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Implementation of cogeneration systems in Greece

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The cogeneration systems of four auto-producers, which cover a wide range of electrical power, are compared. The two larger auto-producers use combined cycle gas turbines of types GE 9FA and GE 6 while the two smaller ones use gas turbines of types GE LM2500 and Ruston Typhoon (now Siemens SGT-100). The comparison is conducted in order to define the level of energy savings, operational cost savings and reduction of CO_2 emissions. On the basis of the results the implementation of cogeneration systems in Greece has been evaluated. Factors, which influence negatively cogeneration and how these can be eliminated, are presented.

1. Introduction

Cogeneration in Greece covers 3.4 % of the total produced electricity. This percentage is one of the lowest within the European Union, which indicates the low level of penetration of cogeneration technology in Greece. For year 2000, the total installed power was 706 MW_e, while the produced electricity was 3122 GWh. However, these numbers are in some way misleading as pointed out by Sarmentero (2003). From the total of 706 MW_e, 495 MW_e are from PPC's (Public Power Company) steam turbine power plants, which were transformed partly to cogeneration systems so that district heating systems could be implemented. But, from the 495 MW_e, only 34 MW_e are cogenerated while the other 461 MW_e are used only for electricity purposes which means that the heat produced is wasted to the environment. So the real installed power from cogeneration in Greece is 245 MW_e and the produced electricity is 1137 GWh.

The low penetration of cogeneration in Greece is due to several reasons. Greece is a Mediterranean country with a warm climate. This, in combination with the lack of heavy industry, hampers implementation of cogeneration systems.

The absence of natural gas as a fuel choice played a significant role. Natural gas offers the possibility for smaller consumers to use cogeneration while it is a clean fuel which can easily be handled.

Two other reasons are the complicated bureaucratic procedures necessary to install and operate cogeneration systems and the lack of know-how of cogeneration technology in Greece. As a result, investors are prevented from choosing cogeneration while they are directed to other energy sources in order to satisfy their energy demands.

Last but not least was the absence of liberalization of the electricity market, which has made it very difficult for cogeneration to compete financially in the market.

Of course, today the situation is different. This is mainly due to the worldwide high energy prices, so that technologies such as cogeneration are becoming competitive. In this paper, a comparison of four different auto-producers is carried out. In the first case, the auto-producers cover their energy demands with cogeneration and in the second case the demands are covered conventionally. Comparison is carried out with regard to energy consumption, CO_2 emissions and finally the economics are established.

2. The four cogeneration systems under consideration

The auto-producers/consumers under consideration are four and their characteristics are given in Table 1. The cogeneration systems are calculated on the basis of the thermal needs of the users. It is assumed that the auto-producer operation is constant throughout the operation with the aforementioned electrical and thermal outputs. It is also assumed that the thermal outputs are transferred to the consumer in the form of steam.

The characteristics of the four cogeneration systems used to cover the energy demands of the consumers are shown in Table 2. As seen from the table, two systems consist of gas turbines and two other systems consist of combined cycles. In all cases, the fuel used was natural gas. Auto-producers 2, 3, and 4 are connected to the medium voltage grid while only auto-producer 1 is connected to the high voltage grid.

3. Calculation of energy savings, CO_2 emissions reduction and operational cost savings due to cogeneration systems

Calculations for natural gas input and energy production (electricity and heat) for each of the four cogeneration systems are shown in Table 3. Electricity and thermal energy production as well as CO_2 emissions are presented together with electrical, thermal and total efficiencies.

