DETAILED TABLES

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Combined heat and power production (CHP) in the EU

Summary of statistics

Data 1994-1998

8

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THEME 8
Environment and energy

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1. Project outline

General

One of the aims of the European Union's energy policy is to improve energy efficiency, thereby making a positive contribution to a safer and healthier environment and reducing the Community's energy dependence on external sources.[1] Improving energy efficiency can substantially slow down climate change by reducing the emission of greenhouse gases. The 1997 Kyoto Convention resulted in a protocol which agreed on a number of mechanisms to reduce such emissions. The EU and its Member States undertook to reduce greenhouse gas emissions by 8% between 2008 and 2012, compared to 1990 levels. The Commission published an “Action Plan to Improve Energy Efficiency in the European Community” in its Communication to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions[2], where concrete measures for removing barriers preventing the improvement of energy efficiency have been defined.

Promoting combined heat and power production (CHP or co-generation) is considered an important part of the Community energy policy for improving energy efficiency. CHP also plays a crucial role in helping meet the commitments of reducing greenhouse gas emissions.

CHP is both extremely energy efficient and environmentally friendly, and can exploit all types of combustible fuels in small and large units. Up to 90% of the energy content of a fuel can be utilised in CHP plants, compared with 30–40% for conventional plants. The target is to increase the fraction of the CHP electricity generation in the total electricity generation from 9% in 1994[3], to 18% in 2010, which would lead to a considerable cut in CO_2 emissions.

Eurostat first collected CHP production data from the Member States in 1994 in a project funded by the SAVE programme. This report summarises the findings for the periods in question (1994 and 1996–98) and highlights relevant trends. It allows initial conclusions to be drawn about the development of CHP production in the Community with a view to achieving the targets in question.

Objectives

The collection of statistics monitoring CHP penetration of the European energy market is an important way of improving the co-ordination of activities which promote the use of CHP production. Prior to the present project, the statistical system did not allow CHP production at European level to be adequately assessed. The findings of the present project have allowed CHP contribution across the EU to be assessed for the first time.

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[1] COM(95)0682 13.12.1995.

[2] COM(2000) 247, 26.04.2000.

[3] COM(97) 514 final, 15.10.1997.

In addition to the collection of topical data on CHP production in the Member States, this project aims to create a sound infrastructure for future data collection, i.e.:

- development of a common methodology for CHP data collection in the Member States;
- assistance for the Member States in setting up systems for the regular collection of CHP data;
- incorporation of CHP statistics into the overall system of energy statistics.

Definitions

In thermal power stations, the energy released from the fuel is transmitted into an intermediate fluid, which is used to drive the generators. In CHP generation, part of the thermal energy of the intermediate fluid is utilised in heat production. The CHP generation involves the simultaneous production of electricity and heat. If the residual thermal energy of the intermediate fluid is not used entirely for producing heat, the generated electricity is not completely regarded as CHP production.

The electrical capacity of a CHP unit is defined as the maximum gross capacity that could be generated continuously throughout a prolonged period of operation, assuming that the heat production always leads to maximum electrical generation.

The heat capacity of a CHP unit is the maximum achievable net output of thermal energy to the heating network, assuming that the method of producing electrical energy leads to the maximum heat production.

In addition to the maximum capacity it is necessary to define the CHP capacity for plants with an inherent non-CHP component. This is the case, for example, in many district heating plants with steam turbines operating in condensing mode in summer time emitting a large portion of the residual thermal energy into the environment.

The concept of declared net capacity (DNC) was applied to distinguish between gross capacity and the actual CHP portion of the unit's electrical capacity. As a rule, CHP capacity is equal to the maximum electrical capacity of the unit, except for the following units:

1. Marginal CHP units with a heat/power capacity ratio of less than 0.25.
2. Steam units with condensing turbine operated with low heat production in relation to electricity generation.
3. Gas turbines or internal combustion engines, which could be operated without heat recovery, whenever heat production is low in relation to electricity generation.

For these three types of units the CHP capacity is reported as declared net capacity (DNC), which is the capacity of a virtual CHP unit. The DNC is calculated from the heat capacity of the unit by dividing it by the default heat to power ratio, a coefficient which varies according to the type of unit.

The electricity production of a CHP unit is defined as the gross production of the unit. The heat production is the net heat production. Any separate heat generated by the unit is not accounted for.

The electricity produced in CHP plants operating in condensing mode was excluded from this study by using a concept of declared net capacity for units fulfilling one of the three above-mentioned criteria. For those units, CHP electricity generation is reported as the net heat production of the unit divided by the default heat to power ratio. Thus, the CHP electricity production corresponds to the generation by declared net capacity.

Both gross and DNC figures are needed for capacity and production. Gross values reflect measured quantities, which should always form the basis for statistics. The amount of energy saved by CHP compared to separate heat and power production can be roughly estimated if the gross production of electricity, net heat production and the fuel input of the CHP units are known. However, the targets at the EU level are defined as doubling the amount of CHP production, and the assessment of the development for this purpose is not possible without excluding the non-CHP component from the generation of the CHP units.

A more detailed description of the definitions is given in Annex 1.

Scope

The units included in the survey were divided into categories based on the type of cycle:

- combined cycle units,
- units with steam backpressure turbines,
- units with condensing-extraction steam turbines,
- gas turbines with heat recovery,
- internal combustion engines,
- others.

A description of the cycles is provided in Annex 2.

Member States provided data on CHP capacity, heat and electricity production and fuel input by cycle. In addition, figures were broken down by public utility / autoproducer. The figures for autoproducers, i.e. undertakings which, in addition to their main activities, generate electrical energy for own use, were further subdivided by area of economic activity (NACE codes). Both gross and DNC capacity and production were reported.

The gross electricity production and net heat production were collected also by fuel type, separately for autoproducers and public utilities. The amount of fuel was provided in specific units and in TJ.

A size limit for the capacity of units for inclusion in the surveys was considered necessary. These were set at

- 1000 kW or over for steam units,
- 500 kW or over for gas turbines,
- 100 kW or over for internal combustion engines.

Details of the data collected can be found in the “CHP statistics project, 1998” Work Programme in Annex 1.

The survey was conducted in each EU Member State for the years 1994 and 1996-98, with the exception of Luxembourg (1994 and 1996). Norway was included in the 1996-98 period and Iceland in 1998. The latter two countries are not included in this report. In Norway, CHP production is marginal, accounting for less than 0.1% of total electricity production, and in Iceland CHP plants are run by geothermal heat only. In Germany, the survey was carried out in 1995 instead of 1994.

The national organisations responsible for data collection in the Member States were as follows:

Member State	**Organisation**
Belgium	Institut Wallon
Denmark	Danish Energy Agency
Germany	Statistisches Bundesamt and Deutsches Institut für Wirtschaftsforschung
Greece	Public Power Corporation
Spain	Ministry of Energy and Industry
France	Centre d’études et de recherches économiques sur l’énergie (CEREN)
Ireland	Electricity Supply Board (ESB)
Italy	Unione Nazionale Azienda Produttrici e Consumatrici di Energia Elettrica (UNAPACE)
Luxembourg	Agence de l’Energie
Netherlands	Central Statistical Office (CBS)
Austria	Ministry of Economy
Portugal	Ministry of Economy
Finland	Statistics Finland
Sweden	Statistics Sweden
United Kingdom	Energy Technology Support Unit (ETSU)

3. Findings

Capacity and production by Member State

Electrical capacity

The installed capacities (DNC) of the CHP plants are given in Table 1. Electrical capacity in the EU increased by 14% between 1994 and 1998, from 63 to 72 GW.

The increase in the electrical capacity was greatest in Italy at around 3.2 GW between 1994 and 1998. The Netherlands and Spain also showed significant increases in CHP electricity capacity, at over 2 GW in each country. In Denmark and in Finland, the increase was also significant at around 2 GW and 1 GW respectively.

The highest electrical capacity for CHP generation between 1994 and 1998 was reported in Germany, though a decrease in absolute terms is observed.

Table 1. Installed capacities of co-generation by Member State.

	Maximum capacities, MW							
	1994**		1996		1997		1998	
Member State	Electricity	Heat	Electricity	Heat	Electricity	Heat	Electricity	Heat
Belgium	728	3085	630	3048	721	3254	797	3189
Denmark	5214	9180	5489	9581	5946	10152	7027	10999
Germany***	26183	46563	22542	40728	20666	41263	22160	35869
Greece	218	552	218	552	218	552	257*	709
Spain	1533	4706	2279	4275	3016	5130	3558	5313
France	2920	11190	3170	11531	3346	13405	3485	18837
Ireland	67	339	82	401	87	327	114	464
Italy	6328	17507	7420	19430	8395	20577	9522	23337
Luxembourg					31	61	98	204
Netherlands	6148	12055	6809	13673	8358	16558	8500	16912
Austria	3246	6001	3134	7257	3409	7284	3416	7346
Portugal	991	4188	961	4292	921	4297	965	3978
Finland	4085	12669	4265	13721	5018	14397	5097	14778
Sweden	2808	8480	2837	9407	3063	10627	3205	12440
United Kingdom	2516	13203	3079	14948	3425	15225	3721	15345
EU-15	**62985**	**149718**	**62915**	**152844**	**66620**	**163109**	**71922**	**169720**

* Eurostat estimate
** German figures are for 1995.
*** German figures are for gross capacity.

Electricity generation

The CHP electricity generated in the Member States as a percentage of thermal power generation and total electricity generation is shown in Table 2.

CHP generation in EU-15 increased clearly from 204 TWh in 1994 to 271 TWh in 1998, representing a relative increase of 33%. CHP electricity as a percentage of total electricity generation increased from 9.0% to 10.9% over the same period. The relative increase of CHP electricity generation as a percentage of total electricity generation in the EU is given in Figure 1.

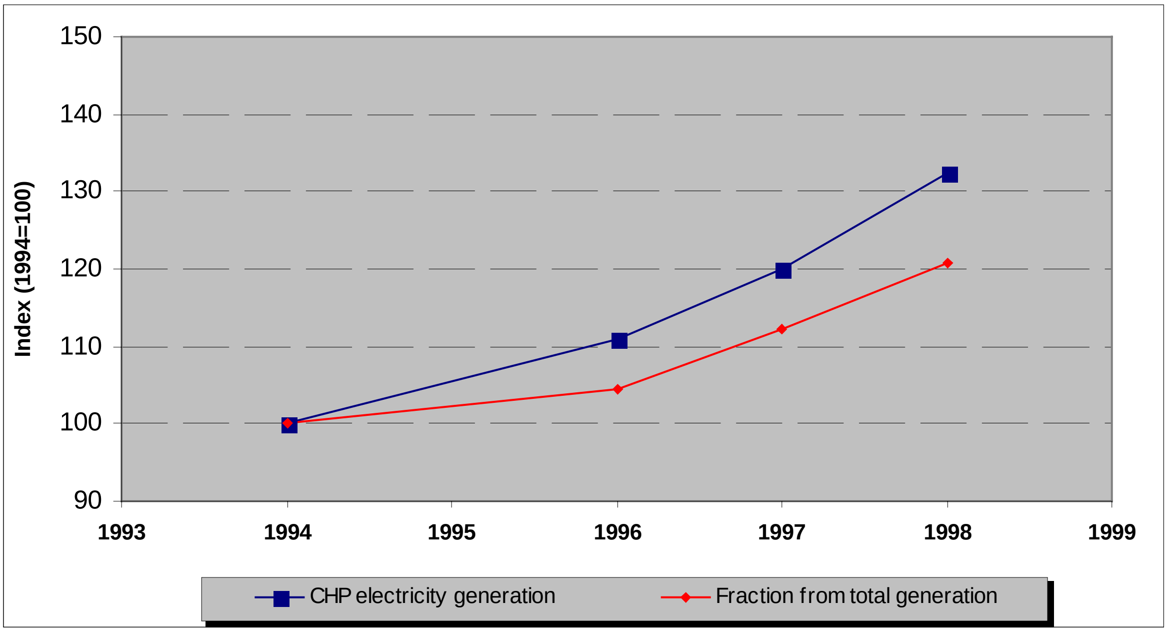

Figure 1. CHP Electricity generation in relation to total electricity generation in the EU between 1994 and 1998 (1994 = 100).

