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List of Abbreviations:

IEA	-	International Energy Agency
AFC	-	Alkaline Fuel Cell
AQS	-	Hot Water for Sanitary Purposes
Bio	-	Biomass and Biogas
CAE	-	Economic Activity Code
CCG	-	Combined Cycle Gas
EC	-	European Community
CEETA	-	Community Empowerment and Education Through the Arts Project
CHP	-	Combined Heat and Power
CO	-	Organic Cycle / Carbon Monoxide
CO2	-	Carbon Dioxide
COP	-	Coefficient of Performance
BP	-	Backpressure
dBA	-	Decibel
DGEG	-	Directorate-General for Energy and Geology
DL	-	Decree-Law
WD	-	Working Days
EDP	-	Energias de Portugal
EE	-	Electric Energy
ET	-	Thermal Energy
FO	-	Fuel oil
Fv	-	Outside High Periods
NG	-	Natural Gas
LPG	-	Liquid Propane Gas
INE	-	National Statistics Institute (Portugal)
MCFC	-	Molten Carbonate Fuel Cell
GE	-	Gas Engine
NREL	-	National Renewable Energy Laboratory
ORC	-	Organic Rankine Cycle
PAFC	-	Phosphoric Acid Fuel Cell
PEMFC	-	Proton Exchange Membrane Fuel Cell
PES	-	Primary Energy Savings
PNAEE	-	National Action Plan for Energy Efficiency
PNALE	-	National Plan for Attributing Emissions Licences
RCCTE	-	Regulations for the Thermal Characteristics of Buildings
REE	-	Electric Yield Equivalent
REN	-	Redes Energéticas Nacionais
SEN	-	National Electric System

SEP	-	Public Electricity System
SOFC	-	Solid Oxide Fuel Cell
GT	-	Gas Turbine
Ton	-	Tonne
GAV	-	Gross Added Value

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Summary of this study

Before ascertaining the potential for high-efficiency cogeneration, a detailed profile of cogeneration activities in Portugal was prepared. Cogeneration currently represents an important component of electricity production, corresponding to approximately 13% of electric energy produced.

As per the data provided by various entities, at the end of 2007 the installed cogeneration capacity was very close to 1 400 MWe, of which the largest percentage was used by chemical, paper and textile industries. The electric energy produced in 2007 in the cogeneration facilities was 5.4 TWh, which complemented a production of approximately 12 TWh of thermal energy. Due to cogeneration around 80 GWh of losses were also avoided, representing a saving of 1 000 kTEPs of primary fuels, as well as a reduction of approximately 2.6 Million tons of CO_2 emissions.

A significant potential for high-efficiency cogeneration was identified both in the industrial sector as well as in the services sector. The percentage of primary energy that could potentially be saved in the diverse industrial sectors varies between 10.9% and 16.4%, while for the service sectors this percentage varies between 9.7% and 16.3%. The reduction in consumption for the different economic sectors was estimated on the basis of the values that were obtained for primary energy savings thus indicating the overall impact of the potential for high-efficiency cogeneration.

In an optimistic scenario, a reduction in the consumption of primary energy can be achieved in the industrial sector of approximately 493 ktep/year, i.e. 81% of the total overall national potential of 608.8 ktep/year. In the field of **Industry** a potential of 1 377 MWe was identified, distributed as 677 MWe from the conversion of fuel oil fuel to natural gas, with the remaining 700 MWe corresponding to the new capacity that will be installed. After adding this to the 1 368 MWe that already existed in 2007, it will represent an installed electric capacity of 2 068 MWe in 2020.

A reduction of approximately 116 ktep/year could be obtained in the services sector, i.e. 19% of the potential for overall reduction. A potential to achieve 252 MW of installed capacity by 2020 was identified in this sector, due to an increase of 221 MWe of this capacity. This is a highly significant increase when compared to the installed capacity in 2007, which only totalled 31 MW.

In effect, the following values were estimated for the national potential, over the course of the diverse timeframes, for the two scenarios that were established.

Year	Optimistic (MWe)	Pessimistic (MWe)
2010	1 750	1 697
2015	2 065	1 862
2020	2 320	1 979

The net total of emissions resulting from the implementation of the added potential that has been identified, already considering the possible substitution of the use of the fuel, would translate into an annual saving of emissions of 4.7 Million tons CO_2/Year.

Given the existing legal framework and bearing in mind the current state of cogeneration technologies that could be used in the residential sector, more specifically their economic viability when compared to other options available on the market for heating and/or cooling, the increasingly better quality of insulation in buildings, as well as Portugal's mild climate, it was concluded that there is no relevant potential for the penetration of high-efficiency cogeneration in this sector before 2020. However, in the long-term, as new cogeneration technologies mature, coupled with access to other energy sources and the inevitable tendency towards increasingly sophisticated systems to manage and distribute energy, the possibility of a greater use of cogeneration systems in the residential sector cannot be discarded.

Notwithstanding this acknowledgement of the positive impact of the existing policy of incentives, various barriers have been identified that hinder a more accentuated development of cogeneration in Portugal, more specifically, technical, economic and political barriers. The following points represent a series of recommendations to be kept in mind with a view to overcoming these barriers:

- Network links should be assessed in a focused manner to ensure a balance between local production and consumption. While conducting studies that analyse the impact on the network associated with the links of producers encompassed by a special regime this impact should mainly be conditioned by a balance between cogeneration production and the local consumption of electric energy by consumers of heat.

- An compulsory declaration on cogeneration potential for every licensing process for new facilities.

- Maintaining a framework of incentives to ensure continuous efforts for environmental and energy optimisation aimed at achieving primary energy savings with regard to new facilities and likewise encompassing existing facilities, which internalise their merits through gains generated by this activity (environmental and energy efficiency, transmission losses, contributing towards the reliability of the electric energy supply system and an increased Gross Added Value (GAV) and enhancing the competitiveness of a vast range of sectors in the national economic fabric, etc.)

- The system of incentives must create stable conditions for promoters of new projects, based on a suitable remuneration for their investments, indexed to the prices of acquiring primary energy sources that are within the reach of the cogeneration facilities and the European context. In particular, the Spanish framework should be kept in mind given the growing integration of the Iberian electricity markets.

- Create bases for supplying equipment and services from national sources associated with the development of cogeneration, especially in areas such as “boilermaking”, “electricity and control systems”, service and maintenance, etc...

- Create bases to encourage a vigorous and feasible expansion of renewable cogeneration, more specifically through initiatives to promote the sustainable expansion of the chain of economic activities linked to the forestry sector, in which Portugal has competitive advantages. Apart from multiple positive impacts on the economy, the industries linked to this sector (cellulose, agglomerates, furniture) have a high potential for using renewable cogeneration.

- Establish clear timeframes for the approval of cogeneration projects, ensuring a simpler and more streamlined licensing process.

- Develop programmes to disseminate information on cogeneration and publicise case studies of success stories in sectors that have higher potential.

1 Introduction

Directive 2004/8/EC of the European Parliament and of the Council, of 11 February 2004, on the promotion of cogeneration based on demand for useful heat in the internal energy market, which amended Directive 92/42/EEC, obliges all Member States to carry out a study on the national potential for high-efficiency cogeneration (Article 6). The said directive similarly stipulated the terms for this analysis, as well as the analytical mechanisms, the means of calculating the electricity produced by cogeneration and the methodology to determine the efficiency of the cogeneration process, amongst other issues. Thus, the directive provides a uniform methodology, with a view to standardising the procedures for assessing the national potential obtained by the different Member States.

Cogeneration is understood to be the process in which thermal energy and mechanical energy (normally converted into electric energy) are produced simultaneously, used for own consumption and/or consumption by third parties, from a fuel source (biomass, fuel oil, natural gas, propane gas, biogas, industrial waste, etc.). It is a technology that significantly increases the efficiency of converting energy resources, thus resulting in primary energy savings (PES).

Directive 2004/8/EC requires Member States to carry out a study on high-efficiency cogeneration. This is defined according to the energy savings obtained through the combined production of heat and electricity, as compared to separate production. Achieving primary energy savings of more than 10%, in cogeneration units that have an installed capacity of more than 1 MWe allows the cogeneration facility to be classified in the category of high-efficiency cogeneration. Should the unit have an installed capacity of less than 1 MWe, it is sufficient for it to achieve positive primary energy savings to be considered a high-efficiency cogeneration facility.

Chapter 2 of this report provides an overview of the current situation in Portugal with regard to cogeneration, including a comparison with the European context. This chapter provides information on the national scenario in terms of the installed capacity of cogeneration units in diverse sectors, more specifically Industry and Services. It also provides a comprehensive survey of the installed capacity according to the different technologies used as well as the evolution of cogeneration in Portugal over the course of the years. Tables have been included that illustrate the consumption by diverse economic activities as well as the production of thermal and electric energy in cogeneration facilities. It also examines the issue of the output of different configurations of cogeneration systems, associating them with typical levels of profitability of equity capitals corresponding to the investments for the respective range of configurations for cogeneration facilities.

Chapter 3 analyses the potential for high-efficiency cogeneration in Portugal. It describes the methodology used to ascertain the economic potential, both for the industrial sector as well as for the services sector. The resulting values underscored the positive impact of the implementation of Directive 2004/8/EC in Portugal. This chapter likewise examines the residential sector although in this case in particular, it was concluded that it is not yet economically viable to implement this technology in Portugal. The final section of Chapter 3 provides an overview of the existing technology, the fuels used and the savings achieved and the evolution of the economic potential within a timeframe extending up to 2020 for an optimistic scenario. It also presents estimated evolution for a pessimistic scenario.

Chapter 4 provides a list and concise descriptions of the main technical, political, economic and other barriers, which hinder the development and a wider proliferation of cogeneration technologies in Portugal. Possible solutions or measures have been suggested for each of the obstacles that were identified, in order to mitigate/ overcome these impediments, thus promoting high-efficiency cogeneration.

Chapter 5 presents the final conclusions derived from the results of this study, while proposing various recommendations to promote the use of high-efficiency cogeneration in the industrial and services sectors.

This analysis entailed an extensive study of the consumption of electric and thermal energy, carried out by means of surveys in the industrial sector and services sectors with the support of the DGEG. The annexes contain a description of the surveys that were used during this study. This report also includes a technical and economic analysis of the various, most relevant, cogeneration technologies that are currently available on the market.

2 Cogeneration (Current Situation)

2.1 Overview of Cogeneration in Portugal

Although cogeneration was introduced in Portugal in the 1940s (in the industrial sector) with the installation of backpressure turbines, it was only during the 1990s that cogeneration witnessed a significant growth in terms of installed capacity and energy produced. Currently, cogeneration represents an important component of electricity production in Portugal, corresponding to approximately **13%** of the energy produced in the country.

