, the relative burden of the fuel costs for electricity generation on the economy can be calculated. Table 2 gives the results. The costs as a percentage of GDP are very low, which illustrates that electricity has a high positive leverage for the economy. Yet, for a less wealthy country such as Poland, the fuel costs are more pronounced. It is also possible to express the fuel costs as a percentage of a country's import value, even if the fuel is indigenous, since the fuel produced in a country can be exported. In that case, the monetary value of the fuel is substantial in Poland and, albeit to a lesser extent, also in Italy and Portugal,.

REASONS FOR THE LOW EFFICIENCY

The energy efficiency of the electricity generating process, or the gross efficiency, in the 5 countries varies between 44 and 34 % (figure 1). The efficiency is based on the lower heating value (LHV) of the primary energy. Internal use by the system and network loss make that the net efficiency, or supply efficiency, ranges between 38% and 24%. The low net efficiency in Poland results from the combination of a low generating efficiency and high system and distribution losses. The generating efficiency depends on the conversion technology used, the age of the power plant and the load

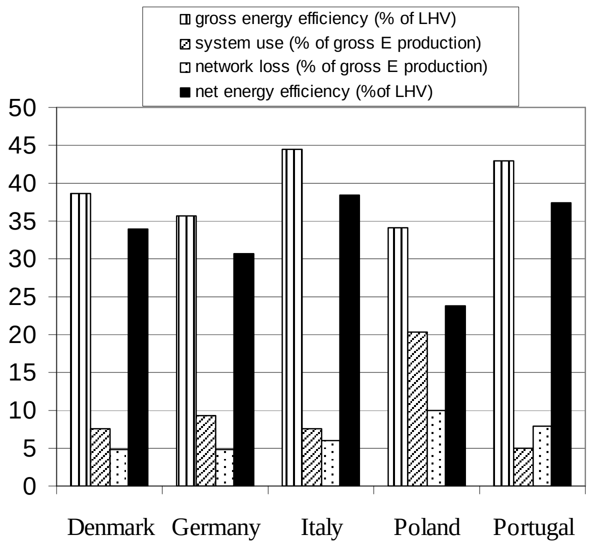

Figure 1: The electricity production efficiency and the electricity supply efficiency in 5 EU countries (year 2004).

pattern of the generators. Modern natural-gas-fuelled combined cycle plants can have a gross efficiency of over 55%, but only at rated load under stationary conditions. Old coal and lignite fuelled power plants can have a gross efficiency under 30%, especially while running below their rated load with much starting and stopping. Hydro based power plants can rapidly follow load changes and that is of much benefit since then the fossil-fuel based units can run at rated power. Often, imports and exports of electricity serve to balance the dynamics caused by demand fluctuations.

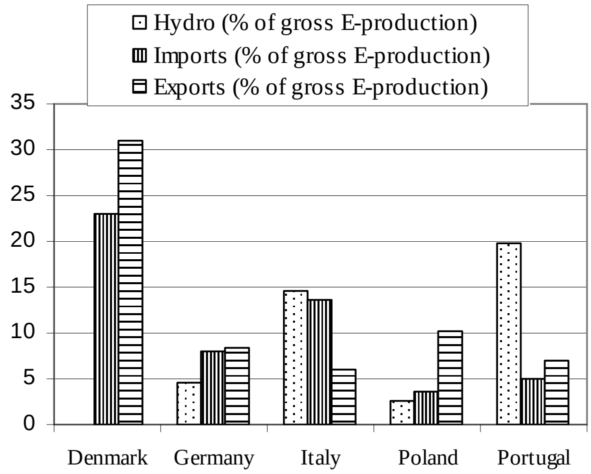

Figure 2: Facilitators for dealing with demand and production dynamics (year 2004).

Figure 2 gives the relative share of hydro and cross-border electricity in the five countries. Portugal and Italy have quite some hydro power. Denmark uses imports and exports extensively, primarily because 16.3% of their electricity comes from wind power that is uncontrollable by nature and causes production fluctuations. Poland and Germany appear to meet the demand fluctuations primarily with their own equipment, resulting in reduced fuel efficiency.

The mean efficiency of the power plants categorised per fossil fuel type is shown in table 3. Germany and Poland use their coal-fuelled power plants for intermediate and peaking load, while Denmark and Portugal use them for continuous base load. Italy and Portugal reach relatively high efficiency with natural-gas-fuelled combined cycles. Countries that have much lignite and peat try to use those fuels for base load.