In absolute terms, CHP generation was greatest in the Netherlands (48 TWh), Italy (45 TWh) and Germany (42 TWh) in 1998. The combined CHP electricity generation of these three countries was about half the total CHP electricity production in the EU in 1998. Denmark, Finland and Spain are also major producers of CHP electricity, each producing more than 20TWh in 1998 (between 21 TWh and 26 TWh)

CHP generation increased substantially from 1994 to 1998 in almost all Member States. The largest increases took place in Italy (18 TWh) and the Netherlands (16 TWh). Germany, however, saw a slight fall in CHP generation.

The lower the figure for co-generation as a percentage of total thermal electricity generation, the better the opportunities to further increase the CHP production by constructing new units - assuming that heat demand is not close to saturation, in which case capacity increase is restricted. In the EU-15, about 21% of thermal electricity is produced by co-generation. The portion of CHP electricity generation is highest in Sweden, at above 95%. Luxembourg, Austria and Finland recorded rates of over 75% in 1998. In Denmark and in the Netherlands, CHP production represents 67% and 55% respectively of thermal electricity production.

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Table 2. Co-generation in the Member States, and CHP as a percentage of thermal and total electricity generation.

	1994**			1996			1997			1998		
Member State	CHP Electricity GWh	Portion of thermal electricity %	Portion of total electricity %	CHP Electricity GWh	Portion of thermal electricity %	Portion of total electricity %	CHP Electricity GWh	Portion of thermal electricity %	Portion of total electricity %	CHP Electricity GWh	Portion of thermal electricity %	Portion of total electricity %
Belgium	2448	8,0	3,4	3000	9,5	3,9	3069	10,2	3,9	3410	9,6	4,1
Denmark	21874	56,2	54,5	29260	55,9	54,6	26562	62,7	59,9	25591	66,9	62,3
Germany	47752	13,5	9,0	37817	10,3	6,8	36834	10,3	6,7	41770	11,3	7,5
Greece	819	2,2	2,0	886	2,3	2,1	968	2,5	2,2	981*	2,3	2,1
Spain	8537	11,1	5,3	13390	17,5	7,7	18567	18,9	9,8	21916	22,2	11,2
France	8506	24,5	1,8	9864	22,0	1,9	10663	26,2	2,1	12660	22,7	2,5
Ireland	259	1,6	1,5	357	2,0	1,9	457	2,4	2,3	404	2,0	1,9
Italy	26477	14,7	11,4	31383	16,2	12,9	40164	20,1	16,0	44856	21,6	17,3
Luxembourg							120	37,1	9,5	320	87,7	22,5
Netherlands	31543	41,7	39,5	36410	45,1	42,7	41502	49,6	47,9	47835	55,4	52,6
Austria	11721	66,0	21,4	13539	70,3	24,7	14025	71,7	24,7	14268	76,2	24,8
Portugal	3111	15,1	9,9	2845	14,5	8,2	2949	14,1	8,6	3288	12,8	8,4
Finland	20312	59,0	30,9	22536	59,3	32,5	23051	64,0	33,3	25128	75,6	35,8
Sweden	9257	85,0	6,4	10241	70.9	7,3	9301	91,4	6,2	9544	95,5	6,0
United Kingdom	11619	5,0	3,6	15108	6,1	4,3	16762	7,0	4,9	18644	7,4	5,2
EU-15	**204235**	**17,6**	**9,0**	**226636**	**18,3**	**9,4**	**244994**	**19,8**	**10,1**	**270615**	**21,0**	**10,9**

* Eurostat estimate
** German figures are for 1995.

Heat production

Details of the heat production by co-generation in Member States between 1994 and 1998 are given in Table 3. Heat production in EU-15 increased by 18% between 1994 and 1998. Trends for individual countries were in line with those for CHP electricity production. The largest increase in both absolute and relative terms took place in Italy, 144 PJ (57%). The increase was also significant in the Netherlands (68 PJ), France (54 PJ), the UK (50 PJ) and Spain (50 PJ). Germany and Belgium showed falls in CHP heat production. Despite the decrease in production in Germany, it was the second largest CHP thermal producer in the EU in 1998.

The increase in CHP heat generation is less than the increase in CHP electricity generation (18% and 33% respectively). At the same time, total thermal efficiency subtracted from reported production remained practically the same in the period concerned. This means that an increasing portion of the energy content of the fuel was converted into electricity in co-generation plants without increasing the share of energy emitted into the environment. In other words, more energy was saved by CHP production per unit energy of consumed fuel in 1998 than in 1994 compared to separate electricity and heat production.

Table 3. Heat production by co-generation 1994 – 1998.

	CHP heat, TJ			
Member State	1994**	1996	1997	1998
Belgium	38969	32194	37102	38029
Denmark	92387	119116	116296	119717
Germany	446886	362984	345510	340761
Greece	5490	6612	7460	7472
Spain	91509	104508	141770	141321
France	116565	128788	154746	170670
Ireland	3930	5827	4670	4861
Italy	253675	296266	367071	397796
Luxembourg			563	2197
Netherlands	171026	206443	223511	238765
Austria	79178	101637	88599	81467
Portugal	46916	48080	51813	50799
Finland	256402	264236	274385	269439
Sweden	124471	138690	144785	155751
United Kingdom	174914	219024	221244	225174
EU-15	**1902318**	**2034405**	**2179525**	**2244220**

** German figures are for 1995.

Capacity and production by economic activity

The structure of the energy sector, and the division between public supply and autoproducers, has an impact on the development of co-generation. The breakdown of CHP production between the public supply and autoproducers is shown in Table 4.

Table 4. Co-generation by public supply and autoproducers in the Member States, GWh.

	1994***		1996		1997		1998	
Member State	Public supply	Auto-producers	Public Sector	Auto-producers	Public supply	Auto-producers	Public supply	Auto-producers
Belgium	1058	1390	1329	1671	1804	1265	2329	1083
Denmark	20891	983	27568	1692	24671	1891	23372	2219
Germany	24721	23031	24499	13318	23085	13749	25538	16232
Greece		819		886		968	*73	908
Spain		8537		13390		18567		21916
France	476	8030	831	9033	854	9809	1130	11530
Ireland		259		357		457		405
Italy	1025	25452	1266	30117	1405	38759	1651	43205
Luxembourg						120		320
Netherlands	16938	14605	18148	18262	21283	20219	24126	23709
Austria	6964	4757	7413	6126	7624	6401	7891	6376
Portugal	550	2561	412	2433	524	2425	822	2466
Finland	10766	9546	12739	9797	12283	10765	13655	11474
Sweden	5445	3812	6331	3910	5931	3370	5782	3763
United Kingdom	**	11619	**	15108	**	16762	**	18644
EU-15	**88834**	**115400**	**100536**	**126100**	**99464**	**145527**	**106369**	**164250**

*Eurostat estimate
**Data for public supply in the UK are confidential and are included in autoproducers.
*** German figures are for 1995.

In Northern Europe, the public supply typically produces more CHP electricity than autoproducers. This is the case for Scandinavian countries (Denmark Sweden and Finland), and also for Belgium, Germany, Austria and the Netherlands. In Denmark, 91% of the CHP electricity is produced in public power stations. The Northern countries have well-developed district heating networks, which explains the large contribution of the public supply.

The Mediterranean region is dominated by autoproducers. Ireland and especially the United Kingdom are exceptions to this North–South divide: domestic fuels have been traditionally used for heating individual houses instead of district heating.

The portion of the public supply from CHP electricity generation was stable at around 40% between 1994 and 1998. In general, trends in the individual Member States follow the North–South pattern. For example, in the Netherlands, Finland, Austria and Denmark, the increase in CHP production between 1994 and 1998 is split between autoproducers and the public supply along the roughly the same lines as in 1994. Belgium is an exception to this pattern, CHP production by the public supply more than doubling between 1994 and 1998 whilst falling amongst autoproducers. In Greece a small district-heating network came into operation in 1998.

Almost all sectors of economic activity produce electricity. The breakdown of the CHP production and capacity in the EU by sector is given in Table 5. The distribution of the electricity generation between the sectors did not change significantly from 1994 to 1998. The chemical industry and paper and printing industry together account for about 45% of the CHP electricity generation by autoproducers in 1998. The share of these two branches, together with refineries and the food, drink and tobacco industries, is about 66%. The share of the "others" category is relatively large, because confidential data are included in this category.

Table 5. CHP capacity and production by sectors in 1998, European Union.*

Sector	Capacity				Production			
	Electrical		Heat		Electricity		Heat	
	MW	Share, %	MW	Share, %	GWh	Share, %	TJ	Share, %
Mining and agglomeration of solid fuels	169	0.5	845	0.7	743	0.5	9498	0.6
Extraction of crude oil and natural gas	44	0.1	113	0.1	181	0.1	1047	0.1
Coke ovens	8	0.0	2	0.0	38	0.0	69	0.0
Refineries	4212	12.7	16177	14.0	24393	14.9	226595	13.2
Iron and steel industry	913	2.8	3417	3.0	4688	2.9	40404	2.3
Non-ferrous metals	121	0.4	673	0.6	314	0.2	5035	0.3
Chemical industry	7570	22.9	28036	24.2	38803	23.6	417218	24.2
Non-metallic mineral products	457	1.4	618	0.5	2705	1.6	15203	0.9
Extraction	714	2.2	2268	2.0	2825	1.7	32599	1.9
Food products, beverages and tobacco	3176	9.6	13864	12.0	10211	6.2	122335	7.1
Textile, clothing and leather	595	1.8	1340	1.2	2605	1.6	16310	0.9
Paper and printing	6515	19.7	26958	23.3	35067	21.3	489452	28.4
Metal products, machinery, equipment	436	1.3	1195	1.0	1528	0.9	11570	0.7
Other industrial branches	1133	3.4	2940	2.5	5360	3.3	38788	2.3
Transport	42	0.1	82	0.1	220	0.1	753	0.0
Services, etc	1202	3.6	3413	3.0	5511	3.4	50603	2.9
Other	5775	17.5	13702	11.8	29060	17.7	244538	14.2
TOTAL	33083	100	115643	100	164250	100	1722015	100

* UK figures include also Public Supply data.

Capacity and production by type of cycle

Five different types of cycles were distinguished in the survey. Descriptions of their characteristics can be found in Annex 2. The changes in the electrical capacities of different types of cycles over 1994 are presented in Fig.2. The relative increase of the capacity is largest for the combined cycle units. The capacity of the steam units has been relatively stable, whilst the capacities of both backpressure and condensing steam units show a very small decrease.

The co-generation by different types of plants is presented in Table 6. An overview of the trends in electricity generation by type of cycle is given in Fig. 3. The generation by steam units has been fairly stable, but that of all other cycles has clearly increased.