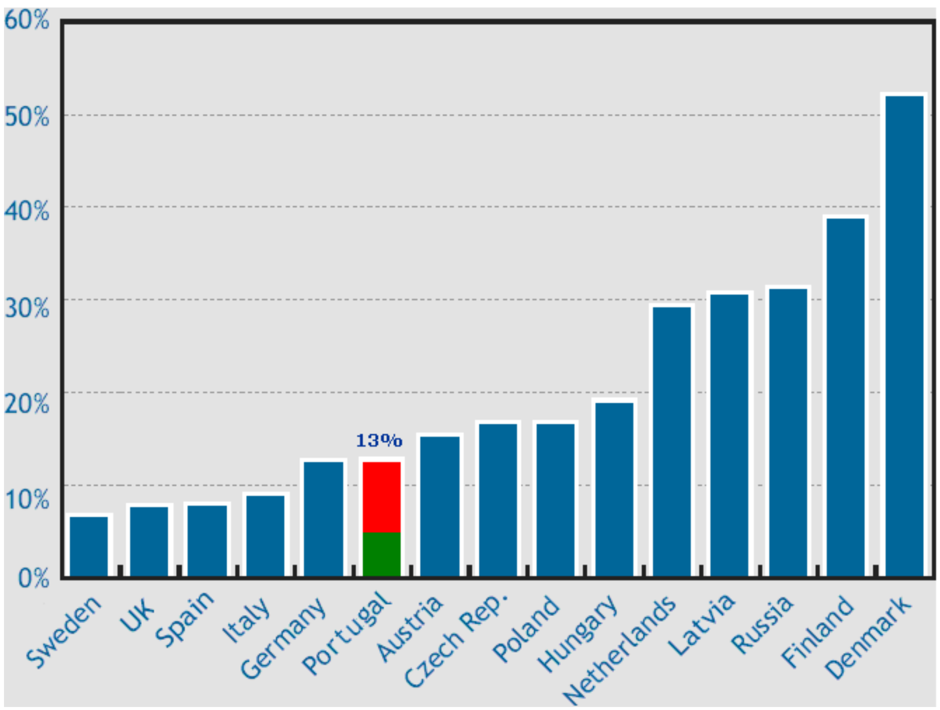


Figure 2.1 *– Total national production of electric energy by means of cogeneration systems, 2006*
Source: IEA

The electric energy produced by means of cogeneration in 2006 was equivalent to 20% of the electric energy produced by the Thermal Power Plants of the National Electricity System (SEN).

Figure 2.2 shows the evolution of accumulated installed capacity up to 2007. Sharp growth can be seen from the beginning of the 1990s onwards, especially after 1993. The existing cogeneration capacity ensures that Portugal is in a comfortable position in European terms with regard to this technology, ranked only behind the countries that use heat distribution networks on a large scale.

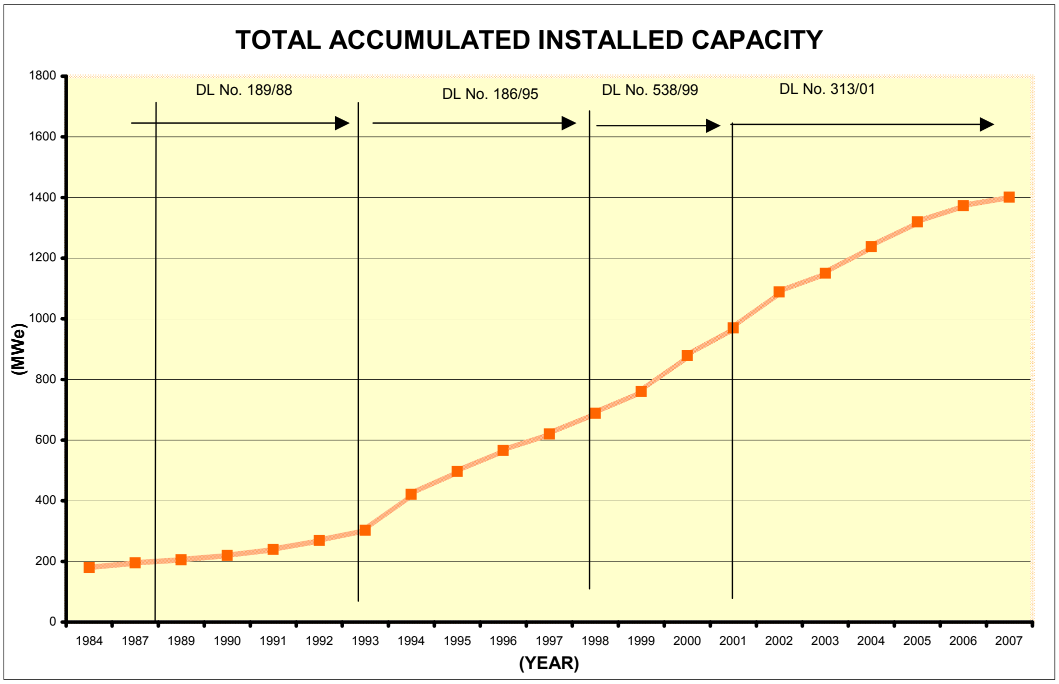


***Figure 2.2** – Total accumulated installed cogeneration capacity in Portugal*
Source: DGEG

Figure 2.3 shows the evolution of the implementation of cogeneration in Portugal, developed by means of the successive legal frameworks that promoted this activity from the 1960s up to 2007. An analysis reveals that, prior to 1990, backpressure turbines were the most common technology used in Portugal in cogeneration facilities. During the 1990s, the increase in cogeneration capacity was associated with the installation of fuel oil combustion engines, until the introduction of natural gas. The use of this fuel in cogeneration units, both through the use of gas turbines, as well as through natural gas engines, began to occur from the end of this decade onwards and was consolidated during the 21st century as the most widely used primary fuel, largely due to its technical and environmental advantages and because it was a reference for establishing the prices for the sale of electricity.

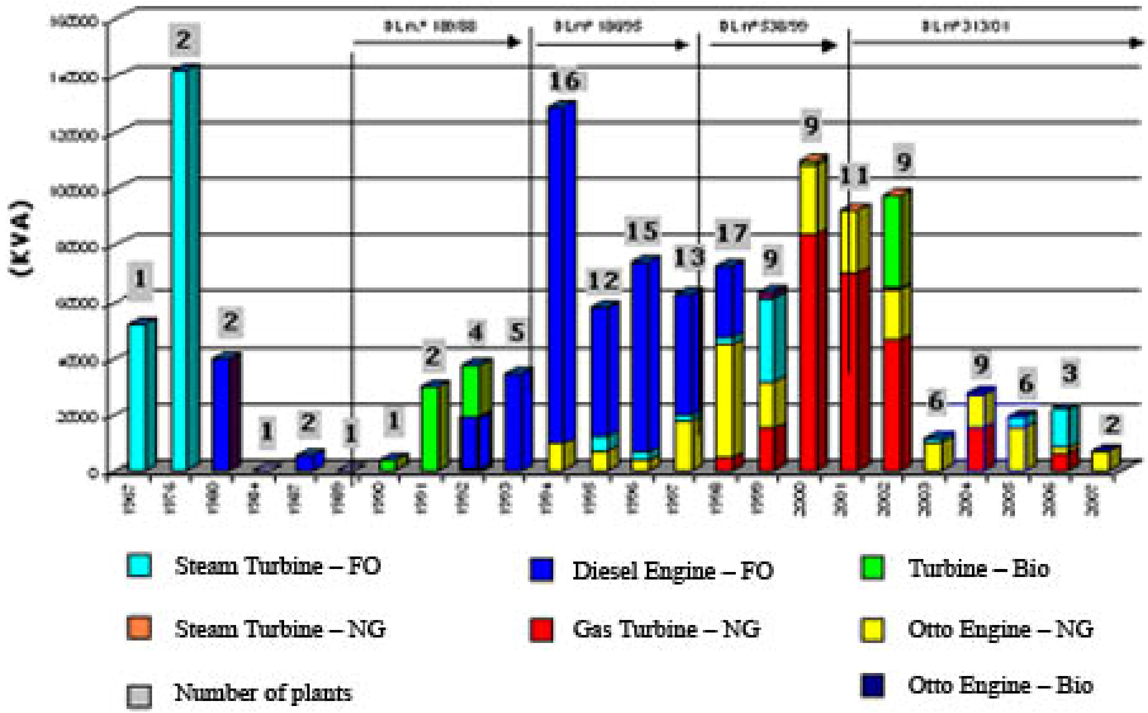


***Figure 2.3** – Evolution of installed cogeneration capacity according to the different technologies used*
Source: DGEG

DL 538/99 and the amendments introduced by DL 313/2001 provided an impetus to improve efficiency, as a corollary to the adoption of the principle of proportional sale prices for all electric energy, according to the costs avoided for the national generation system, which includes environmental costs. It is thus possible to establish an intrinsic relationship between the evolution of cogeneration and a remuneration table for the sale price of electric energy.

Despite the existence of a legal framework from 2002 onwards that has been recognised as having provided the necessary conditions to stimulate the development of this activity, there has been a slowdown with regard to the promotion of expansion in cogeneration, in terms of installed capacity. This slowdown did not extend to the three year period between 2000 and 2002 due to the entry into service in each of these years of three large natural gas combined cycle facilities, with individual capacities of more than 30 Mwe. One of the main reasons for this slowdown was the limited network access as a result of the extensive limitations in terms of conditions for accessing the network for the innumerable cogeneration projects which appeared during this period.

Moreover, it is also necessary to consider the construction delays by promoters of projects whose operating permits were attributed during this period. This was partially due to the increased delivery periods of equipment suppliers, precisely due to an increase in demand.

According to the data provided by different entities (COGEN Portugal, Protermia and the Directorate-General for Energy and Geology), at the end of 2007 the installed cogeneration capacity was very close to **1 400 MW**, of which the greatest percentage related to the chemical, paper and textile industries, as can be seen in Table 2.1 and in Figure 2.4.

***Table 2.1** – Distribution according to Economic Activity of the installed capacity in Portugal, 2007*

Economic Activity	Capacity (MWe)
Food	86.25
Ceramics	33.2
Cork	4.17
Tanning	7.32
Packaging	9.78
Waste Water Treatment Plants	3
Hospitals	4.27
Wood	46.39
Metal working	1.46
Others	86.5
Paper	382.68
Chemicals	491.64
Services	26.64
Textiles	215.64
TOTAL	**1 398.94**

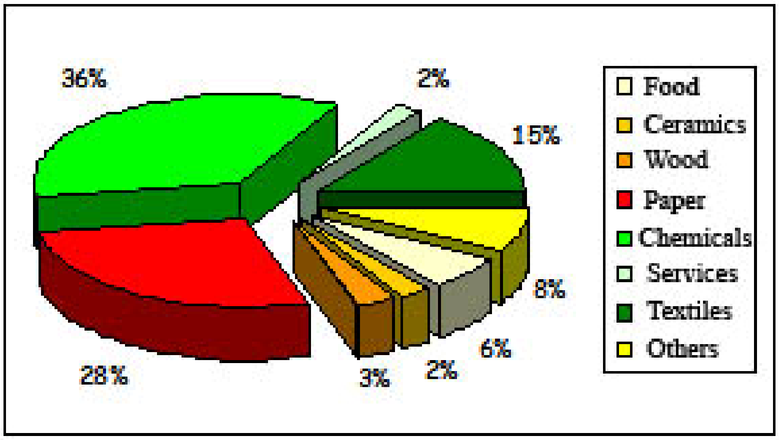


Figure 2.4 – *Distribution of the installed cogeneration capacity in Portugal, according to sectors of economic activity*

The following figure shows the breakdown for cogeneration systems in Portugal in 2007.