Table 1: Energy needs of consumers/auto producers

Auto-producer/consumer	**1**	**2**	**3**	**4**
Consumed electrical output (MW)	100	40	50	2
Consumed thermal output (MW)	245	103	33	6.5

Table 2: Characteristics of the cogeneration systems used to cover the energy needs of the consumers (Ruston Typhoon is now called Siemens SGT-100)

Auto-producer	**1**	**2**	**3**	**4**
Gas turbine	Gas Turbine Combined Cycle GE 9FA	Gas Turbine Combined Cycle GE 6	Gas Turbine GE LM2500	Gas Turbine Ruston Typhoon
Electrical output (MW)	360	80	22	5
Voltage level grid connection	High	Medium	Medium	Medium

Table 3: Calculation of fuel consumption and energy production for the auto-producers

	Units	Auto-producer 1	Auto-producer 2	Auto-producer 3	Auto-producer 4
Plant characteristics		GE 9FA	GE 6	GE LM2500	Ruston Typhoon
Electrical capacity	MW	360	80	22	5
Voltage level grid connection		high	medium	medium	medium
Average hours of operation	h/yr	8200	8200	8200	7500
Fuel (Natural gas)					
Annual natural gas input	MWh/yr	5,850,700	1,690,020	524,800	105,000
Average annual natural gas input	MW	713.5	206.1	64	14
Natural gas CO_2 emissions factor	t/MWh	0.18	0.18	0.18	0.18
Annual Nat. gas CO_2 emissions	t/yr	1,053,126	304,203	94,464	18,900
Electricity					
Av. annual electric output of CHP)	MW	330	70	20	4.5
Annual electric output from CHP	MWh/yr	2,706,000	574,000	164,000	33,750
Av. annual electric consumption	MW	100	40	50	2
Annual electric consumption	MWh/yr	820,000	328,000	410,000	15,000
Average annual electric grid export	MW	230	30	0	2.5
Annual electricity export to grid	MWh/yr	1,886,000	246,000	0	18,750
Av. annual electricity grid import	MW	0	0	30	0
Annual electricity grid import	MWh/yr	0	0	246,000	0
Heat					
Produced steam per hour	t/h	320	135	43	8.5
Annual thermal output	MWh/yr	2,011,733	848,700	270,326	48,875
Average annual thermal output	MW	245	103	33	6.5
Efficiency (LHV)					
Electrical efficiency	%	46.3%	34.0%	31.25%	32.14%
Thermal efficiency	%	34.3%	50.2%	51.5%	46.54%
Total efficiency	%	80.6%	84.2%	82.7%	78.69%

Calculations are also carried out for the conventional way of covering the energy demands as shown in Table 4. The average electrical efficiency of the lignite power plants in Greece is only 38 % (due to the poor energy content of lignite). It is assumed that the efficiency of the natural gas boilers used for conventional systems is 90 %. The average losses of the country's network are estimated at about 9 % according to the Greek ministry of environment (2004). Two cases will be considered to fulfil the user's requirements. The first consists in using cogeneration, while the second consists in producing electricity and thermal energy independently. The produced electricity from the power plant has the same value with the annual electricity output from cogeneration system while the produced thermal energy from the natural gas boiler has the same value with the annual thermal output of the cogeneration system so that comparison between the two cases can be made.

Consecutively, the total CO_2 emissions from the lignite power plant and the natural gas boiler are calculated by using a lignite emissions factor of 0.347 t $_{CO2}$ / MWh of fuel input and a natural gas emissions factor of 0.18 t $_{CO2}$ / MWh of fuel input.

Table 4: Energy savings, operational cost savings and CO_2 emissions reduction comparison between conventional and cogeneration systems