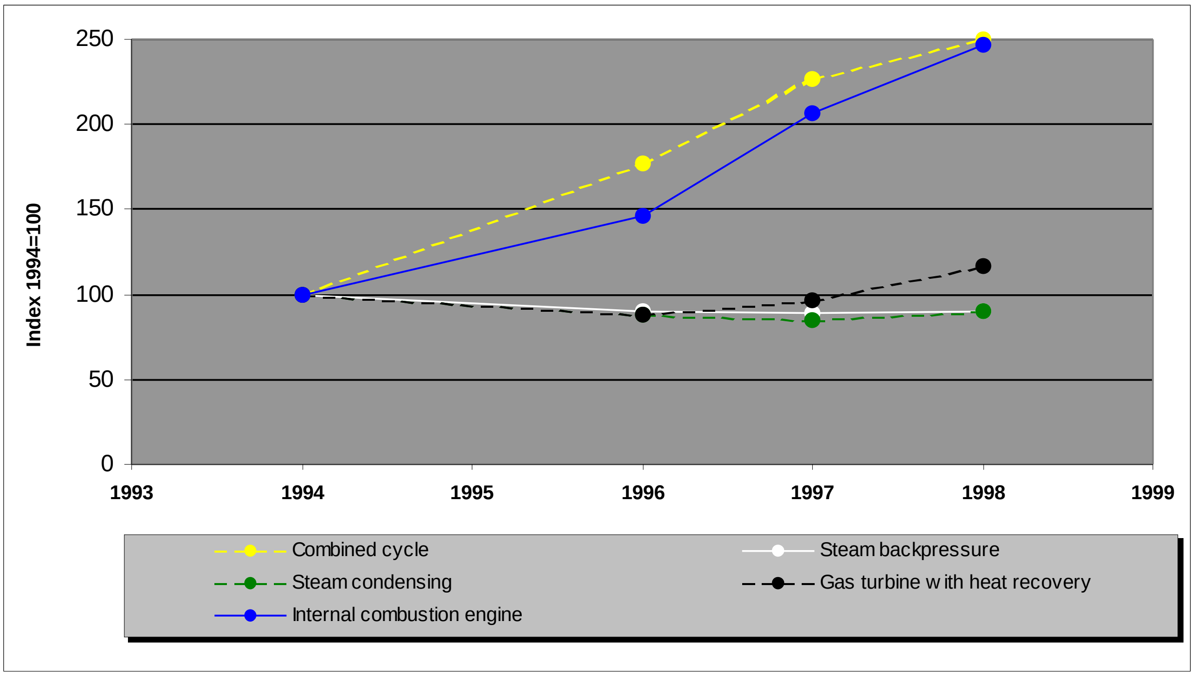

Figure 2. Relative changes of the CHP electrical capacities of different types of cycle in EU-15 (1994 = 100).

The combined cycle plants have increased their share of CHP electricity production from 15.8% to 32.8%, gas turbines with heat recovery from 9.6% to 11.0% and internal combustion engines from 3.9% to 9.0%. Steam units produced about 71% of the CHP electricity in 1994, but in 1998 their contribution fell to 47.1%.

Table 6. Co-generation and capacity by different types of cycles, European Union.

EU-15	1994**	1996	1997	1998
Combined cycle				
Electricity production, EDNC (GWh)	32235	55810	73187	88701
Heat production (TJ)	186871	336017	420834	490240
Electrical capacity[1] (MW)	6380	11317	14482	15981
Heat capacity (MW)	12325	20114	24799	27624
Steam: total backpressure turbine				
Electricity production, EDNC (GWh)	68795	62276	60335	59827
Heat production (TJ)	1140629	1044832	1058940	1024377
Electrical capacity[1] (MW)	18813	16936	16827	16872
Heat capacity (MW)	82925	74792	76739	81434
Steam: condensing turbine with heat extraction				
Electricity production, EDNC (GWh)	75416	73962	68300	67630
Heat production (TJ)	390881	450902	452870	434188
Electrical capacity[1] (MW)	30673	26983	25840	27728
Heat capacity (MW)	40877	44587	45944	41928
Gas turbine with heat recovery				
Electricity production, EDNC (GWh)	19529	19343	23161	29811
Heat production (TJ)	142949	126524	148113	183837
Electrical capacity[1] (MW)	4693	4118	4537	5473
Heat capacity (MW)	10223	8613	9154	11270
Internal combustion engine				
Electricity production, EDNC (GWh)	8018	14540	19722	24482
Heat production (TJ)	38826	72047	96277	109357
Electrical capacity[1] (MW)	2349	3445	4850	5808
Heat capacity (MW)	3227	4546	6343	7301
Others				
Electricity production, EDNC (GWh)	242	705	289	164
Heat production (TJ)	2162	4082	2491	2221
Electrical capacity[1] (MW)	77	115	83	62
Heat capacity (MW)	140	192	129	164

[1] Declared net capacity, except gross capacity for Germany.

** Figures from Germany are from 1995.

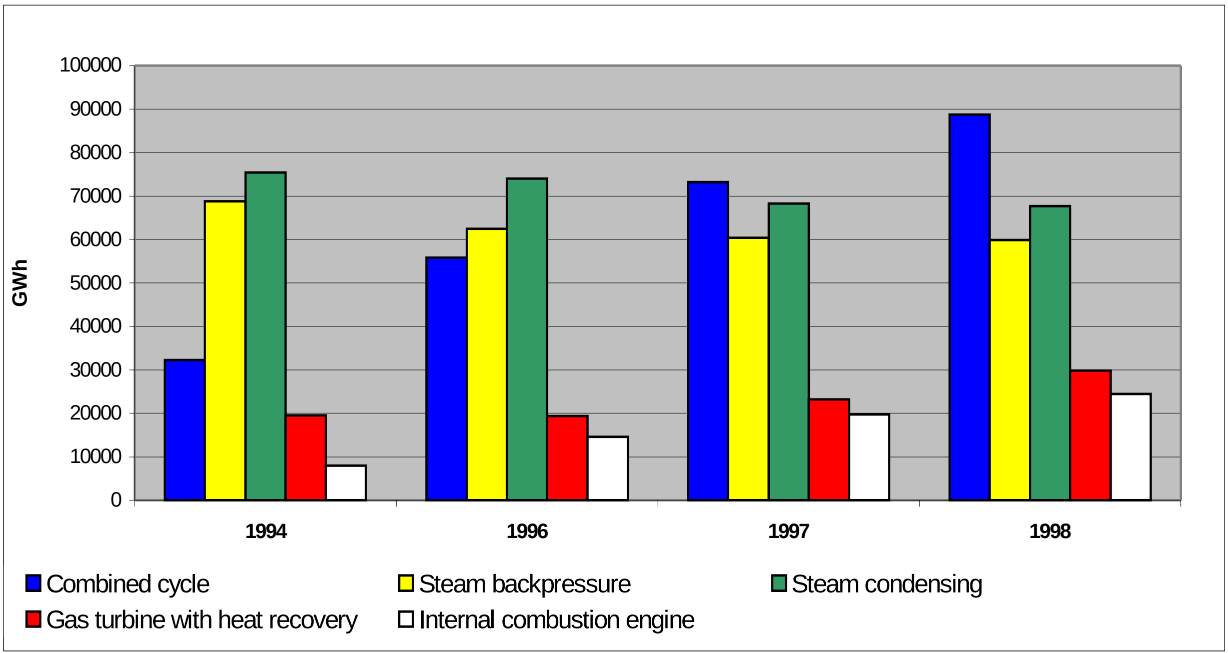

Figure 3. CHP electricity production by type of cycles, European Union.

Capacity and production by fuel

It is difficult to distinguish between capacity by type of fuel, as power plants may burn many types of fuel. The general trend is towards an increase in the capacity of natural gas. The capacity for burning gaseous fuels has increased substantially with the increase of combined cycle units, since the majority of them are gas-fired.

The division into five categories by CHP fuel consumption is shown in Table 7. The relative contributions of different fuels in EU-15 are shown in Fig. 4. Derived gases such as refinery gas, coke oven gas and blast furnace gas make up over 55% of the "other fuels" group in Table 7. The division within this group remained practically unchanged between 1994 and 1998.

The consumption of natural gas almost doubled between 1994 and 1998 in the EU. The use of renewable energy resources also increased substantially. By contrast, there was a decrease in the consumption of solid fossil fuels. This is in line with the overall trend of increasing use of natural gas replacing coal as a source of primary energy. The consumption of liquid fuels has also decreased, but not as much as that of solid fossil fuels.

The steam units mostly consume solid fuels like coal, lignite and renewables, while the other types of unit burn liquid and gaseous fuels. The increase in production by processes other than steam units thus reflects fuel consumption trends.

The consumption of natural gas in CHP production has more than tripled in Spain and almost tripled in Denmark. The largest increase in absolute terms in

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the use of natural gas has occurred in the Netherlands, with consumption increasing by 190 PJ.

The largest decrease in the consumption of coal and lignite for CHP generation occurred in Germany, falling from 437 PJ in 1994 to 262 PJ in 1998. The fall was also considerable in Denmark, from 272 PJ to 202 PJ, as well as in the UK - from 64 PJ to 43 PJ. In the other Member States, consumption of solid fossil fuels decreased less than in these three Member States. In some Member States (Greece, France, Austria, Italy and Ireland) the consumption of solid fuels for CHP actually increased between 1994 and 1998.

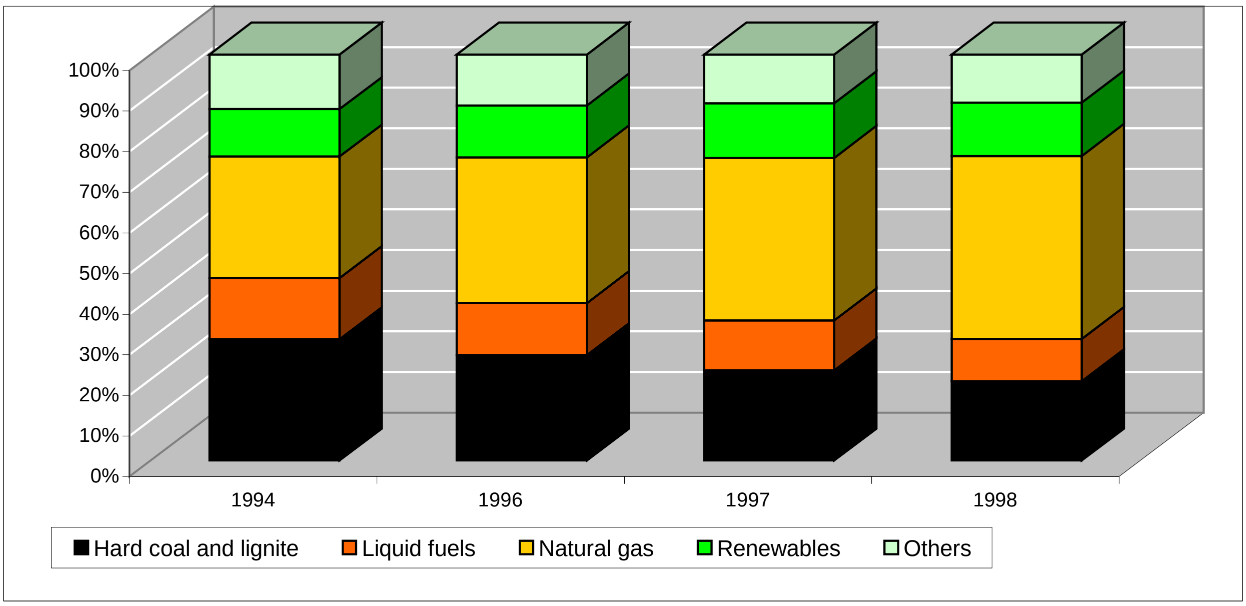

Figure 4. Relative contributions of different fuels consumed in CHP plants.

Table 7. Consumption of different fuels in co-generation in the Member States, TJ (NCV).