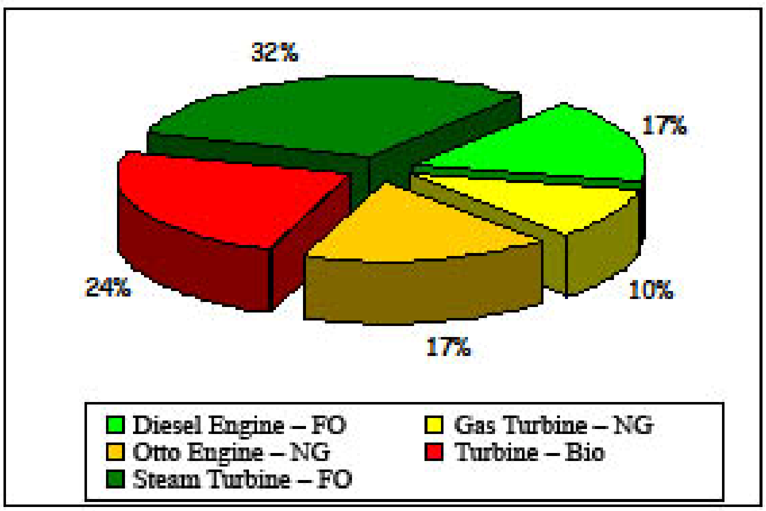


Figure 2.5 *– Installed capacity according to different cogeneration technologies, 2007*

An analysis of existing facilities according to the type of technology used reveals some aspects of cogeneration in Portugal, more specifically the use of natural gas as a fuel par excellence in facilities with the greatest unitary electric capacity, to fuel gas turbines, normally in a combined cycle with steam turbines, representing 27% of the total installed capacity in 2007.

Fuel-fed facilities are responsible for 49% of the total installed cogeneration capacity, of which 17% corresponds to fuel engines, with the remaining 32% used in steam turbines.

There could be a possible marginal economic interest resulting from the alternative of converting part of the fuel-fed facilities to NG, owing to the technical and environmental advantages and as a result of the natural limitations associated with the working lifespan of the equipment, which is currently being operated.

The facilities that use more than 50% renewable fuels (more specifically biomass originating from forestry) also play a relevant role that is worthy of note, accounting for almost 24% of total installed cogeneration capacity.

Given that a series of facilities are currently at an advanced stage of implementation it is possible to predict that by 2010 approximately 350 MWe of capacity will become operational, centred around ten cogeneration facilities with a unitary capacity above 30 MWe. These projects, which have already been licensed and are currently being developed, include facilities with natural gas turbines and also include large units fuelled by biomass, which will go onstream in 2010.

***Table 2.2** – Energy overview of the cogeneration plants that exist in Portugal, 2007*
Source: Protermia

		Installed Capacity (kWe)	Number of Facilities	Average Capacity (kWe)
Total Natural Gas	> 10 MW	144 920	3	48 307
	< 10 MW	238 765	73	3 271
Total Fuel	> 10 MW	437 030	11	39 730
	< 10 MW	211 245	50	4 225
Total Renewables	> 10 MW	357 200	7	51 029
	< 10 MW	9 780	3	3 260
TOTAL		**1 398 940**	**147**	**9 517**
		Prod. of Electric Energy (MWh)	**Prod. of Thermal Energy (MWh)**	**Fuel Consumption (MWh)**
Total Natural Gas	> 10 MW	1 145 585	1 566 708	3 106 425
	< 10 MW	1 257 104	1 601 175	3 729 725
Total Fuel	> 10 MW	571 972	1 585 692	2 765 602
	< 10 MW	1 162 009	1 060 890	3 206 729
Total Renewables	> 10 MW	1 228 186	5 952 418	10 784 250
	< 10 MW	41 666	192 522	337 965
TOTAL		**5 406 522**	**11 959 405**	**23 930 696**

***Table 2.3** – Overview of the annual results of the cogeneration units, 2007*
Source: Protermia

		Operating hours/year	Savings (tep) [Fuel+NG saved]	Prod. of CO2 from the Primary Comb. (ton)
Total Natural Gas	> 10 MW	7 905	134 713	624 237
	< 10 MW	5 265	137 676	749 489
Total Fuel	> 10 MW	1 309	136 345	766 754
	< 10 MW	5 501	91 220	889 055
Total Renewables	> 10 MW	3 438	511 816	-
	< 10 MW	4 260	16 554	-
TOTAL		**3 865**	**1 028 324**	**3 029 535**
		Losses avoided in the SEN (MWh)	**Savings CO2 (ton) [Fuel+NG saved]**	**Prod. CO2 in the prod. of EE+ET (ton CO2/GWh)**
Total Natural Gas	> 10 MW	17 184	314 830 [GN]	230
	< 10 MW	18 854	321 756 [GN]	262
Total Fuel	> 10 MW	8 580	439 628 [Fuel]	355
	< 10 MW	17 430	294 128 [Fuel]	400
Total Renewables	> 10 MW	18 423	1 196 140 [GN]	-
	< 10 MW	625	38 687 [GN]	-
TOTAL		**81 098**	**2 605 170**	**174**

Tables 2.2 and 2.3 and the graphs in the following figures analyse the impact of cogeneration activities, in 2007, and also evidence the balance that exists in terms of sources of primary energy (NG, fuel oil, Renewable). It is also possible to highlight the positive impact of the use of renewable sources, especially with regard to emissions and the useful thermal energy that is contributed in the process.

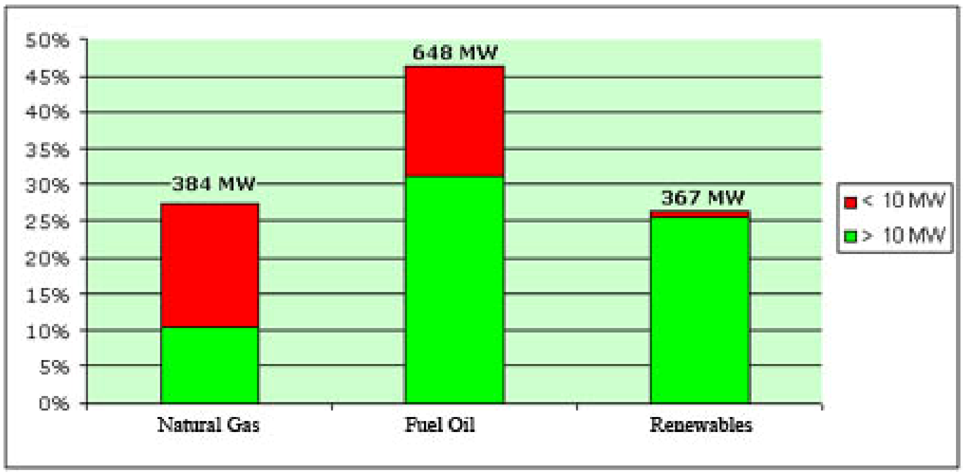


Figure 2.6 ***–*** *Installed cogeneration capacity, according to type of fuel, up to 2007*
Source: Protermia

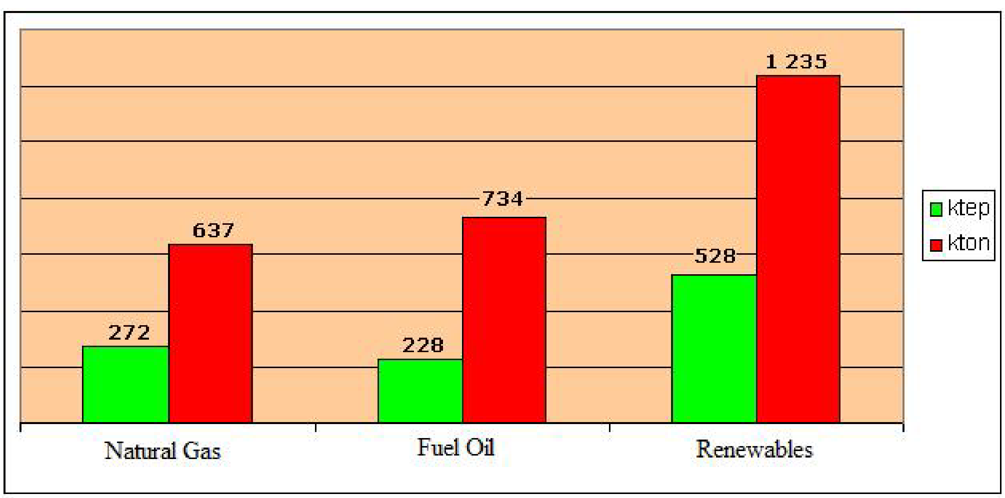


Figure 2.7 ***–*** *Emissions avoided and energy savings according to type of fuel, in 2007*
Source: Protermia

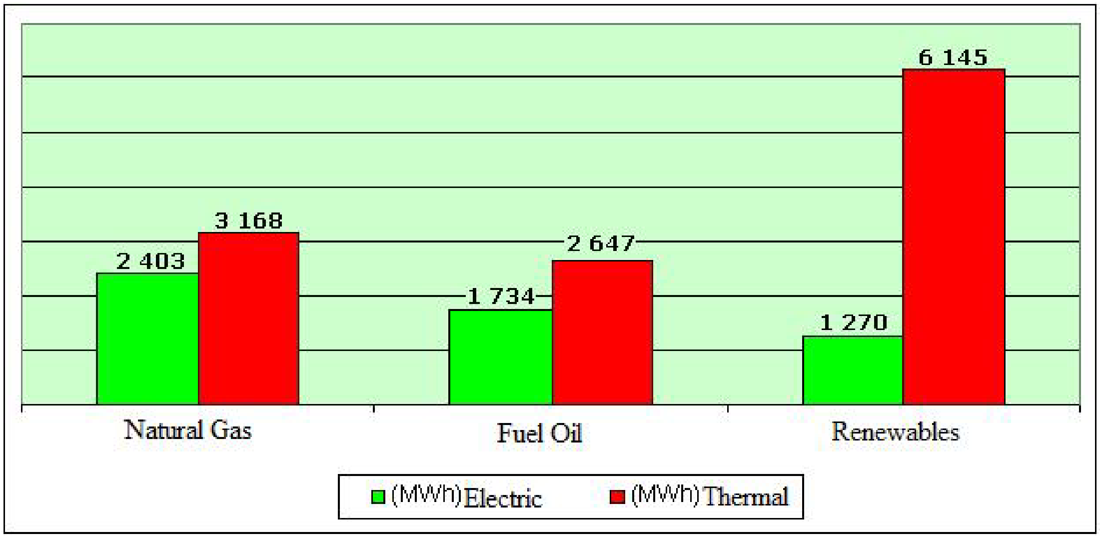


Figure 2.8– *Production of electric energy and useful heat according to type of fuel, in 2007*
Source: Protermia

Table 2.3 shows the results of cogeneration in environmental terms and the losses prevented. Given the regularity of the operating regime of functioning cogeneration plants, a scenario of assessment with regard to the net total of emissions resulting from cogeneration activities can be safely projected. Thus, in 2007, the division between the difference in emissions that resulted from the use of fossil fuels and the emissions avoided owing to the useful heat, which totalled 424 Tons, can be divided by the total production of electricity, which results in a cogeneration emission equivalent of 0.078 Tons CO_2 /MWh.

If the use of fuels in cogeneration processes had been entirely substituted by NG it would have implied that the specific emission of cogeneration along with the contribution of the renewable sources would have been 0.027 Tons CO_2/MWh.

Table 2.4– *Total of specific emissions according to the type of fuel*
Source: Protermia

Fuel	Specific emissions

Fuel oil	0.532 (ton CO_2 / MWh)
Natural Gas	0.306 (ton CO_2 / MWh)
Renewables	- 1.028 (ton CO_2 / MWh)

The total resulting from the conversion to NG of existing plants while maintaining the plants functioning on renewable sources is only due to a reduction in the specific emissions of cogeneration from the current 0.078 to 0.027 Tons CO_2/MWh, since there are practically no gains in improved efficiency in the production of electric energy, as the lesser efficiency resulting from the production of electric energy is offset by an increase in the thermal recovery in the gas circuits.

Figure 2.9 presents the typical profiles for the industrial and services sectors.