Table 3: Mean power station fuel efficiencies in 2004 [1].

country	Hard coal	Lignite/peat	Natural gas
	% of LHV	% of LHV	% of LHV
Denmark	39.0	-	38.7
Germany	35.8	36.1	32.4
Italy	37.5	-	47.2
Poland	31.3	39.3	27.9
Portugal	39.6	-	50.6

Table 4: Fraction of total electricity production per primary energy source (year 2004)

Primary source	unit	DK	D	I	PL	P
Nuclear	%	-	27.5	-	-	-
Hard coal	%	46.1	22.3	15.0	55.5	32.9
Lignite	%	-	26.0	-	36.4	-
Natural gas	%	24.7	10.1	42.8	2.0	25.9
Oil	%	4	1.7	19.4	1.6	12.6
Hydro	%	-	4.6	16.5	2.4	22.5
Wind	%	16.3	4.2	0.6	-	1.8
Biomass	%	8.8	1.9	1.8	-	4.0
Other	%	0.1	1.7	3.9	2.1	0.3
Total	%	100	100	100	100	100

Table 5: Utilisation factor of generating capacity per primary energy source (production/(capacity · 87.60)

Energy source	unit	DK	D	I	PL	P
Nuclear	%	-	92.7	-	-	-
Hard coal	%	?	50.6	57.1	62.6	95.5
Lignite/peat	%	-	81.9	-	68.6	-
Natural gas	%	38	36.0	47.8	44.9	96.5
Oil	%	-	22.7	39.5	-	52.5
Hydro	%	-	38.6	27.5	18.5	23.9
Wind	%	24	17.3	18.7	-	16.8
All	%	34.6	55.9	42.6	55.4	40.5

Tables 4 and 5 show that nuclear and lignite-fuelled power plants provide for the German base load; coal-fired plants cover the intermediate and peak demand. In Portugal, coal and gas plants run most of the time at full capacity, while hydro (see figure 2), oil and some imports take care of the demand fluctuations. The variation in demand from season to season is much less in Portugal than in e.g. Germany and Poland. The difference in local climate is responsible for that. This also explains the high utilisation factor of the coal and gas-based plants in Portugal. Hydro, oil and imports cover the demand fluctuations in Italy. In Denmark, gas-fuelled plants and much import and export take care of the load fluctuations.

Steam-based power plants (lignite, coal, nuclear and the steam part of combined cycles) have difficulty in responding rapidly to load changes. A modern coal-fired plant can only increase its output by 3% of its rated power/minute. Throttling part of the steam in a bypass helps to improve the response to load changes albeit at the cost of a much lower fuel efficiency. This is one of the reasons that the generation efficiency of the electricity sector is so low in Germany and Poland, next to the already mentioned outdated equipment. The interesting aspect in this is that the average utilisation of the generators in Germany and Poland is quite high. With their typical demand patterns, their utilisation of 55% requires additional capacity. This is an interesting opportunity to renew their production approach. One should notice the low utilisation factor for wind capacity in all countries, ranging between 17 and 24%. This is typical for wind power, where due to wind speed variations even the best off-shore site cannot reach a higher utilisation than 30%. This means that the effective capital investment for wind power is much higher than that based on the nominal power. Moreover, the fact that the output of wind farms has this stochastic nature means that extra spinning and stand-by back-up capacity is always needed. Hydro energy is one of the good back-up providers, but that is not available in many countries. However, even the seasonal rain fall is quite unpredictable in some areas. In Portugal, the contribution of hydro power was 16 TWh in 2003 but only 10 TWh in 2004.

THE EMISSION ASPECT

Since the power sector is the single largest primary energy consumer, it can have a large impact on emissions. However, legislation in the EU is generally such that the stationary plants have much stricter limits for NO_x, SO_2, CO and particulates than the transportation sector that is responsible for about 20% of the fuel consumption. The power sector in the EU cannot be considered as a large polluter (apart from some plants in new member states) with respect to air quality. However, the relative contribution of electricity production to the CO_2 emissions, a major greenhouse gas, is quite high. Figure 3 illustrates this.

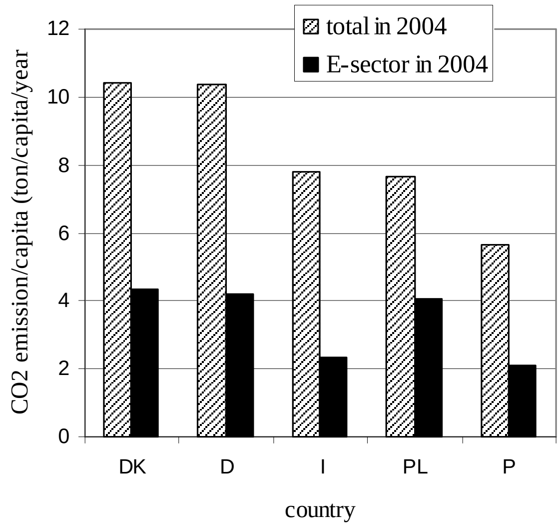

Figure 3: CO_2 emissions per capita in 5 EU countries, total and for the E-sector, data from [1] and [2].