Member State	1994**	1996	1997	1998
Belgium				
Hard coal and lignite	4735	4033	3531	3726
Liquid fuels	19606	11626	11705	7754
Natural gas	20675	27836	36001	45296
Renewables	888	1102	1445	4966
Others	11712	9689	10073	1392
Denmark				
Hard coal and lignite	272134	310289	243766	201993
Liquid fuels	25483	15867	11076	15122
Natural gas	30629	62771	71742	85687
Renewables	15338	22317	23397	25533
Others	2512	39960	43533	35934
Germany				
Hard coal and lignite	436578	304540	288844	261831
Liquid fuels	40724	31770	29941	27599
Natural gas	206968	201605	188741	253547
Renewables	14784	5747	6413	11973
Others	113261	38541	35306	51800
Greece				
Hard coal and lignite				42798
Liquid fuels	4577	4183	3749	2942
Natural gas	1251	1262	2245	1123
Renewables				
Others	7633	8768	9616	9750
Spain				
Hard coal and lignite	9801	7917	7705	9366
Liquid fuels	43411	52794	57515	68954
Natural gas	46329	85197	129114	148857
Renewables	23082	25967	30667	25890
Others	39492	35645	39174	38800
France				
Hard coal and lignite	14779	13170	18188	19208
Liquid fuels	47071	42164	35242	36263
Natural gas	50524	66899	77850	104521
Renewables	41826	62951	84607	92909
Others	43969	54847	30198	25092
Ireland				
Hard coal and lignite	2248	2604	2255	2255
Liquid fuels	714	6	508	508
Natural gas	5526	6835	4448	4034
Renewables		2	2	5
Others		1223	574	493
Italy				
Hard coal and lignite	3050	5603	4755	6866
Liquid fuels	148121	137219	129317	117852
Natural gas	264135	332760	452066	534041
Renewables				
Others	70573	84208	114396	124471

(Table 7. Continued)

Member State	1994	1996	1997	1998
Luxembourg				
Hard coal and lignite				
Liquid fuels			3	3
Natural gas			1664	4576
Renewables				
Others				
Netherlands				
Hard coal and lignite	94412	107403	98227	90650
Liquid fuels	20878	18517	19230	782
Natural gas	209226	285070	325900	399765
Renewables	3188	11658	11926	13065
Others	70720	53017	47783	57010
Austria				
Hard coal and lignite	21394	34489	31713	27462
Liquid fuels	23032	26686	32364	31638
Natural gas	72155	108051	102646	101720
Renewables	27869	44544	40862	36700
Others	28843	25386	25963	25778
Portugal				
Hard coal and lignite				
Liquid fuels	37363	42123	45065	49393
Natural gas			142	1167
Renewables	31361	32464	36296	35782
Others	8955	7101	8262	7580
Finland				
Hard coal and lignite	125908	140655	131909	120313
Liquid fuels	21958	23337	23692	10272
Natural gas	74436	84765	79097	104663
Renewables	147417	156129	183761	190816
Others	15144	17242	13839	14781
Sweden				
Hard coal and lignite	28888	31827	26689	28100
Liquid fuels	39203	43764	53930	39588
Natural gas	12786	10848	11514	11928
Renewables	109728	129062	124326	132396
Others	9010	10272	14042	29617
United Kingdom				
Hard coal and lignite	64391	51576	52498	42690
Liquid fuels	71212	52431	48314	47392
Natural gas	87084	129652	156489	176478
Renewables	5839	5439	6577	6726
Others	64484	106240	98035	97316
EUR-15				
Hard coal and lignite	1078318	1014105	910080	857258
Liquid fuels	543353	502487	501650	456061
Natural gas	1081724	1403550	1639660	1977403
Renewables	421320	497383	550278	576761
Others	486309	492139	490794	519814

** German figures are for 1995.

4. Load factors and thermal efficiencies

Two parameters are used to evaluate the performance of CHP plants - load factor and thermal efficiency. A unit's load factor is defined as the electricity generated in a year divided by the maximum amount of electricity that could have been generated during that year. The formula is as follows:

$$L = \frac{G_{DNC}[GWh]}{E_{DNC}[GW] \cdot 8760[h]}$$

where L is the load factor, E_{DNC} the declared net electrical capacity and G_{DNC} the generated CHP electricity in gigawatt hours. The load factor thus describes the degree of utilisation of CHP generation potential. The total electricity generated by the CHP unit is always greater than or equal to G_{DNC}.

A unit's thermal efficiency is the ratio of the useful energy to the energy content of the consumed fuel. The useful energy comprises electricity and heat production. Gross electricity generations of CHP plants are used to calculate their thermal efficiencies.

The load factors and the thermal efficiencies for CHP generation are shown in Table 8. The average load factor in EU has increased from 37% in 1994 to 43% in 1998, a fact borne out by Fig. 7. Note that, for Germany, gross capacity has been used instead of DNC, which explains why the load factor is low.

The average thermal efficiency for CHP generation in the EU is in the order of 75%. The results should be regarded with caution, since there were differences in the reporting practices between Member States. In units producing both CHP and condensing power, the portion of fuel consumed for condensing power generation was deducted from the total fuel used in some Member States, resulting in high thermal efficiencies.

Table 8. Load factors and thermal efficiencies of co-generation.

	1994*		1996		1997		1998	
Member State	Load factor %	Thermal efficiency %	Load factor %	Thermal efficiency %	Load factor %	Thermal efficiency %	Load factor %	Thermal efficiency %
Belgium	38.4	83.0	54.4	81.4	48.6	77.7	48.8	80.7
Denmark	47.9	63.0	60.9	63.3	51.0	65.9	41.6	68.1
Germany	20.8	76.2	19.2	85.8	20.3	87.0	21.5	80.9
Greece	42.9	62.7	46.4	69.0	50.7	70.1	43.6	50.3
Spain	63.6	75.4	67.1	74.6	70.3	80.2	70.3	76.7
France	33.3	74.3	35.5	68.4	36.4	78.5	41.5	77.8
Ireland	44.2	57.3	50.0	66.7	60.0	81.1	40.5	86.6
Italy	47.8	71.8	48.3	73.7	54.6	73.6	53.8	71.9
Luxembourg					44.5	62.8	37.2	69.5
Netherlands	58.6	71.4	61.0	73.2	56.7	74.8	64.2	74.8
Austria	41.2	70.0	49.3	64.3	47.0	61.2	47.7	60.6
Portugal	35.8	74.8	33.8	74.4	36.6	74.0	38.9	71.1
Finland	56.7	85.6	60.3	81.8	52.4	82.7	56.3	81.6
Sweden	37.6	79.1	41.2	78.3	34.7	78.5	34.0	78.7
United Kingdom	52.7	74.0	56.0	79.2	55.9	77.8	57.2	78.9
EU-15	**37.0**	**73.0**	**41.1**	**75.1**	**42.0**	**76.5**	**43.0**	**75.1**

* German figures are for 1995.

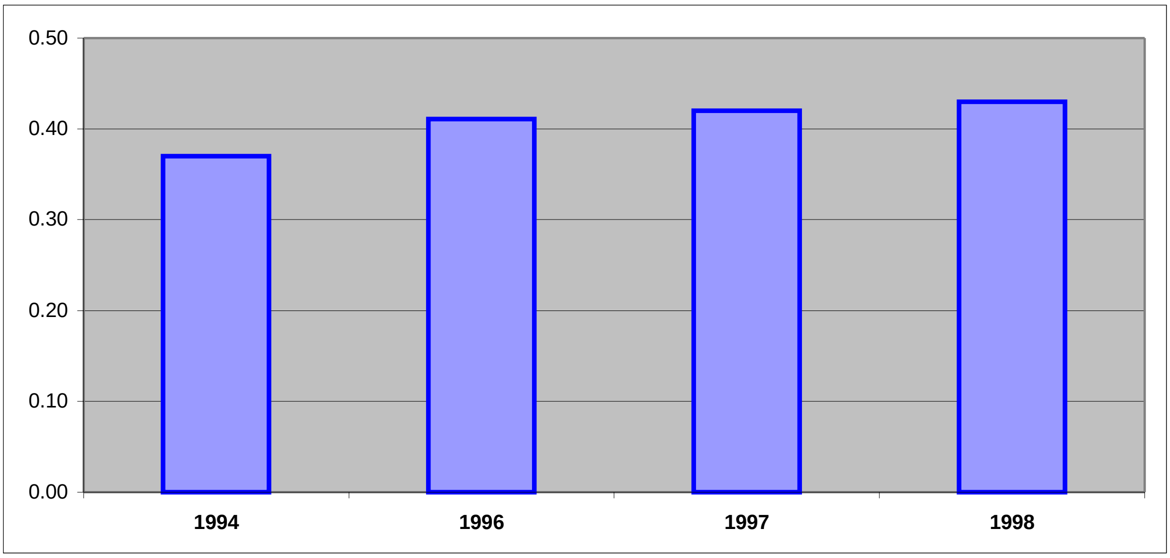

Figure 5. Average load factors for CHP electricity generation in EU-15.

5. Energy savings

The differences in fuel input between separate heat and power production and co-generation is the amount of energy saved by CHP. Cogeneration displaces electricity and heat that would have otherwise been generated in a wide range of plants using a range of fuels, which produces significant uncertainty in the calculations. Estimated average efficiencies of separate generation and the reported characteristics of CHP production can be used to produce a rough calculation of the energy save, H_{saved}:

$$H_{saved} = \frac{G_{CHP}}{\eta_E} + \frac{H_{CHP}}{\eta_H} - \frac{G_{CHP} + H_{CHP}}{\eta_{CHP}}$$

where

H_{saved} is the energy saved, TJ
G_{CHP} is the electricity generated in CHP plants, TJ
H_{CHP} is the heat generated in CHP plants, TJ
η_E is the thermal efficiency of separate electricity generation, ~0,36
η_H is the thermal efficiency of separate heat generation, ~ 0,85
η_{CHP} is the thermal efficiency of CHP production.

It should be noted that the last term in the formula is actually the fuel input for CHP plants. The fuel consumption reported by some Member States was the input for the CHP plants without subtracting the portion used for condensing power generation. The correct way to calculate the amount of energy saved is thus to use the reported gross electricity values. The use of pure CHP electricity and total fuel consumption would lead to artificially low - and therefore erroneous - figures for energy savings.

Energy savings calculated using the above formula are shown in Table 9 for different cycles. The rising trend in savings is clear - an increase of 75.7% between 1994 and 1998. The absolute increase in the amount of energy saved is in the order of 507 PJ.

Table 9. Energy savings calculated for different cycles in the EU, TJ.

	1994**	1996	1997	1998
Combined cycle	139349	240175	309744	385842
Total backpressure steam turbine	329604	321296	326528	278328
Condensing steam turbine with heat recovery	83645	258982	247361	236937
Gas turbine with heat recovery	79041	91287	128305	149877
Internal combustion engine	36684	71375	103506	124823
Others	1068	4015	2585	138
Total EU-15	669391	987130	1118029	1175946

** German figures are for 1995.

The absolute primary energy saving in 1998 - 1176 PJ or 28 Mtoe - corresponds to 2.0% of the primary energy requirement of the European Union. The amount of energy saved is indicative only, since the choice of efficiency for separate generation in the formula above affects the results.

ANNEX 1

CHP PLANTS STATISTICS PROJECT 1998

WORK PROGRAMME

1. The objective of the project is to collect statistics on CHP plants in the Member State for the reference year 1998. The statistics refer to:

   - fuel utilisation and electricity/heat produced by operational CHP units in 1998 **(Table A)**

   - electricity/heat produced as well as installed capacities of operational CHP units for 1998 **(Tables B1, B2, B3)**

   - electrical installed capacities of CHP units planned or under construction in 1998 **(Tables C1 and C2)**

   The contractor will collect information only for the Member State he represents.

2. The statistics will be collected for individual CHP units. Should a plant have more than one unit, data should be collected on **each unit basis**. If a plant comprises non-CHP units, data on the latter should not be included in the present report.

3. The surveys will include CHP units with a *minimum* electrical capacity, of:

   -1000 kW for steam units,

   -500 kW for gas turbines,

   -100 kW for internal combustion engines.