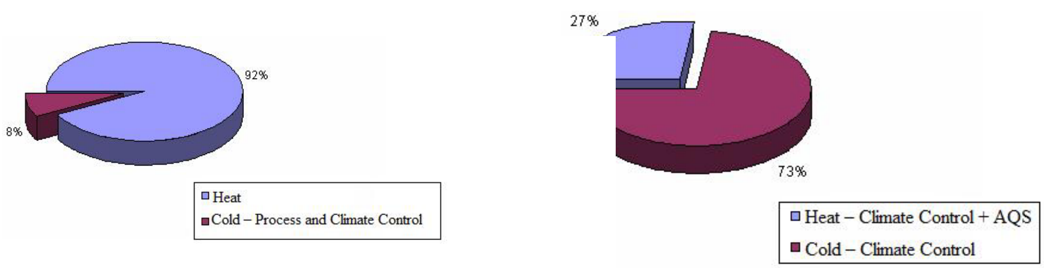


***Figure 2.9**– Typical profile of thermal consumption in cogeneration in the Industrial (left) and the Services sectors (right) Source: Protermia and EDP*

It is evident that cogeneration in the industrial sector is typically characterised by supplies of useful energy almost exclusively in the form of heat, 92%, while the production of cold has marginal uses, totalling 8%. This results in a saving, above all, in the use of NG or even fuel, which would otherwise have been used to produce that process heat. Cogeneration used in the activities of the services sector practically inverts the previous situation, since thermal energy is used primarily in the form of cold, totalling approximately 73%, mainly for climate control. In this case heat only represents 27% of the total. These facts demonstrate that in this sector cogeneration mainly represents savings in terms of electricity consumption.

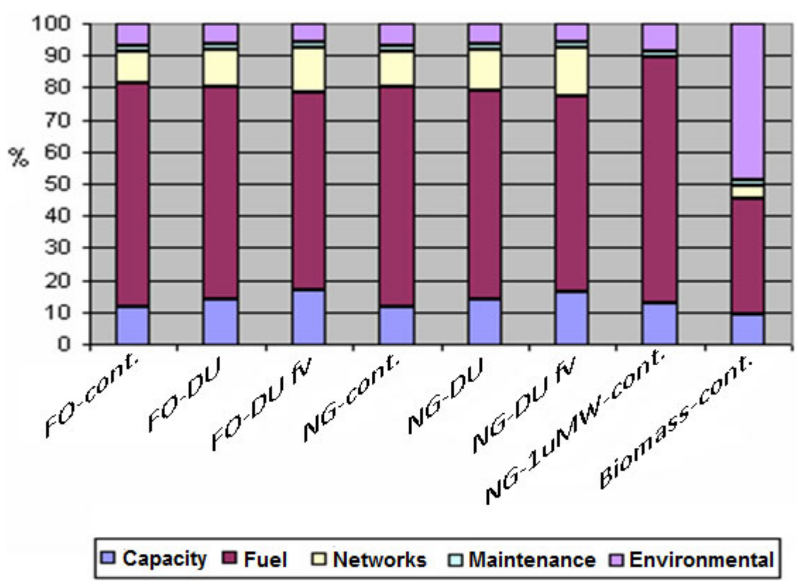
Table 2.5 presents a summary of the underlying logic of the remuneration of useful electricity produced for the different types of cogeneration facilities, according to the size, the type of fuel and the operating regime derived from the application of DL 538/99, specifying the parameters that are considered in the origin of the average sale price, i.e. the weighting of the constituent shares, the periods considered and the characteristics of an operational plant.

***Table 2.5** – Values per kWh for cogeneration under the special regime, based on the price of fuels in January 2008*

Fuel		**Oil**			**Renewables**
Capacity	kW	4 000	4 000	4 000	25 000
Operating hours		Continuous	WD	WD peak	Continuous
Inaugurated	Year	< 2000	< 2000	< 2000	< 2000
Operating for	Years	< 10	< 10	< 10	< 10
Modulation		Yes	Yes	Yes	Yes
REE		0.6	0.6	0.6	-
Capacity share	%	11.6	14.2	16.6	9.3
Fuel share		69.6	65.7	61.9	35.7
Networks share		10.0	11.7	13.7	4.1
Maintenance share		2,0	1,9	1,8	2,0
Environmental share		6,8	6,4	6,1	48,9
Full period	€/MWh	115	116	116	113
Peak period		194	194	194	176
High period		56	56	56	61
Average weighted value		**100**	**115**	**139**	**99**
Fuel		**Natural Gas**			
Capacity	kW	3 000	3 000	3 000	50 000
Operating hours		Continuous	WD	WD peak	Continuous
Inaugurated	Year	< 2000	< 2000	< 2000	< 2000
Operating for	Years	< 10	< 10	< 10	< 10
Modulation		Yes	Yes	Yes	Yes
REE		0.65	0.65	0.65	0.75
Capacity share	%	11.5	14.1	16.4	12.8
Fuel share		68.9	65.1	61.2	76.8

Networks share		10.9	12.6	14.7	-
Maintenance share		2.0	1.9	1.8	1.8
Environmental share		6.7	6.4	6.0	8.6
Full period	€/MWh	117	117	117	93
Peak period		195	196	196	168
High period		56	56	56	55
Average weighted value		**101**	**116**	**140**	**87**

Using the exchange rates recorded in January 2008 between the USD and the euro as a reference, it can be seen that the weight of the "fuel" component, during the first quarter of 2008, accounted for 62% to 77% of the remuneration per kWh produced by means of cogeneration. This latter value is nominally in line with the variation in the price of NG as a reference fuel for cogeneration from fossil sources: NG and fuel.



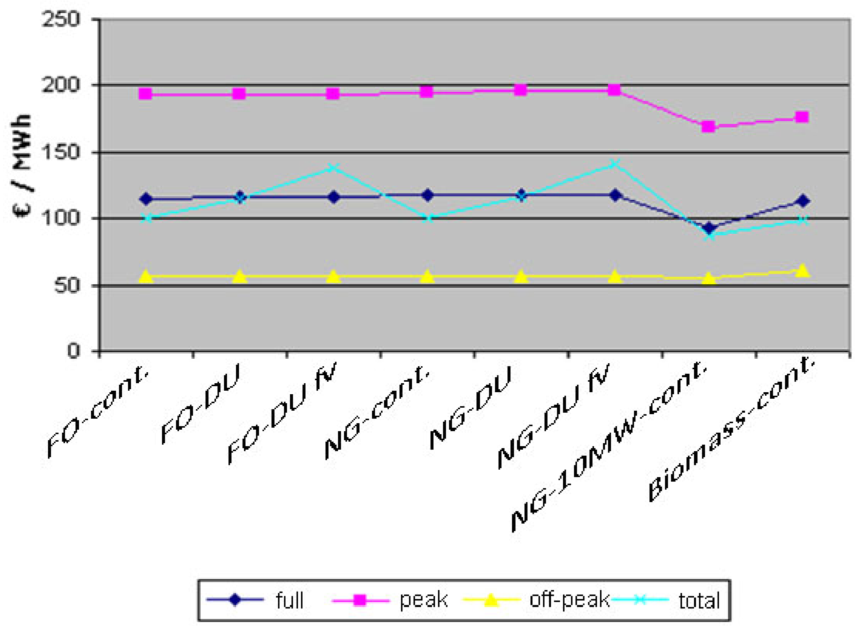


***Figure 2.10** – Formation of the average sale price (above) and the average price per tariff (below), January 2008*

The variations in the remuneration in plants which choose to operate continuously or to function outside high periods are due to the application of the capacity share as remuneration for the contribution of production outside the high periods, i.e. in "peak and full hours".

2.2 Conclusions

At the end of 2007, cogeneration activities contributed significantly to the national energy and environmental equilibrium, reflected in the following indicators:

1 – The net total of CO_2 emissions avoided through cogeneration activities resulted in a saving of 6.8% of the total emissions envisaged in the PNALE 2005-7, while simultaneously accounting for the equivalent of 20% of the national production of electricity by the Thermal Plants of SEN, in 2006;

2 – Of the total installed cogeneration electric capacity in Portugal, 24% of these facilities are fuelled by renewable sources, which accounted for 47% of the total emissions avoided and for 51% of the national total of useful heat produced;

3 – In 2007, the primary energy sources which fuelled cogeneration activities were distributed as follows: 49% of plants ran on oil, 27% on NG and 24% on renewable fuels.

3 Potential for High-Efficiency Cogeneration

3.1 Methodology used to ascertain the economic potential

3.1.1 Introduction

Given the size of the territory in question (Portugal), any analysis of the potential for high-efficiency cogeneration is an extremely complex task. This complexity is even greater when a higher degree of reliability for the results of the analysis is required.

A simplified approach to the task at hand would entail carrying out an analysis aimed essentially at those sectors in which this technology has typically been successfully implemented and, based on some experience, case descriptions and recent trends, providing a rough estimate of this potential in the sectors that have traditionally used this technology.

In the specific case of this study and considering the large number of plants in the industrial and services sectors, analysed by *Protermia* and *EEP*, over the course of more than 23 years, involving energy audits (under the terms of the RGCE or otherwise), energy diagnoses, viability studies to implement cogeneration plants, etc., it was decided to “make the most” of this vast archive of specialised information, to carry out a more elaborate analysis of the issue, which, although more laborious, ensures that more reliable results will be obtained.

This choice was reinforced further from the moment when the DGEG provided the members of the consortium with a detailed description of the consumption of fuels (LPG/FUEL) and NG according to economic activities, while also making available the reports of energy audits carried out in sectors that were not included in the “database” of the said consultants. Moreover, the survey of the industrial and services sectors that was carried out within the scope of this study, albeit with a limited representation, further complemented the available information.

Once this option had been chosen, an IT tool was created with all the pertinent information, **collected company by company**, involving, more specifically, the following fields:

- CAE
- Final product
- Annual production
- Working system
- Annual consumption of primary energy, with a breakdown showing electricity, petroleum derivatives, natural gas, solid fuels, etc.
- Overall consumption of primary energy (tep)
- Type/form of the use of thermal energy, which can be substituted by cogeneration (steam, hot air, hot gases, hot water, thermo-fluids, cold water, glycol water, etc.).
- Substitutable primary energy (natural gas, fuel oil, electricity, etc.) and annual quantity substituted (in absolute values and in percentages as compared to the total thermal energy and the total energy).
- Selection of the technology (engine, turbine, etc.) and the electrical capacity to be installed, the function of the relationship between electric energy/thermal energy, the operating regime and the type of use of the thermal energy.

- Electric and thermal production of the solution, according to the type and size of the cogeneration group (e.g. NG engine <1 MW; 1 to 4 MW; 4 MW).

- Typical profile of the operating regimes of the establishments and, consequently, the annual operating hours of the cogeneration group.

- Percentage of cogenerated electric energy, consumed internally.

- Corrective factors pertaining to the network losses avoided (both for exported electricity as well as for electricity consumed internally), according to the supply voltage.

- Harmonised reference values (REF Eη), in terms of efficiency, for the separate production of electricity, in accordance with Annex I of the Commission Decision of 21.12.2006 (base 52.5%, natural gas, 2006-2011), corrected with the values from previous columns.

- Harmonised reference values (REF Hη), in terms of efficiency, for the separate production of heat –90% was always used (natural gas), since it is the most unfavourable value (the analysis opting to err on the side of caution).

- Calculation of the PES – primary energy savings (percentage) – according to the harmonised reference values and the electric and thermal production, projected for the cogeneration group.

Once this (large) matrix for calculations had been prepared (see the excerpt in the following figure), the companies were grouped on the basis of the common radical of the classification of the respective economic activity, so as to establish average sector values. It must be noted that in cases in which the facility was already associated with a cogeneration plant it was necessary to consider the facility to be "without cogeneration" (converting the thermal outputs of the cogeneration into primary energy), so as to ensure coherence in the processing and in the percentages that were obtained in terms of PES.