	Units	Auto-producer 1	Auto-producer 2	Auto-producer 3	Auto-producer 4
CO_2 and Energy Savings					
Power plant electrical efficiency	%	38%	38%	38%	38%
Natural gas boiler efficiency	%	90%	90%	90%	90%
Average network losses for Greece	%	9%	9%	9%	9%
Annual power plant lignite input	MWh/yr	7,825,332	1,659,919	474,262	97,600
Annual boiler natural gas input	MWh/yr	2,235,259	943,000	300,363	54,305
Total annual fuel input	MWh/yr	10,060,592	2,602,919	774,625	151,905
Lignite power plant CO_2 emissions	t/MWh	0.347	0.347	0.347	0.347
Nat. gas boiler CO_2 emissions	t/MWh	0.18	0.18	0.18	0.18
Annual power plant CO_2 emissions	t/yr	2,715,390	575,992	164,569	33,867
Annual boiler CO_2 emissions	t/yr	402,347	169,740	54,065	9,775
Annual total CO_2 emissions	t/yr	3,117,737	745,732	218,634	43,642
Annual fuel saving from CHP	MWh/yr	4,209,892	912,900	249,825	46,905
Fuel savings from CHP	%	41.84%	35.07%	32.25%	30.87%
Annual CHP CO_2 emissions reduction	t/yr	2,064,611	441,529	124,170	24,742
CO_2 emissions avoided from CHP	%	66.22%	59.21%	56.68%	56.69%
Electricity tariff from CHP	€/MWh	20.548	45.61	45.61	45.61
Electricity tariff	€/MWh	47.6	47.6	47.6	61
Natural gas tariff	€/MWh	22.628	22.628	22.628	28.14
Costs					
Annual fuel cost of CHP	€/yr	132,389,640	38,241,773	11,875,174	2,954,700
Specific maintenance cost of CHP	€/MWh	6	6	6	6
Annual maintenance cost of CHP	€/yr	16,236,000	3,444,000	984,000	202,500
Total annual cost	€/yr	148,625,640	41,685,773	12,859,174	3,157,200
Benefits					
Annual cost of avoided electricity	€/yr	39,032,000	15,612,800	19,516,000	915,000
Annual avoided boiler fuel	MWh/yr	2,235,259	943,000	300,363	54,305
Annual avoided boiler natural gas cost	€/yr	50,579,451	21,338,206	6,796,614	1,528,158
Annual income of exported electricity	€/yr	38,753,528	11,220,060	0	855,187
Annual total economic benefits	€/yr	128,364,979	48,171,066	26,312,614	3,298,346
Operational Cost Savings					
Annual operational cost savings	€/yr	-20,260,661	6,485,293	13,453,439	141,146

As can be seen from Table 4, the electricity tariff from cogeneration, the electricity tariff and the natural gas tariff are provided. So by using these tariffs the fuel cost savings can be calculated. At first, the annual fuel cost of cogeneration is calculated by multiplying the annual natural gas input by the natural gas tariff. Then, considering a specific maintenance cost of 6 €/MWh for all cogeneration systems, the annual maintenance cost is calculated. Then, all the economic benefits of cogeneration are calculated and added in order to obtain the total annual economic benefits. These benefits consist in the annual cost of the avoided electricity, the annual cost of the avoided natural gas for the boiler and the annual income of the exported electricity.

4. Primary Energy Savings from the EU Cogeneration Directive

In 2004, the European Parliament and the Council (2004) agreed a Directive on cogeneration. This Directive requires all Member States to promote the use of high efficiency cogeneration. To determine what is high efficiency cogeneration is compared with separate production of heat and power from plants using the same fuel and built in the same year as the cogeneration plants. Thus, a natural gas-fired cogeneration plant built in 2006 is compared with a natural gas-fired Combined Cycle Power Plant and a natural gas-fired boiler, both built in 2006. The European Commission (2006) and National experts have just concluded the reference plant data. These data are harmonised across Europe and include temperature corrections for power plant operation and corrections for the avoidance of grid losses.