4. The contractor will supply the following tables for the Member State he represents.

4.1 Units where the design heat-to-power capacity ratio is less or equal to 0.25 are considered marginal cases. For such units only aggregate statistics will be supplied for 1998 on:

-Gross electrical capacity (MW)
-Declared net capacity (DNC, see definitions) (MW).
-Net heat capacity (MW).

4.2 Units where the design heat-to-power capacity ratio is higher than 0.25 the following information will be supplied by the contractor:

4.2.1 <u>CHP units data for 1998</u> **(Table A, B1, B2, and B3)**

- Aggregate information (for all units) on fuel input, gross electricity generation, heat production and heat sold to third parties, by type of input fuel for operational CHP units in 1998 **(Table A).**

- Information on fuel input, gross electricity generation, heat production, electrical and heat installed capacities as well as the number of units, by type of cycle and sector for operational CHP units in 1998 **(Table B1 and B2)**.

- Information on the electrical and heat capacity, by fuel type for operational CHP units in 1998 **(Table B3)**.

4.2.2 CHP units data for units planned or under construction **(Tables C1 and C2)**

- Information on the gross electrical capacity and number of units, by type of cycle and sector for CHP units planned and under construction will be supplied for the reference year 1998 **(Table C1 and C2)**.

4.3 Methodology

A description of the collection methodology will also be supplied; estimates and assumptions made as well as an evaluation of the coverage and quality of the information supplied will also be included in the report.

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Table A: Operational CHP units fuel input and heat/electricity production by fuel for 1998

FUELS		UNITS	Public Utilities	Auto-producers
HARD COAL AND DERIVED PRODUCTS	fuel input	10³ mt		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
LIGNITE AND DERIVED PRODUCTS	fuel input	10³ mt		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
RESIDUAL FUEL OIL	fuel input	10³ mt		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
GASOIL	fuel input	10³ mt		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
NATURAL GAS	fuel input	TJ(GCV)		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
REFINERY GAS	fuel input	10³ tm		
	fuel input	TJ (NVC)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
COKE OVEN GAS	fuel input	TJ(GCV)		
	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
BLAST -FURNACE GAS	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
RENEWABLES	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
OTHER FUELS	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		
TOTAL	fuel input	TJ(NCV)		
	gross electricity generation	GWh		
	net heat production	TJ		
	of which sold to third parties	TJ		

NCV=Net Calorific Value
GCV=Gross Calorific Value

Table B1: Operational CHP units capacity and production by type of cycle for the year 1998

Type of cycle	Maximum capacity			Production			Fuel Input	Number of units
	Electrical		Heat	Electricity		Heat		
	DNC MW	Gross MW	Net MW	EDNC GWh	Gross GWh	Net TJ	TJ(NVC)	n
Combined cycle								
Steam : backpressure turbine								
Steam: condensing turbine								
Gas turbine with heat recovery								
Internal combustion engine								
Others								
TOTAL								

Table B2: Operational CHP units capacity and production by sector for the year 1998

Sector	Maximum capacity			Production			Fuel Input	Number of units
	Electrical		Heat	Electricity		Heat		
	DNC MW	Gross MW	Net MW	EDNC GWh	Gross GWh	Net TJ	TJ(NVC)	n
Public supply								
Autoproducers								
Mining and agglomeration of solid fuels								
Extraction of crude oil and nat. gas								
Coke ovens								
Refineries								
Extraction and processing of nuclear fuels								
Iron and steel industry								
Non-ferrous metals								
Chemical industry								
Non-metallic mineral products								
Extraction								
Food products, beverages and tobacco								
Textile, clothing and leather								
Paper and printing								
Metal products, machinery, equipment								
Other industrial branches								
Transport								
Services, etc								
Other								
TOTAL								

Table B3: Capacity of operational CHP units by fuel type for the year 1998

Type of fuel	Maximum capacity			Number of units
	Electricity		Heat	
	DNC MW	Gross MW	Net MW	n
Single-fuel fired units				
Solid				
Liquid				
Gas				
Others				
Multi-fuel fired units				
Solid & liquid				
Liquid & gas				
Solid & liquid & gas				
Others				
TOTAL				

Table C1: Capacity of CHP units under construction or planned by type of cycle and status
Reference year 1998

	Under construction		Planned	
Type of cycle	Maximum gross electrical capacity MW	Number of units	Maximum gross electrical capacity MW	Number of units
Combined cycle				
Steam : backpressure turbine				
Steam: condensing turbine				
Gas turbine with heat recovery				
Internal combustion engine				
Others				
TOTAL				

Table C2: Capacity of CHP units under construction or planned CHP by sector and status
Reference year 1998

	Under construction		Planned	
Sector	Maximum gross electrical capacity MW	Number of units	Maximum gross electrical capacity MW	Number of units
Public supply				
Autoproducers				
Mining and agglomeration of solid fuels				
Extraction of crude oil and nat. gas				
Coke ovens				
Refineries				
Extraction and processing of nuclear fuels				
Iron and steel industry				
Non-ferrous metals				
Chemical industry				
Non-metallic mineral products				
Extraction				
Food products, beverages and tobacco				
Textile, clothing and leather				
Paper and printing				
Metal products, machinery, equipment				
Other industrial branches				
Transport				
Services, etc				
Other				
TOTAL				

DEFINITIONS

A **CHP (Combined Heat and Power) unit** is a thermal installation in which the energy released from fuel is transmitted to an intermediate fluid. This intermediate fluid is normally directed in its entirety to electrical *generator sets*, designed and equipped in such a way that energy is partly used for driving the generator sets to produce electrical energy and partly to supply heat for various purposes: industrial uses, district heating, etc. The essential characteristic of a **unit** is that it is self-contained.

1. General Information

1.1 **Status** describes whether the unit is **operational, under construction or planned.**

1.2 **Economic activity code** is the activity code of the operator according to NACE classification.

The following classification will be used (including a breakdown for autoproducers):

Public supply system

Electricity production and distribution	NACE 40.1
Heat production and distribution	NACE 40.3

Autoproducers

Mining and agglomeration of solid fuels	NACE 10
Extraction of crude oil and natural gas	NACE 11
Coke ovens	NACE 23.1
Refineries	NACE 23.2
Extraction and processing of nuclear fuels	NACE 12, 23.3
Iron and steel industry	NACE 27.1, 27.2, 27.3, 27.51, 27.52
Non-ferrous metals	NACE 27.4, 27.53, 27.54
Chemical industry	NACE 24
Non-metallic mineral products	NACE 26
Extraction	NACE 13, 14
Food products, beverages and tobacco	NACE 15, 16
Textile, clothing, leather	NACE 17, 18, 19
Paper, publishing and printing	NACE 21, 22
Metal products, machinery, equipment	NACE 28, 29, 30, 31, 32, 34, 35
Other industrial branches	NACE 20, 25, 33, 36, 37, 45
Transport	NACE 60, 61, 62
Wholesale and retail trade, banking,	NACE 40.2, 41, 50, 51, 52, 55, 63,

administration, etc.	64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93, 95, 99, 01, 02, 05
Other (specify)	

1.3 **Public utility** is an undertaking whose principal objective is either:

- generation, transmission and distribution, or
- transmission and/or distribution of electrical energy for supply to third parties.

1.4 **Autoproducer** is an undertaking which, in addition to its main activities, generates electrical energy wholly or partially for its own use.

2. Technical Features

2.1 **Co-generation cycle type** refers to the different types of fossil-fuelled CHP units, namely:

- **Combined cycle** power units, where the plant comprises one or more gas turbines whose exhaust gases are fed to a waste-heat boiler, with simultaneous heat recovery
- **Steam plant with backpressure turbine**, which includes backpressure turbines with steam extraction
- **Steam plant with condensing turbine** where steam is extracted from the turbine (passout)
- **Gas turbine with heat recovery** at the exhaust or at another point in the cycle
- **Internal combustion** engine with heat recovery
- **Other** (to be specified).

2.2 **Maximum electrical capacity** of a co-generation power station is the maximum capacity, assumed to be active power, that could be generated continuously throughout a prolonged period of operation, with the additional assumption that the magnitude and method of production of the heat supply are, under all conceivable circumstances, those which generate maximum electrical capacity. This capacity must be related to benchmark climatic conditions representative of the assumed mean ambient conditions for the unit.

As regards the distinction between gross and net capacity, all the auxiliary services of the installation should be taken into account. These include the auxiliaries relating to the electrical energy and heat production circuits. However, they do not include the auxiliaries corresponding to the heat transport and distribution network (e.g., hot water circulation pumps).

2.3 **Maximum net heating capacity** of a co-generation power station is the net heat transfer from the installation to the heating network. It is the heat in the hot fluid supplied to the heating network less, where appropriate, the heat returned to the installation by the fluid returning from the network.

This capacity is **net**, meaning that it is related to the point of entry to the heating network, and excludes the heat consumed by the installation's auxiliaries, which use a hot fluid (space heating, liquid fuel heating, etc. ...), and losses in the installation/network heat exchangers.

This net heating capacity is said to be the maximum achievable, meaning that it assumes that the output and method of production of electrical energy supply are, under all conceivable circumstances, those which generate maximum heat production.

2.4 **Declared Net Capacity (DNC)** of a CHP unit is normally the maximum net electrical capacity of a CHP unit. However, in the following three cases:

a) marginal CHP unit of a heat-to-power capacity ratio less than 0.25
b) steam units with condensing turbine operated with low heat production compared with electricity generation
c) gas turbines or internal combustion engines which could be operated without heat recovery whenever there is a low heat production compared with electricity generation. The declared net capacity (DNC) is defined as:

$$DNC = \frac{H}{Cm}$$

where H is the heat capacity of the unit and Cm a default value for the heat/power ratio.

Cm default value	
Combined cycle	1
Steam turbines (condensing, back pressure)	4
Gas turbines	2
Internal Combustion engines	2

Clearly, the DNC is the capacity of a notional CHP unit with the default Cm value whenever the actual CHP unit has a low design heat/power ratio or whenever a well designed unit is operated with low heat production due to a low heat demand.

2.5 **Electricity generation of a CHP unit** (E_{DNC}) will be equal to the actual gross electricity generation of the CHP unit. However, in the three cases mentioned under point 2.4, it will be calculated as:

$$E_{DNC} = \frac{\text{net heat production}}{Cm}$$

Where Cm is the default heat/power ratio given in paragraph 2.4. It is actually the electricity generation corresponding to the DNC capacity

2.6 **Fuel input** refers to the total fuel consumed during a year by the CHP unit for the production of both heat and electricity.

2.7 **Net Heat production** refers to the total heat produced during the year. The portion sold to third parties refers to the heat transferred outside the company (minus the heat consumed *in situ* by autoproducers).

2.8 **Gross electricity generation** is the electricity generated by the CHP unit during the year measured at the output terminals of the main generator.

3. Classification by fuel for conventional thermal CHP units

3.1 **Single-fuel fired** refers to units using only one designated type of fuel on a continuous basis.

3.2 **Multi-fuel fired** refers to units using more than one designated type of fuel successively and/or in combination on a continuous basis.

A distinction is made between the following types of fuel:

- solid fuels, including all types of coal, lignite and derived products, blast furnace gas and coke oven gas
- liquid fuels, including all oil products, refinery gas and petroleum coke
- natural gas, including natural gas, gas works gas/substitute natural gas
- other fuels, including all other fuels such as peat, wood, wood waste, municipal and industrial waste, black liquor, biogas, landfill gas etc.

4. Fuel types

4.1 **Hard coal and derived products** comprise:

- Hard coal
- Patent fuel
- Coke i.e. hard coke, gas-works coke and coal semi-coke.