Under the Kyoto Protocol arrangements, emitting CO_2 will cost money. Currently, emission rights for CO_2 are traded at around 15 €/ton, while expectations are that the price might rise to 40 €/ton in due time. For the 40 €/ton level, it would add 5.6 €cents/kWh in case of electricity generated from coal with only 25% net efficiency as is the case in Poland. This is a reason that CO_2 sequestration and renewable energy will gain in importance.

THE ROAD TO EFFICIENCY IMPROVEMENT

Outdated technology, part-load operation and high system and distribution losses are main reasons for the low energy efficiency of the electricity sector. Uncertainty about fuel and electricity prices makes investors hesitant under the current conditions of open electricity markets. That is why insufficient renewal of production capacity takes place. Diversification in primary energy sources, including renewables, is necessary to avoid that the sector becomes a captive customer of one fuel type. Gas, coal and nuclear will all play an important role in electricity production during the life span of power plants for the next four decades. Nuclear and coal-fired power plants are most suitable for large-scale base-load electricity production.

Local generation offers excellent possibilities for cogeneration of heat and power (CHP), emergency and back-up power as well as peaking power. The combined fuel efficiency of a modern CHP plant can reach 85% for an electrical efficiency of about 44%. Positioning such a plant close to the users means that the distribution loss is very low. Such high quality cogeneration saves 45% of the fuel input of separate production with the same conversion efficiencies, and still 25% if a combined-cycle plant with 55% efficiency had produced the electricity.

Figure 4 illustrates the performance of a gas-engine-driven cogeneration plant versus load. The electrical efficiency is quite flat in the load range between 100% and 70%, while the heat fraction remains constant. This means that such a generating set can vary its electrical and heat output without substantial sacrifice in efficiency. High efficiency systems with a power capacity ranging between 2 MW and 20 MW are available on the market. Their specific CO_2 emission is only 250 g/kWh if corrected for the use of the heat.

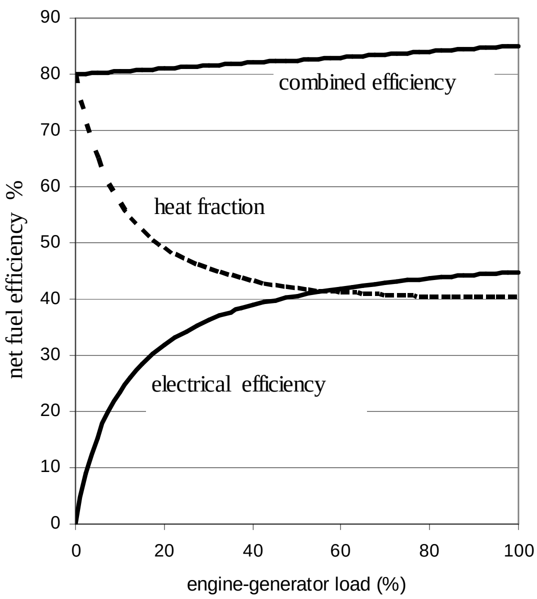

Figure 4: The electrical and combined fuel efficiency of a modern CHP plant.

Interesting examples exist where multiple engine-generator sets in parallel provide peaking power [3]. Such units have a power ramping rate of 50%/minute. The control strategy is such that an individual unit will not run below 90% of its capacity. If less power is needed, individual engines are being switched off while the opposite will happen when more power is needed. This means that peaking capacity can have an efficiency of about 44%. Cogeneration and peaking plants can also act as back-up power for wind power and in case of black outs. Examples of the latter can be found in hospitals, at airports and at process plants. Distribution system operators (DSOs) can use local power plants in their strategy to optimise the grid load and to increase the reliability of supply. The prime movers applied can be designed to run on liquid as well as gaseous fuels.

Extensive use of local generation with high-efficiency equipment, in combination with coal fired and/or nuclear units to cover base load together with combined-cycles for intermediate load, can easily increase the net efficiency of the electricity sector from the current 34% in Europe to roughly 42%. That is a reduction of about 24% in specific fuel consumption for the electricity sector or more than 9% in TPES. If 30% of the electricity is produced with CHP, an additional reduction of close to 10% in TPES is possible compared with separate production. The investment cost in CHP and engine-driven peaking power is certainly competitive, especially when considering the resulting lower investment in transmission and distribution grid [4].

SUMMARY OF THE VALUES OF LOCAL ELECTRICITY GENERATION

1. A combination of local electricity generation and central base-load power plants can reduce TPES and CO_2 emissions more than 15%. For Poland, it would roughly mean a 25 % reduction in TPES.
2. There are no additional costs for local generation compared to central generation additions; the costs are even lower if the reduced investments in transmission and distribution systems are considered.
3. Local generation can improve the supply reliability, which is of benefit for direct users and DSOs.

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