Table 5: Calculation of Primary Energy Savings using the Methodology from the EU Cogeneration Directive

	Units	Auto-Producer 1	Auto-Producer 2	Auto-Producer 3	Auto-Producer 4
Cogeneration System		GE 9FA	GE8	GE LM2500	Ruston Typhoon
Grid Connection Voltage	kV	> 100	50-100	0.4-50	0.4-50
Electric Efficiency (P)	%	46.3	34.0	31.25	32.14
Thermal Efficiency (Q)	%	34.3	50.0	51.5	46.54
Total Efficiency (R)	%	80.6	83.9	82.7	78.7
Cogeneration Directive Primary Energy Savings Calculation					
Power Station Reference (T)	%	52.5	52.5	52.5	52.5
Temperature Correction (U)	%	0.5	0.5	0.5	0.5
Grid Loss for Imports (Vi)	%	96.5	94.5	92.5	92.5
Grid Loss for Exports (Ve)	%	98.5	96.5	94.5	94.5
Power Station Reference after corrections	%	50.9	49.5	48.1	48.7
Boiler Reference (W)	%	85.0	85.0	85.0	85.0
Primary Energy Savings	%	23.8	21.4	20.4	17.1

In this methodology, shown in eq. 1, the cogeneration power and thermal efficiencies are compared with the power station efficiency adjusted for temperature and grid losses, which are dependent up on whether the cogeneration electricity is used on site or exported to the grid and the boiler efficiency. The cogeneration plant must achieve greater than 10% Primary Energy Savings (PES). Thus:

$$PES = (1-(1/((Q/W)+(P/(T-U)*((Vi*G+Ve*I)/E)))))*100\% \quad (1)$$

Where E is the Average annual electricity output from CHP and all other factors are given in Table 5.

Table 5 gives the results of applying the Cogeneration Directive methodology to the 4 auto-producer plants. The key assumptions include that all plants are built in 2006, the average annual ambient temperature for Greece is 20°C and all cogeneration plants receive condensate return from the steam distribution systems. All other data are identical to Table 4.

5. Discussion

From the results of Table 4, it is shown that for all four auto-producers there is a significant reduction in the consumed fuel and also in CO_2 emissions. This has a positive effect on the environment and on the economics of the system since cogeneration is a CO_2 tax-free technology according to the Greek ministry of environment (2004).

The Cogeneration Directive methodology reduces the energy savings, but all four auto-producer schemes pass the threshold for high efficiency cogeneration of 10%. The key impact of the Cogeneration Directive is for gas-fired cogeneration whereby the comparison is against the most efficient power station technology, which appears to reduce the benefit of cogeneration over separate production when compared with offsetting the average national power station efficiency or the marginal generation efficiency. Nevertheless even with this stricter test these cogeneration plants all achieve the status of high efficiency.

Auto-producers 2, 3 and 4 have significant financial benefits due to the installation of the cogeneration systems. However, auto-producer 1 presents losses although the opposite was expected. This is due to many reasons.

First, the PPC tariff for electricity from cogeneration with high voltage grid connection is very low so that the incoming capital cannot cover the natural gas cost. A side effect of this factor is the fact that when the electrical efficiency of the cogeneration system increases, then the loss increases as well.

The fact that the electricity tariff in Greece is one of the lowest in Europe must also be taken into consideration. This low price is due to low-cost in-land lignite used by the PPC's power plants.

Another important factor is the lack of significant economic incentives from the State in order to make the use of cogeneration more competitive.

Finally, it should be stated that liberalization in Greece, for both the electricity and the natural gas sectors, has not yet been fully implemented. This of course hampers the creation of an energy market operating in terms of fair competition, which could offer natural gas and electricity to the consumer at lower prices.

6. Conclusions

It is concluded that cogeneration systems in Greece can be feasible for medium grid connection. With today's situation, the installation of a cogeneration system is not economically interesting. Several reasons mentioned in this paper hamper further development of cogeneration. The Greek State should take the necessary steps in order to improve the economic advantages of cogeneration. The price for cogeneration electricity should be subsidised in order to increase the profit margins for producers.

Procedures for the liberalization of the energy market in both the electricity and natural gas sectors must be accelerated. The implementation of this incentive will increase the number of natural gas and electricity suppliers and create fair competition, which should improve the prospects for cogeneration in Greece in the future and help Greece meet its obligations under the EU Cogeneration Directive and other policy requirements such as CO_2 reduction targets.