***Table 3.1** – Calculation matrix for an economic activity (CAE 14220) with PES > 10%.*

Main Product	Annual production		Reference Year	Consumption of Primary Energy				
	Quantity	Unit		Electric		Natural Gas		Total
Atomised powder	358 700	ton	2005	21567(MWh)		11 734 (X1000 Nm3)		145 101 (MWh)
Substitutable by cogeneration						Yield		
Type of use of thermal energy	Primary energy substituted	Fuel (% MWh)	Total (% MWh)	Type	Power	Electric	Thermal	Overall
Hot gases	11 000 (x1000 Nm3) of Natural Gas	93.7%	79.8%	Turbine	10MW	29	51.6	80.6
Internal consumption	Hours/year	Voltage	Network losses			REF Eh (base 52.5%)	REF Hh	PES
			Exported	Internal consumption				
25.9%	7 900	30 (kV)	0.945%	0.925%		49.3%	90%	13.9%

***Table 3.2 -** Calculation matrix for an economic activity (CAE 15413) with PES < 10%.*

Main Product	Annual production		Reference Year	Consumption of Primary Energy			
	Quantity	Unit		Electric	Fuel Oil	Other	Total
Oils	18 021	ton	1988	2 232 (MWh)	88 (ton)	6 472 (ton) White spirit + skin	33 326 MWh

Substitutable by cogeneration				Type	Power	Yield		
Type of use of thermal energy	Primary energy substituted	Fuel (% MWh)	Total (% MWh)			Electric	Thermal	Overall
Steam and thermo fluid	88 ton fuel + 6472 ton solid fuel	100%	93.3%	Turbine	3.5 MW	28.2	48.5	76.7
Internal consumption	Hours/year	Voltage	Network losses			REF Eh (base 52.5%)	REF Hh	PES
			Exported	Internal consumption				
11.5%	6 300	30 (kV)	0.945%	0.925%		49.3%	90%	9.8%

In the following phase, this database, with approximately 70 CAE, was juxtaposed with the information pertaining to the annual energy consumption per CAE, provided by the DGEG (see excerpt below), and was further complemented by the respective number of establishments (data provided by INE), thus obtaining a further database with 202 CAEs (from *0100 – Agriculture* to *9900 – International organisations*), which required additional processing. This processing consisted of a sorting procedure carried out by several technical experts familiar with the area, with a view to eliminating categories of activity that did not have any potential whatsoever for cogeneration, both due to the level of energy consumption recorded as well as the type of energy consumed, or even the large number of companies in the respective category (e.g. CAE *2810 – Manufacturing metal construction elements*, consumes 10 902 tep annually, spread over 2 534 companies, i.e. an average consumption of 4.3 tep/company).

Table 3.3 *– Example of associated thermal and electric consumption in the case of two economic activities (CAE 110 and 1420)*

CAE	Economic Activity Code	Electrical Consumption			Thermal Consumption		
					Butane		
		(MWh)	(TJ)	(ktep)	(ton)	(GJ)	(tep)
110	Agriculture	730 022	2 628	211,7	-	-	-
1420	Sand and clay quarrying	74 465	268,1	21,6	-	-	-

Thermal Consumption								
Propane			Gas oil			Thick Fuel oil		
(ton)	(GJ)	(tep)	(ton)	(GJ)	(tep)	(ton)	(GJ)	(tep)
3 641	173 807	4 151	104	4 551	109	-	-	-
420	20 031	478	63	2 758	66	958	38 855	928

Thermal Consumption								TOTAL
Coke			Natural Gas			Total		
(ton)	(GJ)	(tep)	(x1000Nm3)	(GJ)	(tep)	(GJ)	(ktep)	(ktep)
-	-	-	272	10 353	247	188 711	4,5	**216,2**
-	-	-	23 459	893 792	21 348	955 436	22,8	**44,4**

A characterisation of the typical profile of a representative consumer of each CAE made it possible to characterize the cogeneration technology for each CAE in which there was potential (GT-Gas Turbine /GE – Gas Engine, CCG – Gas Combined Cycle, BP – Biomass/Gas Backpressure, OC – Organic Cycle).

Once this classification had been concluded there remained 49 categories of activities (110, 1420, 1510, …, 8510 and 9260) in which there was potential for implementing high-efficiency cogeneration (PEP>10%) and the percentage values that had been established were then applied to the annual energy consumption of the respective sector in order to obtain the primary energy savings; at this stage it was naturally necessary to subtract from this latter value the impact of existing cogeneration, in order to ascertain the real savings.

Table 3.4 *– Examples of solutions identified for two economic activities (CAE 110 and 1420) with PES > 10%*

CAE	Economic Activity	Solution Identified	PEP
110	Agriculture	Natural Gas Engine	15.5 %
1420	Quarrying of sand and clay	Natural Gas Turbine	13.9 %

In order to ascertain the economic potential of cogeneration by 2020 this study used a reference framework of aggregate contributions, some of which had contrary indications, which result from efficiency gains, the reduction of energy intensity, the growth of the product as a result of the evolution of economic growth and efforts to increase the penetration of cogeneration. The following elements are some pivotal factors, amongst others, which influence the use of the economic potential that has been identified, in the case of approximately 60% of the existing technical potential:

- Substitution of the production of heat and cold based on the use of NG and electricity obtained from the heat derived from cogeneration, whenever there are primary energy savings.
- Substitution of the use of fuel as the primary fuel.
- Upgrading the technology of existing cogeneration equipment.
- Use of the potential to recover sources of residual heat to produce electric energy.

Given that the separation obtained after the assessment carried out on the basis of activity codes occasionally produced results which were not particularly clear, both due to recent changes in the logic of the classifications as well as due to changes resulting from economic activities that exceed the bounds of a single CAE as more than one product is produced, it was decided to group the CAEs into 12 families of similar activities, more specifically:

Industry:

1. Primary Sector and Agriculture
2. Manufacturing Industry associated with Food Processing
3. Textile Industry, Other Articles and Accessories, Clothing, Footwear
4. Forest Products, Pulp and Paper Industry
5. Industries Associated with Petroleum, Chemical, Pharmaceutical and Plastic Products
6. Ceramics, Bricks and Tiles Industry
7. Manufacturing Industry Associated with Metal and Mechanical Products

Services:

1. Hotels
2. General Services
3. Malls
4. Hospitals
5. Sports Activities

Finally, it is important to note that the methodology used for “buildings” (of which typically the buildings that encompass “services” stand out and for which detailed knowledge exists on their respective energy consumption profile) also considered that there was some potential to concentrate these buildings, according to the type of activity, to provide a broader assessment perspective. To this end, the study also contemplated the plan for “urban spaces” that typically occurs in hospital complexes, universities, malls, service centres, etc., **except for the exclusively residential sector**, in an attempt to optimise the scale factor that is indispensable in order to ensure the feasibility of such initiatives.

The methodology used was based on the principles contained in Directive 2004/8/EC. The criteria to evaluate the PES (Primary Energy Savings) factor were derived from the application of the criteria contained in the note by the European Parliament pertaining to the Guidelines for using Annexes II and III of the March 2007 Directive, coupled with the environmental conditions existing in Portugal.

Figure 3.1 and

Figure 3.2 provide an overview of the methodology used to determine the national economic potential for high-efficiency cogeneration.