4.2 **Lignite and derived products** comprise:

- Lignite
- Peat
- Brown coal briquettes
- Peat briquettes

4.3 **Residual fuel oil** is diesel oil with a viscosity greater than 115 seconds Redwood at 37.7 °C

4.4 **Gasoil** has viscosity of less than 115 seconds Redwood at 37.7 °C

4.5 **Natural gas:** essentially methane but contains small proportions of other gases. It covers non-associated natural gas, associated natural gas and methane recovered in coal mines

4.6 **Refinery gas** composed mainly of hydrogen, ethane, methane and olefines

4.7 **Coke-oven gas:** gas recovered as by-product of coke ovens

4.8 **Blast furnace gas:** gas recovered as by-product of blast furnaces

4.9 **Renewables:** fuels that are renewable in nature, such as wood, wood waste, straw, black liquor, biogas, landfill gas and municipal solid waste

4.10 **Other fuels:** gases, solids or liquids not mentioned above.

ANNEX 2

CHP PLANTS - TECHNICAL FEATURES

1. GENERAL FEATURES OF CO-GENERATION

It is a well known fact that the conversion of thermal energy, such as that released from fuels, into mechanical energy (and subsequently into electricity) is subject to the second law of thermodynamics, whereby some of the heat (hot source) degraded by the conversion itself must inevitably be released into the environment (cold source). In relative terms, this fraction is greater the lower the absolute temperature at the start of the conversion cycle (Carnot’s law). The most efficient conventional steam-condensing power stations have difficulty in reaching an actual efficiency of 40%, which means that around 60% of the potential heat from the fuel used goes to waste with undesirable consequences for the environment.

Even with more modern and sophisticated cycles, such as the combined gas/steam cycle that has recently established itself in large-scale power generation, the global efficiency in practice is no more than 50% in the most technically advanced plants. Even under these circumstances, therefore, the heat released into the environment is still well over half the thermal energy developed by the fuel used. Similar efficiencies are found in the other types of prime movers (e.g. Otto or Diesel reciprocating cycles), and gas turbines come lower still.

On the other hand, in many industrial processes and in other human activities there is often a need to produce low- or medium-temperature heat, so direct use is made of fuels capable of much higher fuel temperatures and, in these cases, the benefits of being able to generate higher forms of energy are wasted and their best qualities are largely degraded.

This serious drawback can be avoided, by first producing (from the same or other equivalent fuels) mechanical energy converted into electricity, and using the waste heat from the prime mover, which otherwise would have to be discharged to the environment.

This combination of both uses in sequence means that the primary energy actually required for the combined power and heat production (co-generation) is substantially lower (by 15 to 30% depending on the type of plant) than what would usually be needed if the power and the useful heat were produced separately.

An installation of this type is known as a "combined heat and power station" or, briefly, a "co-generation station". This description applies only when both outputs are closely associated and interdependent.

For example, if a complex consists of a boiler that feeds a steam thermal power plant for producing electricity only but is also connected to some thermal outlet to which it supplies live steam directly, this cannot be described as a co-generation plant. In this case, the electricity produced is not associated with the supply of useful heat, so no energy benefit is gained from combining the two outputs, which are not in sequence.

Since the fundamental characteristic of co-generation lies in the saving of primary energy, co-generation results not just in economic and energy savings - it also helps protect the environment, as the reduced fuel requirement means a reduction in pollutants. This benefits society as a whole, enhances the quality of life and stabilizes the global environment.

Co-generation plants differ according to the type of thermal prime mover used to convert the energy of the fuel into mechanical energy and then into electricity. Each type has its own benefits and limitations and is better suited than the others to the characteristics and requirements of various fields of application.

There is not, therefore, a single optimum solution - each case must be carefully evaluated in order to identify the type of plant best suited to the specific technical and economic requirements of the particular case.

The basic types are as follows:

- steam-turbine units using back pressure (Fig. 1.1) or condensation and extraction units (also known as extraction plant, Fig. 1.2);

- gas-turbine plant with a boiler to recover the heat from the exhaust gas (with or without further boiler combustion = after-burn) (Fig. 1.3);

- plant with internal-combustion reciprocating engines (Diesel or Otto cycle) recovering the heat from the exhaust gas and from other points of the cycle (Fig. 1.4).

In recent years a further type of plant has been establishing itself in the form of a combination of a gas-turbine with recovery boiler and a steam turbo-set downstream, fed with the high-pressure super-heated steam generated by the boiler itself. This cycle is known as "combined gas and steam" (Fig. 1.5). Even though its name is rather similar to the term for "combined heat and power" plant, this type of compound plant is not necessarily a co-generation plant: it becomes so if most of the heat discharged from the steam generator is usefully exploited.

The thermodynamic efficiencies from this latter type of plant are among the highest obtainable in thermal power generation, for it combines the benefit of the high starting temperature in the cycle with good use of the waste heat from the gas turbine to produce high-quality steam capable of feeding steam cycles; if used in co-generation, it simultaneously yields high electricity output and very high efficiency in the use of the primary energy from the fuel. Advances in the technology of gas turbines and of high-pressure recovery boilers now enable this type of plant to be used widely.