7. References

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Annex 1 Calculation of natural gas and electricity tariffs

To establish the calculations of section 3, it is necessary to know the natural gas and electricity tariffs, as well as the tariffs of electricity from cogeneration. As can be seen from Table A1, the electricity tariff from cogeneration depends on the voltage level grid connection (PPC, 2005). Table A2, which provides the load time zones as set by PPC, will be used to calculate the tariff for the high voltage connection to the grid. Auto-producer 1 operates throughout the three time zones and its average electricity tariff is 20.548 €/MWh. The tariff for auto-producers 2, 3, and 4, which use intermediate voltage connection to the grid, is 45.61 €/MWh. Table A3, summarises the tariffs for each of the four auto-producers

Table A1: PPC electricity tariff from cogeneration

	Electricity tariff (€/MWh)	
High voltage	Maximum load	29.78
	Intermediate load	20.63
	Minimum load	15.31
Medium voltage	45.61	
Low voltage	56.39	

Table A2: Minimum, maximum and intermediate load time zones as provided by PPC

	October - April	**May - September**	**% Annually**
Maximum load time zone (Monday-Friday)	10.00 - 14.00 and 18.00 - 21.00	10.00 - 14.00	17.09
Minimum load time zone	01.00 - 08.00	24.00 - 08.00	30.92
Intermediate load time zone	Remaining hours	Remaining hours	51.99

Table A3: Electricity tariffs from cogeneration for the four auto-producers

	Auto-producer 1	**Auto-producer 2**	**Auto-producer 3**	**Auto-producer 4**
Tariff (€/MWh)	20.548	45.61	45.61	45.61

Table A4: Electricity tariffs from PPC for each of the four auto-producers

	Auto-producer 1	**Auto-producer 2**	**Auto-producer 3**	**Auto-producer 4**
Eurostat Category	Very Large Ind Consumers (62.5-75 MW)	Very Large Ind Consumers (37.5-62.5 MW)	Very Large Ind Consumers (37.5-62.5 MW)	Large Ind Consumers (< 37.5 MW)
Tariff including VAT 9% (€/MWh)	47.6	47.6	47.6	61

Table A5: Energy cost for the fourth auto-producer

Auto-producer 4	**Energy cost (€/MWh)**
Consumption up to 180 MWh/month	31.06
Consumption between 180 MWh - 560 MWh/month	30.17
Consumption between 560 MWh - 2000 MWh/month	28.69
Consumption between 2000 MWh - 5000 MWh/month	27.8
Consumption over 5000 MWh/month	22.18

The electricity tariffs used for the calculation are average tariffs obtained from Eurostat (2005a, 2005b) and presented in Table A4 (these include CO_2 taxes). Each auto-producer belongs to one of the consumer categories. Auto-producer 1 belongs to the highest category of 75 MW for very large industrial consumers. Auto-producers 2 and 3 belong to the 50 MW category for very large industrial consumers. Finally, auto-producer 4 belongs to the category of large industrial consumers with less than 37.5 MW.

According to the Public Gas Company (PGC, 2005), the natural gas tariff for the three large auto-producers 1, 2 and 3 is 22.628 €/MWh. For the smaller auto-producer 4 the natural gas tariff is calculated from the power cost, the energy cost and the VAT. According to Attica Gas (2005), the maximum power cost for this consumer is 224 €/MW, so the power charge per MWh of consumed natural gas is 0.306 €/MWh. The energy costs of the fourth auto-producer are obtained according to Table A5. By using these costs it is possible to calculate the average energy cost of the fourth auto-producer which is 25.51 €/MWh. Finally, all the aforementioned data are gathered in Table A6 in order to calculate the final natural gas tariff for the fourth auto-producer.

TableA6: Natural gas tariff for cogeneration from PGC

Auto-producer 4	
Power cost (€/MWh)	0.306
Energy cost (€/MWh)	25.51
Gas price excluding VAT 9% (€/MWh)	25.816
Gas price including VAT 9% (€/MWh)	28.14

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