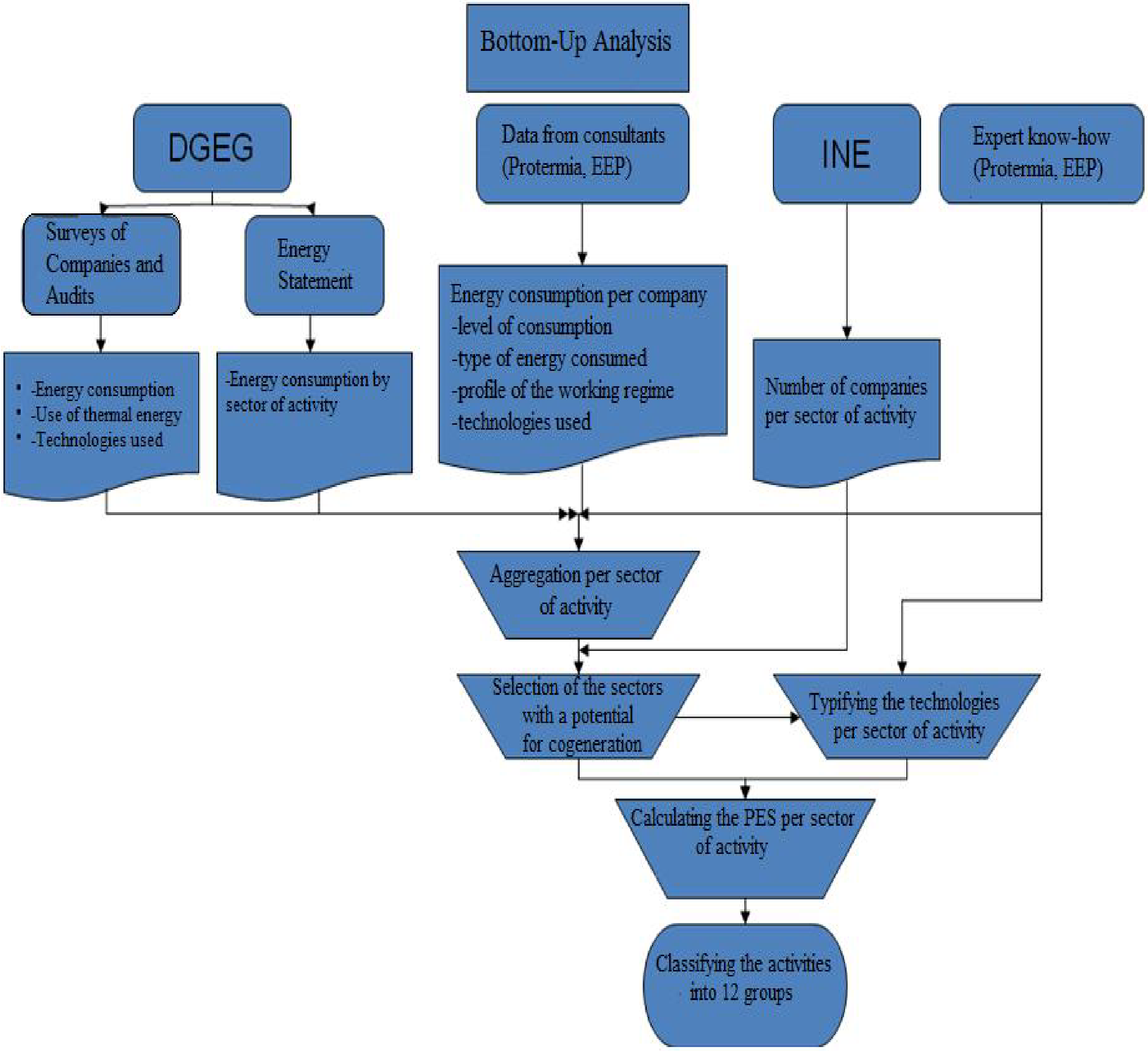


***Figure 3.1** – Flowchart depicting the methodology used in the study (Part I)*

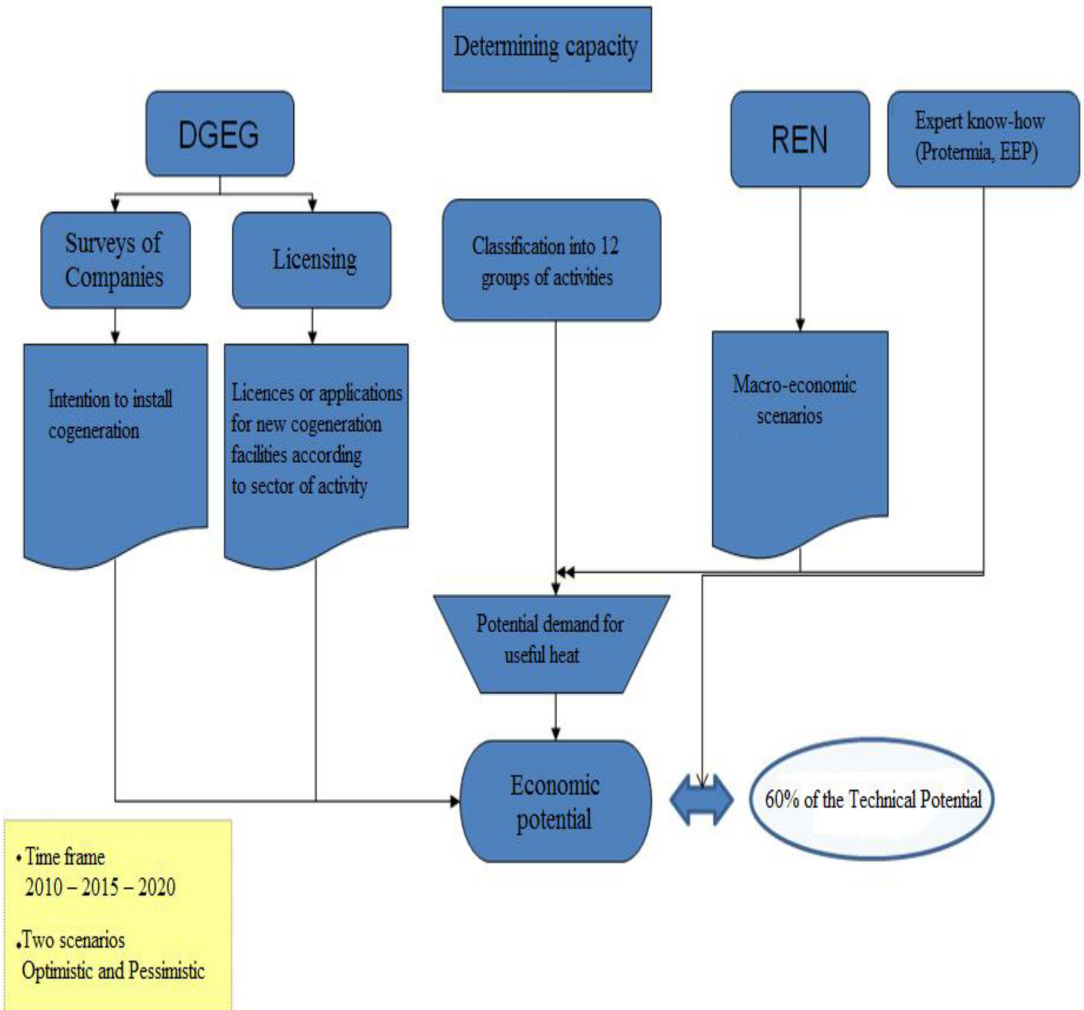


***Figure 3.2** – Flowchart depicting the methodology used in the study (Part II)*

3.1.2 Analysis of the Surveys

The aim of the surveys was to obtain data which could complement the profiles of the diverse economic sectors in terms of the potential for cogeneration, seeking to obtain additional information on energy consumption, the use of thermal energy which could be supplied by cogeneration and estimates of the power to be installed.

A preliminary analysis of the surveys made it possible to identify cases in which there could be potential for cogeneration, based on data regarding the consumption of heat in a form that could be supplied by a cogeneration unit, such as environmental heating, laundries or hot water for sanitary facilities, in the services sector, and drying or other processes in the industrial sector. The survey also requested data on the fluids used to transport heat, to ascertain whether they are compatible with cogeneration. The installed capacity in existing thermal equipment, as well as electricity consumption and capacity, likewise served as a basis for subsequent conclusions.

The data obtained on thermal consumption for the main heat producing equipment made it possible to estimate approximately some points along the heat load duration curve, which indicate the capacity to be installed. It is a known fact that a cogeneration unit typically becomes viable if it functions for at least 4500 hours. The thermal power derived from the power duration curve at 4500 hours is thus a good indicator of the power that should be installed, after being subject to a ratio between recoverable thermal power and electric power generated, suitable for the cogeneration unit to be installed.

For the services sector, the estimate of the power duration curve is derived from diagrams depicting typical consumption, included in the questionnaire, and the integral diagrams indicating monthly consumption for the thermal production equipment that can be substituted by cogeneration, as well as the reference yields for the production of heat. The monthly diagrams, standardized for the entire consumption and obtained from the aforesaid typical diagrams, make it possible to recreate an annual diagram and thus obtain a power duration curve, from which is derived the necessary power for 4 500 hours.

A cogeneration unit sized with this thermal capacity would function for at least this time at the rated capacity, and could continue beyond this at an inferior capacity, up to the minimum that is technically acceptable, without wasting any heat. Naturally, it is possible to contemplate some wastage of heat, as long as the necessary primary energy savings are maintained in overall terms to classify the unit as high-efficiency cogeneration, under the terms of the directive. However, owing to the uncertainty associated with the process of estimating the power duration curve, the capacity which has been determined for the 4 500 hours should be used as is, to indicate the thermal capacity to be installed, likewise because at current prices it could be necessary to have a greater number of operational hours in order to ensure the viability of the unit.

In the case of industry, it would not be admissible to typify thermal consumption due to the diversity of situations. Hence, the survey opted to only request some information on the duration of the periods of thermal consumption in daily and weekly terms. The power duration curve was thus estimated on the basis of the average power obtained by dividing the integrals by the number of hours of service in each month, thus obtaining the power over a period of 6 months.

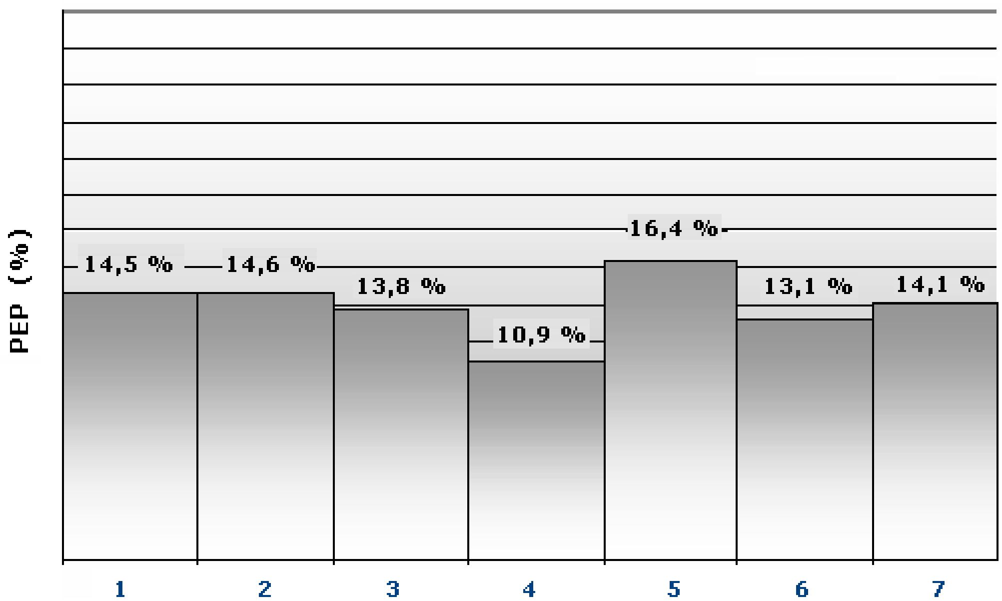
The data on cooling systems was likewise important to define possible trigeneration solutions, more specifically in the services sector in which the production of cold can complement the use of heat, thus making it possible to ensure the feasibility of slightly larger facilities. It must be noted that in some cases in which the heating is also electric, it was not possible to distinguish consumption for heating from consumption for cooling. The estimate obtained for the 4 500 hours includes, in this case, a part that could correspond to the production of cold, which must be carefully analysed.

It can be noted that equipment used to produce cold based on residual heat, both by means of absorption as well as adsorption, is still quite costly, especially for small capacities, and has a very low yield, mainly when compared to the better coefficients of performance (COP) that are already available for conventional equipment. Thus, it would not be socially opportune that the sole use of the heat produced in the cogeneration unit would be to produce cold, since it would not result in real primary energy savings. However, the calculation of primary energy savings according to the directive does not take into account inefficiency in terms of the use of the heat.

The surveys also obtained some information on decisions made in the past relating to cogeneration units, more specifically the purposes for which they were designed and the barriers in terms of their implementation. Finally, it was possible to calculate some statistics according to the economic activity codes (CAE), more specifically the average capacity of the cogeneration unit to be installed, capacity per m^2, capacity per occupant, etc.

3.2 Industrial Sector

The graph in Figure 3.3 shows that there is a potential for high-efficiency cogeneration in all the CAE categories shown on the map. Its configuration makes it possible to carry out a separate and de-aggregated analysis with regard to the potential for high-efficiency cogeneration assessed on the basis of PES (primary energy savings) for the entire range of industrial activities, including the Primary Sector.

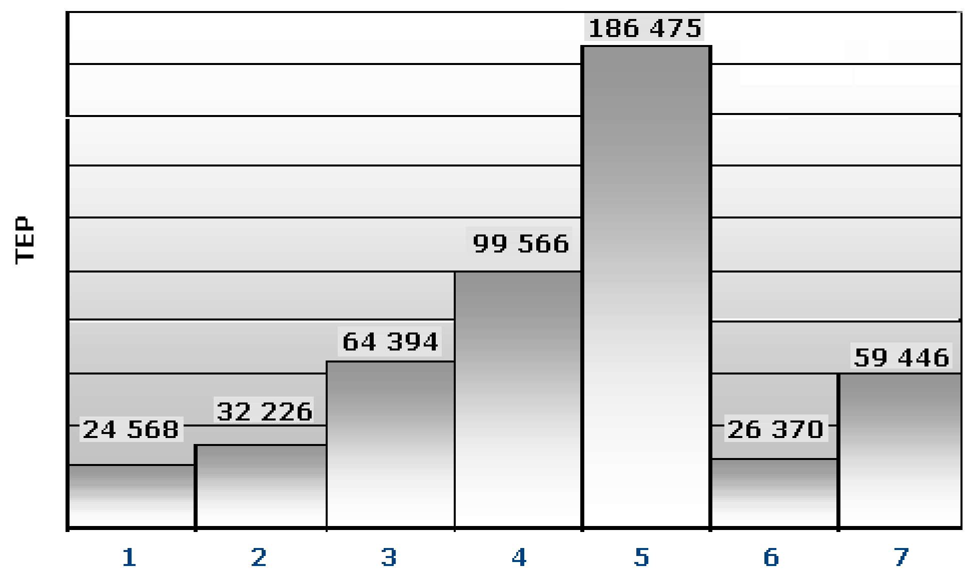


1 – Primary Sector	**2** – Food	**3** – Textiles and Tanning
4 – Pulp and Paper	**5** – Oil refineries, Petrochemicals	**6** – Ceramics
	7 – Metal Working	

Figure 3.3 *– Margin for increases up to 2020 for Primary Energy Savings (PES) per sector of economic activity in the "Manufacturing Industry"*

By means of the values obtained for primary energy savings, identified in the figure above, it is possible to infer the reduction in consumption according to the different sectors of economic activity (Figure 3.4). An analysis of this new graph makes it possible to ascertain the overall impact of the potential for high-efficiency cogeneration in the industrial sector, at around 493 ktep/year, i.e. 81% of the total overall economic potential of 608.8 ktep/year, a figure that corresponds to approximately 2% of the national consumption of primary energy.