Figure 1.1: Steam turbine unit of back pressure type

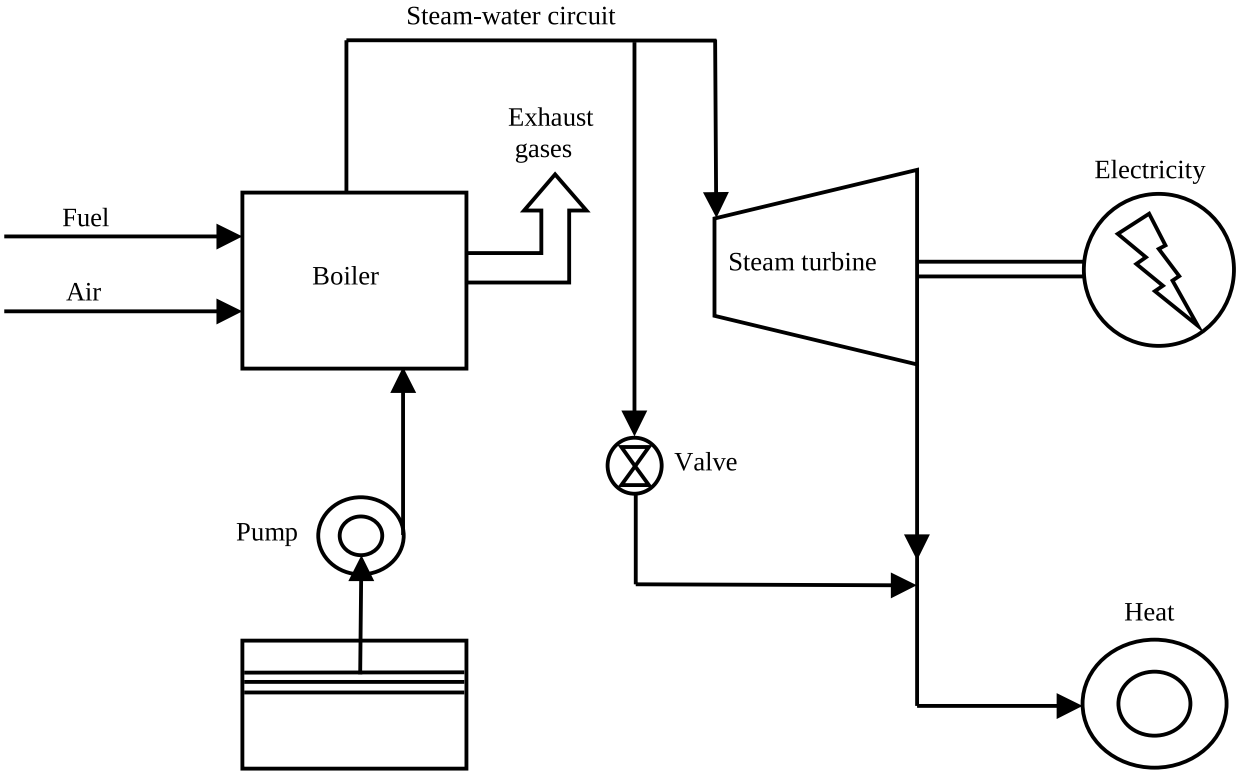


Figure 1.2: Steam turbine unit of condensation/extraction type

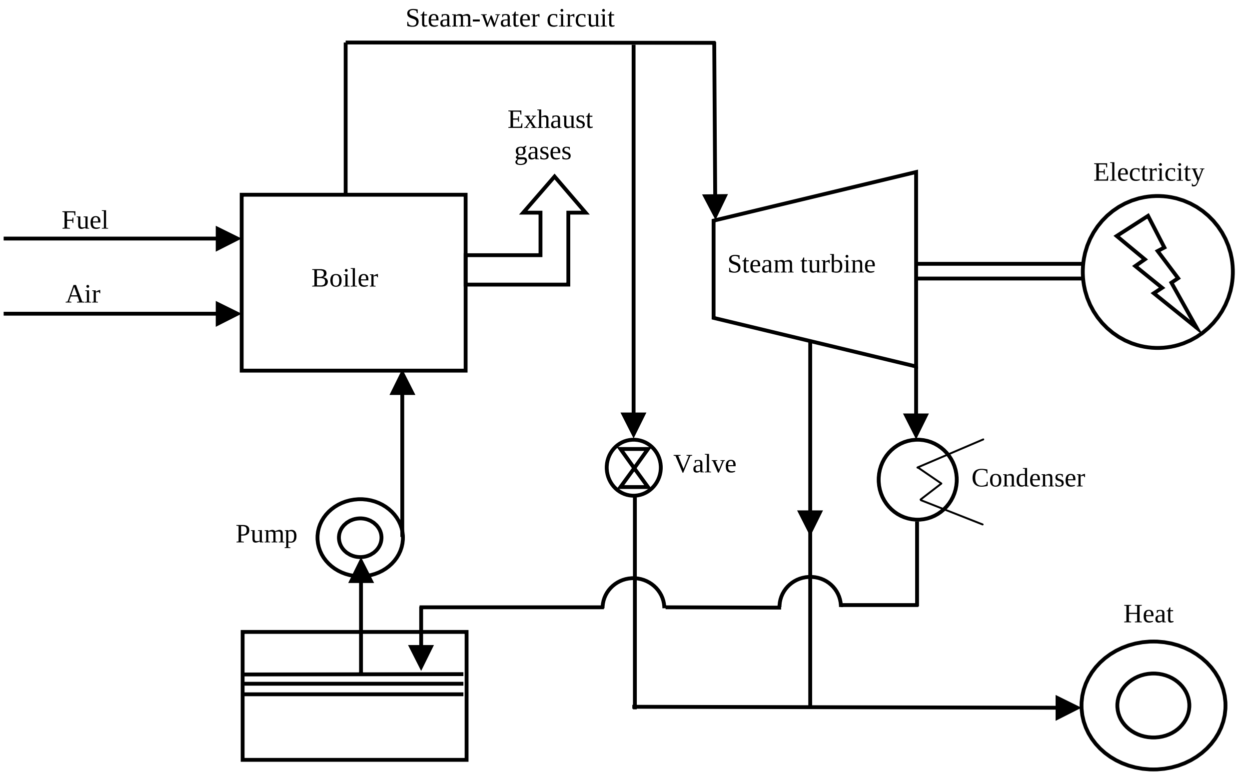


Figure 1.3: Gas turbine with heat recovery

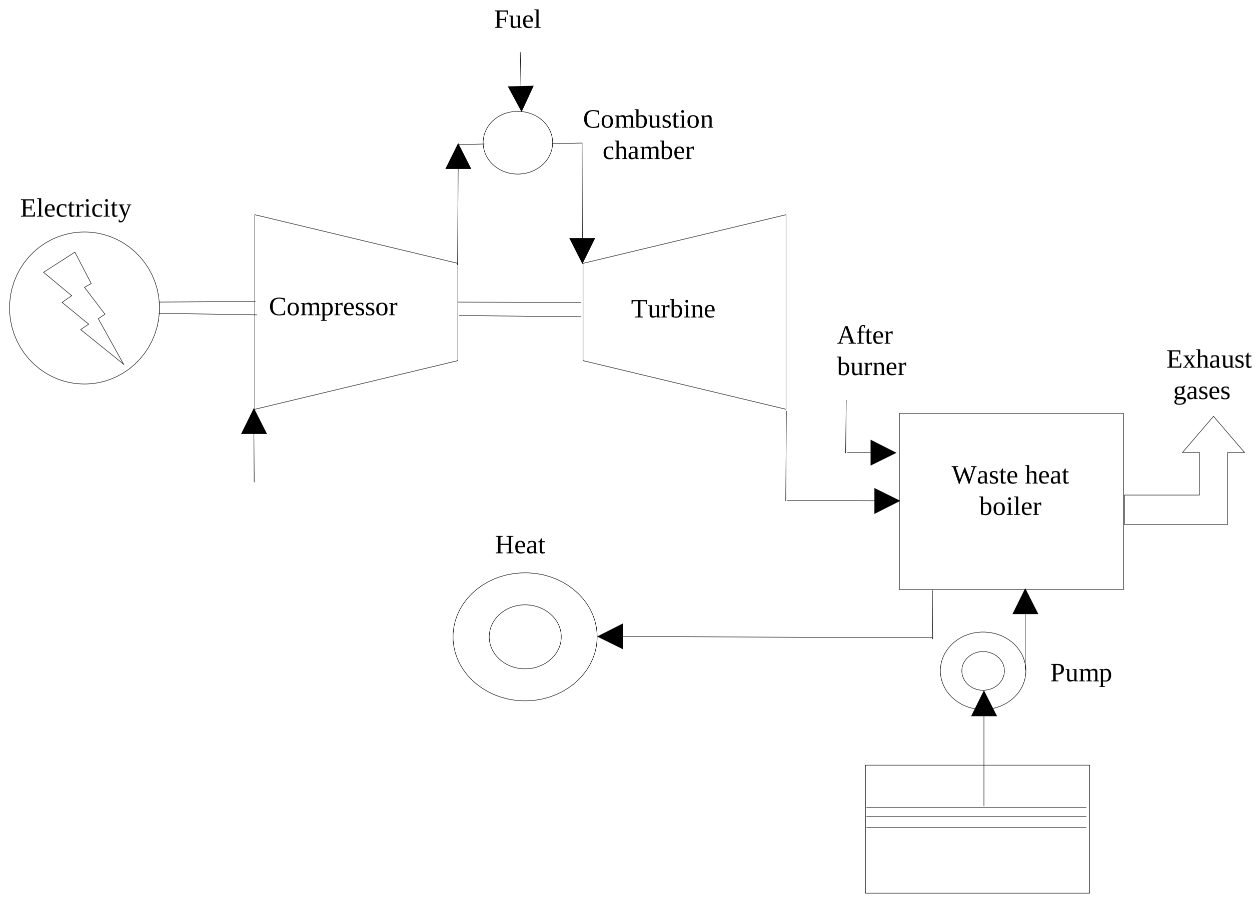


Figure 1.4: Internal combustion engine

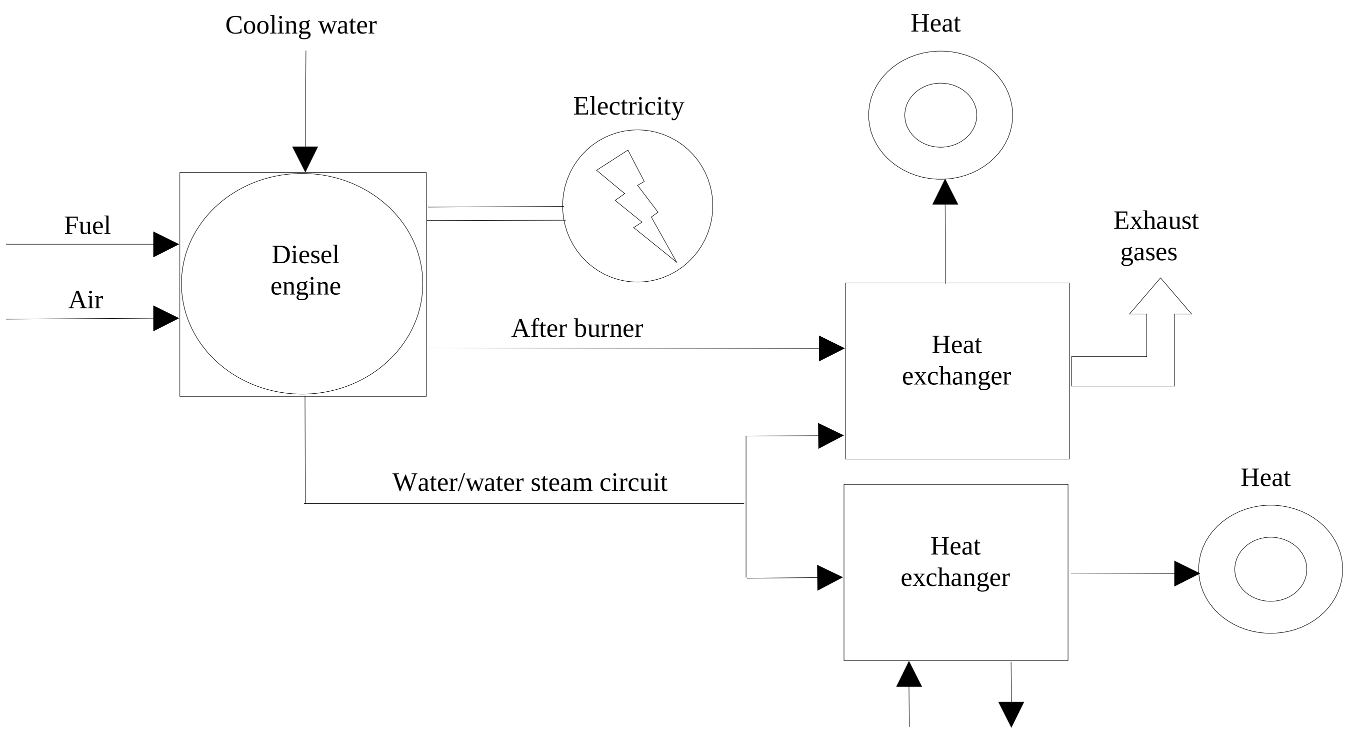
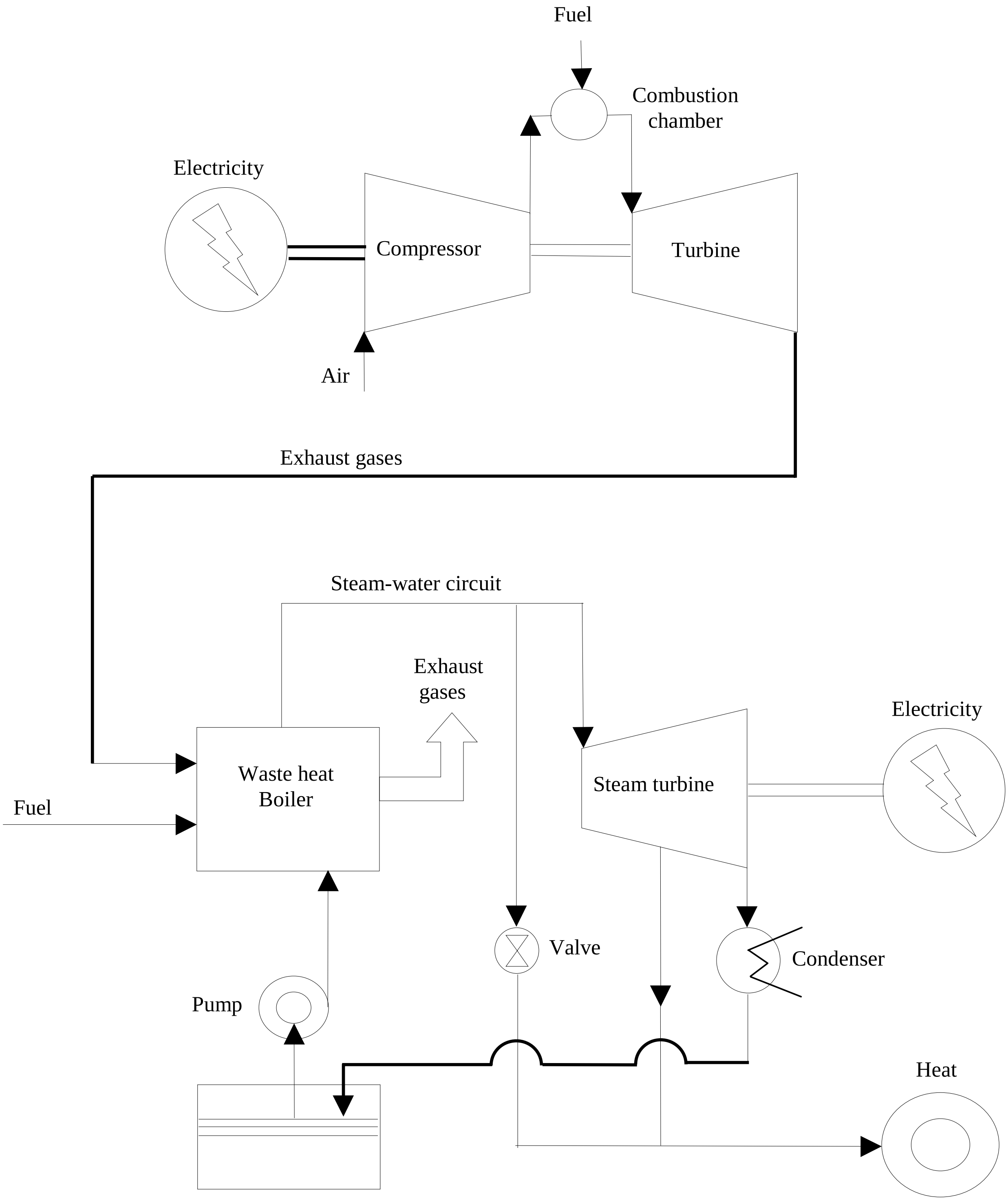


Figure 1.5: Combined cycle



2. TYPICAL PARAMETERS FOR A CO-GENERATION PLANT

A conventional parameter for evaluating the performance of a given system (engine or plant) is its "efficiency", i.e. the ratio between what is delivered by the system and what is consumed.

Let us consider a co-generation plant where H is the useful heat supplied to the process fluid. If R_c is the efficiency of a conventional boiler (or that replaced by the co-generation plant), the consumption of heat H_c to be assigned to the production of useful heat is given by:

$$H_c = \frac{H}{R_c}$$

If the input heat (fuel) required by the prime mover is H_m (assuming that the fuel is fed in at a single point in the cycle), the consumption of heat to be assigned to the production of electricity, H_e, is:

$$H_e = H_m - H_c$$

This procedure (also known as the Ecabert method) is based on the approach of deducting from the total energy requirements of the cycle that portion relating to the heat, and so finding the marginal consumption to be attributed to the production of electricity.

If E is the output of electricity of the co-generation plant, the specific consumption C_{se} to be assigned to the production of electricity is given by:

$$C_{se} = \frac{H_e}{E} = \frac{H_m - H/R_c}{E}$$

The marginal efficiency for electricity generation is given by:

$$R_e = \frac{1}{C_{se}}$$

The marginal efficiency for electricity generation, R_e, is a single quantity in numerical terms, although this depends on the value assumed for the efficiency R_c of the conventional boiler to which we attach the consumption H_c required to supply heat H to the process fluid.