Thus, the role that the manufacturing industry could play in terms of the potential to reduce the consumption of primary energy is quite evident, owing to the intense concentration of energy associated with the demand for heat, closely linked to the variation of the tendency resulting from fulfilling the installed production capacity.



1 – Primary Sector	**2** – Food	**3** – Textiles and Tanning
4 – Pulp and Paper	**5** – Oil refineries, Petrochemicals	**6** – Ceramics
	7 – Metal Working	

Figure 3.4 – *Distribution (TEP) of the margin for the potential to reduce primary energy consumption according to different sectors of economic activity in the "Manufacturing Industry" up to 2020*

The increased demand for comfortable environments with regard to industrial activities, on one hand, and the quest for energy efficiency derived from the primary energy savings indexes, on the other hand, will result in a broader range of applications for cogeneration, so as to meet the demand for thermal energy for the production of cold.

The industrial sector will continue to be the area in which there is the greatest potential for the application of high-efficiency cogeneration, both in terms of numbers, as well as size, with applications typically in the small and medium scale manufacturing industries with a capacity that is normally below 10 MW, based, above all, on the production of heat and cold, or mainly cold (through absorption chillers) in trigeneration. The aim of the typical case of the aforesaid applications is to meet a decentralised context of demand, focused on a diverse range of thermal consumers encompassing, above all, the need to treat air and industrial processes that require heat and/or cold, involving the need to install networks to distribute energy, typically employing four tubes (using water or another type of fluid as a means of transferring heat), fed directly and in a centralised manner by a given cogeneration unit.

A national economic potential for high-efficiency cogeneration was identified in this sector of approximately 2 068 MWe up to 2020, which corresponds to an increase of around 50% as compared to the coverage of cogeneration which existed in 2007.

3.3 The Services Sector

As in the case of the study and profile of the different sub-sectors of the industrial sector, according to their potential for cogeneration, the following graphs summarise the primary energy savings and the reduction of consumption according to different sectors of economic activity in the Services Sector. The sub-sectors of General Services, Malls, Hospitals and Sports Activities have a PES of more than 10%, while the Hotel Sector is slightly below this figure.

It can be noted that the band stipulated by the Directive to define high-efficiency cogeneration considers a PES value of above 10% for the cogeneration units that have an electric capacity of more than 1 MWe. However, owing to its nature, the Services Sector typically encompasses a range of facilities the size of which is predominantly less than 1 MWe. This is the case almost across the board in the area of hotel activities (CAE 5510).

The limited dimensions of the unit capacity to be installed in the hotel industry, coupled with the consequent limitations pertaining to the use and the efficiency of cogeneration systems, results in marginal levels of primary energy savings, when compared with similar applications employing other systems.

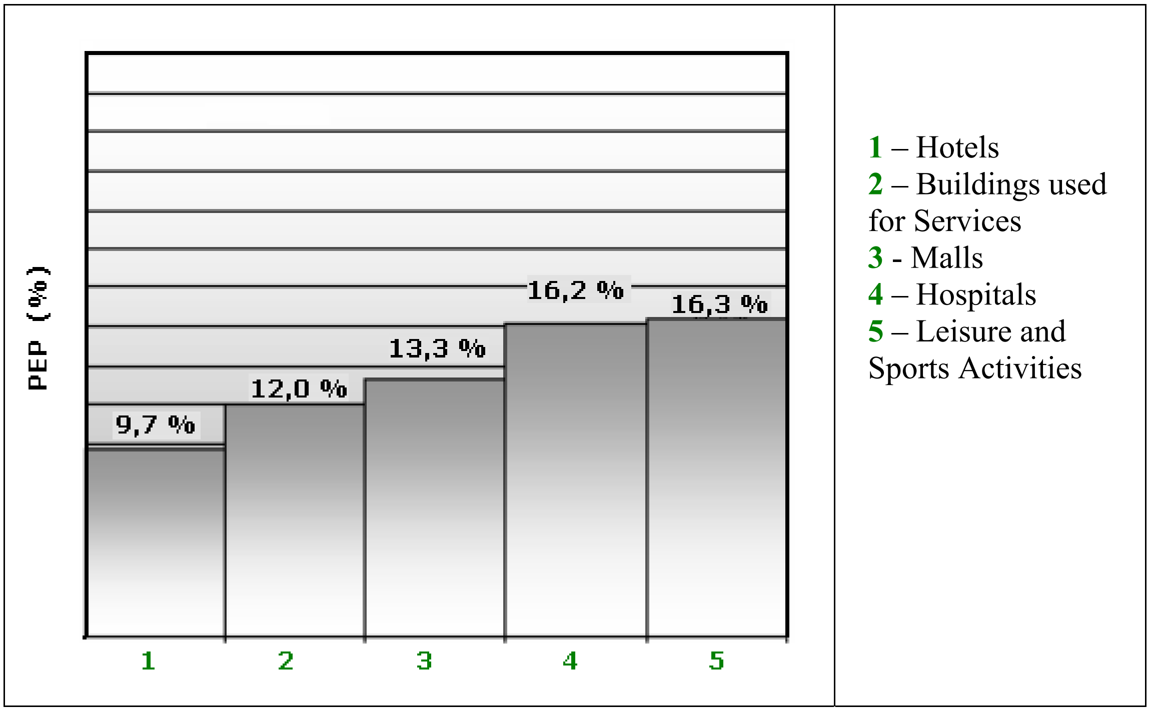


***Figure 3.5** – Distribution of the margin for the potential for Primary Energy Savings (PES) according to the different sectors of economic activity in the field of "Services" up to 2020*

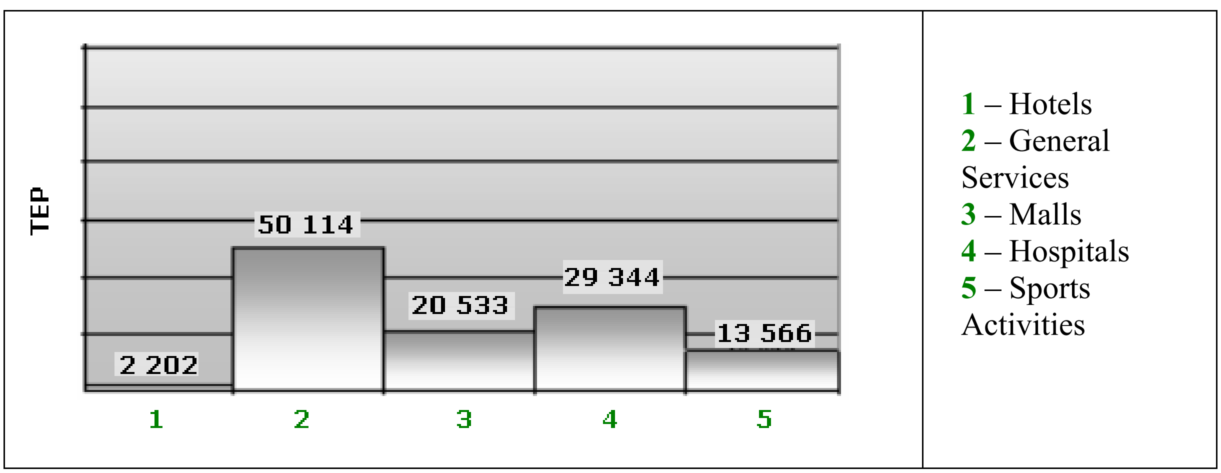


***Figure 3.6** – Potential for the margin to reduce primary energy consumption according to the different sectors of economic activity in the field of "Services"*

An upper limit for the national economic potential for high-efficiency cogeneration of approximately 252 MWe was identified in this sector, which corresponds to an eight-fold increase as compared to the existing coverage of cogeneration.

When compared to the industrial sector, the activities relating to the Services Sector manifest a greater numerical and geographic dispersion of the points of consumption and, quite naturally, a smaller dimension of facilities. The profile for energy consumption in the Services Sector reveals, above all, the need to satisfy climate control requirements and hence the potential that was identified for cogeneration revolves around the production of cold and heat, with a particular emphasis on the former. High-efficiency cogeneration will thus play an important role in the quest for comfortable working conditions.

Although various cogeneration systems in the Service Sector have already existed for some time now, typically in district heating/cooling, hospitals, malls, swimming pools, etc., it is expected that their limited expansion will be due, above all, to the high investments involved in producing cold and heat and the establishment of networks to distribute energy (cold and heat) to support and complement conventional climate control systems. The requirement for additional investments to produce and distribute cold and heat is in stark contrast to the typical need to only produce heat in North European countries, an aspect which will have to be considered by legislators.

The recent publication of legislation encompassing energy efficiency associated with the services and residential sectors has emphasised the role of cogeneration (along with the adoption of efficient passive solutions with regard to architecture and the design of energy systems) to contribute towards achieving the necessary energy efficiency indexes, by adopting integrated solutions. As a consequence, it is expected that there will be additional pressure to generalise the range of applications for cogeneration, typically in areas such as healthcare, services, leisure, etc.

3.4 The Residential Sector

The concept of micro-cogeneration has frequently been defended as an option to reduce primary energy consumption and greenhouse gas emissions. Advocates of this concept often indicate the residential sector as an obvious target since it is the most visible sector for the average citizen, mainly after the development of micro-systems, with thermal and electric capacities similar to those habitually used in single-family residences for climate control and heating water for sanitary purposes (AQS). In fact, there has been significant development in this market, for example, in the United Kingdom. However, the climate conditions in Portugal are quite different, given the high percentage of annual hours in which climate conditions, temperatures and thermal range coincide over the course of the year with thermally comfortable conditions. As is common knowledge, the season during which heating is required is far shorter and during much of the year ambient outdoor temperatures mean that almost no consumption is required in the climate control of residences, with the exception of the summer months, in which cooling is needed instead of heating, although in such cases it is possible to satisfy this need by means of a trigeneration unit.

However, analyses of the thermal consumption of residences with central heating revealed that the number of hours during which any potential cogeneration unit would function would be too low to justify the additional investment, which is particularly relevant in small units. In order to understand this phenomenon it is enough to recall that the season for the use of heating in most districts in mainland Portugal, as defined in DL No. 80/2006 (RCCTE) is less than or equal to 6 months and that during this period, for much of the time, the temperatures are sufficiently high to dispense with any consumption for heating. Furthermore, it is an extremely well known fact that improving the thermal performance of residential spaces in Portugal could easily result in buildings with zero consumption for climate control purposes.

The production of cold by absorption is often indicated as a solution to increase the use of the heat produced by cogeneration, however, it remains to be seen whether the low yield of the chillers that use this operational principle can compensate for the high COP of conventional cooling systems. Moreover, the cost of the smaller absorption chillers is extremely high and this can be a viable solution only if they are highly subsidised.

An analysis of an apartment building in Lisbon with a small shopping centre attached revealed the difficulties involved in defining a trigeneration system with a sufficient capacity to provide a viable solution, both from the practical point of view, since absorption chillers only exist for larger capacities, as well as from the economic and social point of view, since it is hard to justify the additional costs. Moreover, a comparison of the absorption chillers which could be installed in buildings that are not very large and more recent conventional chillers raise doubts from the point of view of social interest, since the COP of the latter largely compensate for the difference in the efficiency of the production of electric energy. It can thus be seen that the primary energy savings obtained from the cogeneration unit can be annulled by the absorption chillers, and hence a trigeneration unit should always have a significant component of the direct use of heat.