This quantity is useful whenever we compare the electricity generation obtained with various plant types. In order to understand how the plant reacts to the effects of using the heat, we must look at the corresponding calorific flows.

The thermal efficiency, U, of a co-generation plant is defined as:

$$U = \frac{E + H}{H_m}$$

where:

H = heat supplied to the process fluid

E = electricity generated

H_m = primary energy requirement of the prime mover (fuel consumption)

The index of energy saving evaluates the quantity of primary energy saved by a co-generation plant compared with the separate production of thermal energy and electricity in conventional units:

$$S = \frac{E}{R_p} - \left[H_m - \frac{H}{R_c} \right]$$

where:

R_p = efficiency of a reference thermal power plant for producing electricity only. It may be another unit installed at that outlet (in which case S gives the actual saving of that outlet), or it may be the efficiency of thermal generation (S then gives in relative terms the primary energy saved at national level by using co-generation).

R_c = efficiency of the equivalent conventional boiler replaced by the co-generation plant.

3. PRIME MOVERS

The prime movers available on the market for use in co-generation are as follows:

- steam turbine
- gas turbine
- reciprocating internal-combustion engine.

The parameters which may influence the choice, regardless of the co-generation parameters listed above, are:

- type of fuel available
- reliability of operation
- start-up time
- maintenance cost and time
- ease of adaptation to the requirements of the process
- operational costs.

A prime mover alone, even if suitable for supplying one of the two forms of derived energy, does not represent a co-generation system but requires a series of appliances which constitute the system as fitted to meet the purpose of co-generation.

There are also variants, which allow a prime mover to be adapted for different types of plant, or for mixed-type plants to improve exploitation of the energy by making optimum use of the characteristics of the two types of prime mover.

Steam turbines

To date, steam-turbine plants have been the most common type used for the combined production of electricity and heat. A steam unit consists of a boiler suitable for producing super-heated steam which is sent to a steam turbine that can be either condensation or back-pressure or combined (condensing plus extraction).

A. Back-pressure turbine (Fig. 1.1)

High-pressure steam generated in a boiler is run through a turbine, where it expands and cools. If electricity generation is to be maximised, the exhaust pressure should be kept as low as possible. This implies that the exhaust steam is saturated and therefore its pressure, energy content and temperature are interdependent. If the temperature of the exhaust steam is only a few dozen degrees celsius, there is in practise no useful energy obtainable from the steam after the turbine and a large portion of the energy is exhausted into the cooling water or air.

In backpressure power plants, the purpose is not to maximise electricity production, but to satisfy the heat demand of an industrial process or a district-heating network. The energy content of the exhaust steam depends mainly on its pressure, and by changing the exhaust pressure it is possible to control the heat to power ratio of a backpressure turbine. Increasing backpressure decreases the electricity generation in favour of heat production. It may also be possible to extract steam at an intermediate pressure from the turbine, in which case the heat production is increased.

Where hot water is required, as it typically is in the case of urban district heating, the exhaust steam from the turbine condenses in a "hot condenser" where the heat is extracted by the water going to the grid.

The electricity generation of a total backpressure turbine can be considered completely CHP production.

Backpressure turbines are the most common types used for CHP generation in industry. They can exploit any type of solid, gaseous or liquid fuel. Unlike internal-combustion engines and gas turbines, which are chosen according to the sizes available on the market, steam turbines may, to a certain extent, be customised to the power demand of the plant. Backpressure steam-turbine units are characterised by high thermal efficiencies, which can reach and sometimes exceed 90%. The efficiency for the electricity generation is usually in the range 15-25%.

B. Steam Turbine with Extraction and Condensation (Fig. 1.2)

If the exhaust steam from the turbines is fully condensed at a very low pressure, no useful heat is produced unless steam is extracted at intermediate pressure from the turbines. Condensing steam turbines must allow steam extraction if they are to be eligible for CHP generation. In this type of unit, part of the steam expands within the turbine down to a pressure less than atmospheric, whilst some of it is taken off at an earlier stage.

Unlike pure backpressure plants, the thermal efficiencies produced are not particularly high because not all the exhaust steam is extracted and sent to the process: some of it (generally no less than 10-20%) is dissipated to the condenser.

The efficiency of the electricity generation of condensing steam plants with heat extraction very much depends on the amount of heat produced. In completely condensing mode, when no useful heat is produced, the efficiency can be around 40%.

In the industrial field, extract-and-condense turbines can be used where high levels of electrical power are required, with a variable characteristic thermal index. This is because, unlike the backpressure turbine, which is inflexible as regards ability to vary the thermal load, the condense-and-extract turbine is very flexible in operation, with wide modulation of steam output for the process.

Condensing steam turbines are generally used in large electricity generating power plants. In Northern Europe in particular they are often used for generating district heat and often operate in full condensing mode in summertime, producing electricity only. This electricity, known as “condensing power”, is not considered CHP generation.

The term “condensing electricity” is also sometimes used for the electricity generation of other types of cycles, when the generation does not fulfil the definition of simultaneous exploitation of the thermal energy for electricity and heat production by co-generation. In steam turbines in particular, even if a small percentage of the steam is condensed, the portion of the generated electricity corresponding to the amount of wasted heat should not be considered CHP generation.

In steam power plants, backpressure or condensing-type units, steam may often be extracted before the heat-generation turbine. This is done by means of a steam reduction station. The heat obtained by this method is not CHP heat, since the steam is not run through the turbines and the thermal energy of the reduced steam is therefore not used for electricity generation.

The following conclusions may be drawn from an initial comparison between the two previous types of CHP plant:

- the backpressure turbine supplies a lot of thermal energy and not much electricity, at low unit cost, but cannot adapt to major variations in the heat/power ratio.
- the extract-and-condense turbine can adapt instantly to the demands of the process, for either heat or power, but at the cost of lower energy efficiency, i.e. unit cost of production, which rises as more steam goes to the condenser.

Gas Turbine with heat recovery **(Fig. 1.3*)***

Industrially produced gas turbines cover a range of unit power from a few hundreds of kW up to 100 MW and beyond. There are "heavy-duty" machines and aviation-derived machines, the latter having more advanced characteristics and higher efficiency. Electrical efficiency varies from 17% to 33%. Gas turbine cycles may be used as stand-alone power-generating units or they may be combined with steam cycles or with internal combustion engines.

Gaseous or liquid fuel is injected into high-pressure air, where the combustion occurs. The hot gas is led through turbine and the exhaust gases are used to generate useful heat. The temperature of the exhaust gases from a gas turbine may vary from 400°C to 600°C, making it possible to exploit the heat recovered in many different forms: hot water or industrial super-heated steam, and steam for generating electricity in a steam turbine. The characteristics of the steam that can be produced, which relate directly to the temperature of the exhaust gases, assume maximum guideline values of 480°C and 65 bar for direct recovery from a typical gas turbine.

The heat recoverable from gas turbines is almost totally concentrated in the exhaust gas. This characteristic substantially reduces the complexity of the thermal section, which is restricted to a single heat exchanger, although this is large, because of the quantity of gas involved.

As stated above, the thermal level of the exhaust flow from the gas turbine is quite high and lends itself particularly well to the recovery of exhaust heat. Within the limits of its characteristics, and according to the user's requirements, it is possible to reach high values for the total thermal efficiency (75 to 80%).

Another special feature of the exhaust flow from gas turbines is the high percentage of oxygen that remains present (more than 16 to 17% by weight). Hence an after-burn is possible without adding air for a further upgrade of the quantity and/or quality of the heat recoverable. Additional fuel is also fed into the exhaust gases and marginally improves combustion efficiency (close to 100%), as the thermal power lost on the way remains practically unchanged. The excessive heat generated by post-firing is not, of course, CHP heat.

Gas turbines may be run by partly or completely bypassing the heat recovery station. In this case, the thermal energy remaining in the exhaust gases is not used for heat production and the electricity generation corresponding to the bypassed gases is considered "condensing power" rather than CHP generation.

The efficiency of the electricity generation of a simple stand-alone gas turbine unit is typically lower than that of a condensing steam unit. However, the construction costs of a simple gas turbine power plant per kW are relatively modest, which is why they are often used to cover demand for electricity during peak load conditions.

Reciprocating internal-combustion engines (Fig. 1.4)

The range of reciprocating engines used for co-generation covers a value up to about 20 MW in power, starting from power levels of the order of a few kW with car-derived engines.

The reciprocating engines most used for co-generation fall into two clearly distinct categories:

- Diesel-cycle engines, using gasoil or (for sizes above 800 or 1000 kW) heavy fuel oil,
- Gas Otto-cycle engines, using fuel gas (natural gas, biogas, etc.).

The main difference lies in the ignition (the Otto-cycle engines have spark ignition), in the electrical efficiency and in the heat released to exhaust gases.

An important characteristic of the Diesel-cycle reciprocating engine is its high efficiency in generating electricity: this ranges from 35% to around 41% for the smaller and large sizes respectively.

Heat is recovered by exploiting, in addition to the exhaust gas, other sources of heat such the cooling water, lubricants and sometimes, in supercharged engines, the heat available from the need to cool the supercharge air.

The quality of the heat recovered is not high owing to the modest temperatures characteristic of the various sources, except for the exhaust gases - though these contribute only about 50% of the total. Large- and medium-range generator sets may yield hot or super-heated water or even low-pressure steam (6-7 bar). With small diesels, the recovery is on average restricted to the production of hot water only at about 90°C.

The internal combustion engines can be combined with some other cycles, for example with steam or gas turbines.

The internal combustion engines are used for a wide range of purposes. They have been popular as reserve capacity in hospitals, nuclear power stations etc., but are increasingly being used in conventional power generation. Gaseous fuels can be used in internal combustion engines in addition to traditional liquid fuels.

The combined gas/steam cycle in co-generation (Fig. 1.5)

More than one (usually two) types of cycle are placed one after another so that the residual heat of the previous cycle is exploited in the next cycle. In principle, any combination of cycle is possible, but the second cycle is most often a steam generator with corresponding turbine. The first cycle is gas turbine or in some cases internal combustion engine.

In many cases, the heat of the exhaust gases from the gas turbine used to supply thermal energy into the steam cycle is supplemented by injecting additional primary energy into the boiler through post-firing, where fuel is burned by using the remaining oxygen in the exhaust gases – see Fig. 1.5. If the steam turbine is of the fully condensing variety with no heat extraction facility, the electricity generated by the turbine should not be considered CHP production.

This type of plant makes it possible to attain high thermal efficiencies in converting the primary energy of the fuel into mechanical and electrical energy, since there is an actual temperature change close to 1000°C, compared with the approximately 550-600°C used in the most modern steam cycles, and – separately – in single cycles using gas turbines.

As stated above, efficiency here approaches and – in the most recent and larger units – may exceed 50%. By combining the thermodynamic benefits of this cycle with the useful exploitation of the final exhaust heat from the steam cycle (which would otherwise be lost into the environment), co-generation occurs, producing a major increase both in the coefficient of use of the fuel and in marginal efficiency for the production of electricity. This all means that the unit has substantial economic profitability, but there are also good savings in primary energy for the same heat and power requirements, and resultant concrete advantages to the community in terms of savings of energy resources and environmental protection.

The combined gas/steam cycle has recently been adopted more widely, especially in some sectors of industry and in the small-to-medium power range (a few kW), through the increased market availability of efficient and proven models of gas turbines even in these power ranges.

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This report contains a summary of statistics on Combined Heat and Power (CHP) production in the EU for the period 1994-1998. Collection of these statistics was co-funded by the European Commission under the SAVE programme. The report gives a description of the applied methodology as well as trends in CHP capacity and generation by Member State and type of cycle. The use of various fuels is also included.