Without wishing to generalise on the basis of the cases that have been analysed, the aforementioned results indicate that there is limited justification for the use of cogeneration in the residential sector in Portugal, firstly, due to the mild climate which does not require extended periods of time when heating is needed, and secondly due to a comparison between the performance of low capacity absorption chillers and conventional chillers to complement the thermal load and thus maximise the use of cogeneration systems. Additionally, the residential sector is part of the area in which cogeneration activities cannot be viewed in an isolated manner, firstly due to the risks of not withstanding an individual analysis, given the question of the scale, and, above all, due to the recognised limitations in terms of the occupation of spaces, which affects use. This is not the case when this analysis is transposed to the scale of the urban space, of which only the facilities of the Parque das Nações and Tagus Park areas are examples, which will apparently not be replicated in the near future. The viability of joint systems that encompass both residential and other spaces, such as a network to distribute heat and cold, cannot be entirely ruled out, as long as the direct use of heat for heating, AQS or other purposes represents a significant component as compared to the use of heat to produce cold in absorption chillers, or that the system allows the use of dual effect absorption chillers.

3.5 Economic Potential

The graph in Figure 3.7 shows two scenarios for the estimated evolution of the economic potential, assessed up to the year 2020. For this purpose this study used the data provided by REN, especially the evolution of the Gross Added Value for each of the main sub-sectors of economic activity. In the optimistic scenario, apart from a higher level of economic growth, there is a pro-active logic in terms of the development of the cogeneration market, focusing on the potential scope that could exist for cogeneration while satisfying the demand for energy, duly framed within a suitable system of incentives, which reflects, on the part of legislators, the aim of substituting the need for useful heat/cold by cogeneration. The pessimistic scenario was also based on a sector analysis, keeping in mind more moderate perspectives for economic growth in each sector in which there is installed cogeneration capacity.

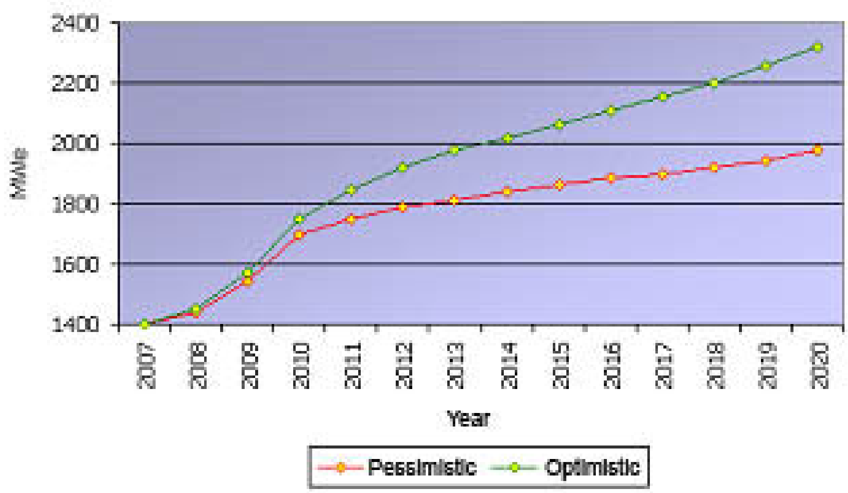


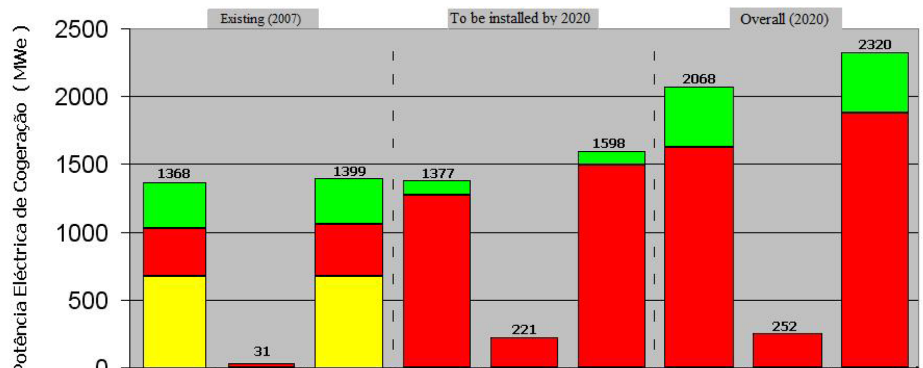
Figure 3.7 *– Evolution of the Economic Potential for High-Efficiency Cogeneration*

Table 3.5 – *Economic Potential in 2010, 2015 and 2020, for the scenarios being considered*

Year	Optimistic (MWe)	Pessimistic (MWe)
2010	1750	1697
2015	2065	1862
2020	2320	1979

The integration of the potential for primary energy savings made it possible to aggregate the national economic potential for high-efficiency cogeneration (Figure 3.8), translated into installed electric capacity, likewise presented separately according to activities classified as "Services" and "Industry" and according to source of primary energy.

Figure 3.8 –



	Existing (2007)			To be installed by 2020			Overall (2020)		
	Industry	Services	Total	Industry	Services	Total	Industry	Services	Total
Biomass	338	0	338	105	0	105	443	0	443
Natural Gas	353	31	384	1272	221	1493	1625	252	1877
Fuel Oil	677	0	677	0	0	0	0	0	0

National Electric Economic Potential for High-Efficiency Cogeneration

In the optimistic scenario the national economic potential for high-efficiency cogeneration has been identified at 2320 MWe. It has been estimated that capacity will increase by approximately 221 MWe in the Services Sector, combined with the 31 MWe that already existed in 2007, for a total of 252 MWe of installed capacity. A 700 MWe increase in the installed capacity of the Industrial Sector is possible, while all the remaining 677 MWe of the fuel oil plants will be reconverted to natural gas by 2020, considering an extreme situation in which every difficulty that arises will be overcome.

No visible gains in efficiency will generally be achieved by converting fuel oil facilities to natural gas and this transformation will result essentially in environmental gains, which need to be suitably supported by legislators, without which this objective may not be achieved on its own.

The following table provides an estimate of the percentage of use of the different types of fuels employed for cogeneration in Portugal, for the reference years of 2010, 2015 and 2020.

***Table 3.6** – Estimated evolution according to type of fuel for 2010, 2015 and 2020*

Fuel	2007	2010	2015	2020
Fuel	49%	33%	16%	0%
Natural Gas	27%	46%	65%	81%
Renewables	24%	21%	19%	19%

The evolution according to the different technologies follows the same trend as the evolution according to the different fuels. The use of fuel oil engines is conditioned by environmental policies. In the same way, the use of fuel oil in boilers associated with cogeneration in backpressure configurations will face the same conditioning factors and the additional constraint of being normally associated with large-scale facilities, which either already exist, or in the case of new facilities, will unequivocally use natural gas as a fuel.

The engines, natural gas turbines and natural gas combined cycles (where greater growth is expected) will depend on the factor of the scale of the facilities and the demand for thermal energy in the process as well as the intensity of the process itself, which, in turn, will depend on Portugal's economic situation.

The technology used with biomass fuel is strongly linked to the use of backpressure cycles (biomass/waste boilers + steam turbines), while the use of engines will be residual.

The following table and figures present an estimate based on these assumptions, and on the evolution of the installed capacity for high-efficiency cogeneration, according to the different technologies.

***Table 3.7** – Evolution of the installed capacity for high-efficiency cogeneration according to the different technologies*

Technology	2010	2015	2020
Combined Cycle	23%	31%	40%
NG Engine	18%	25%	31%
NG Turbine	6%	8%	10%
FO Steam Turbine	21%	11%	0%
Diesel – FO Engine	11%	6%	0%
Bio Turbine	21%	19%	19%

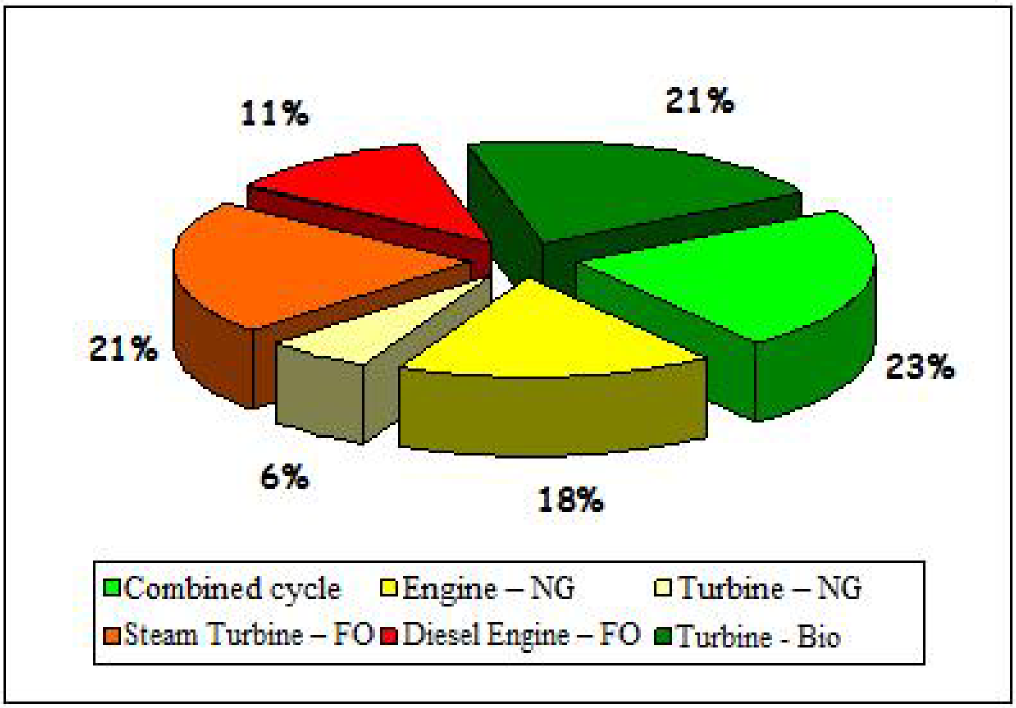


***Figure 3.9** – Breakdown of the installed capacity according to the different technologies in 2010*

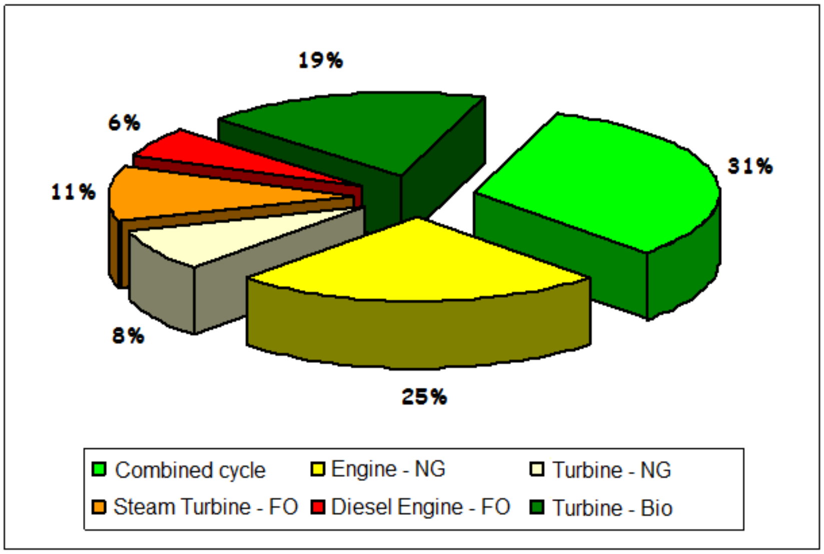


__Figure 3.10__– Breakdown of the installed capacity according to the different technologies in 2015

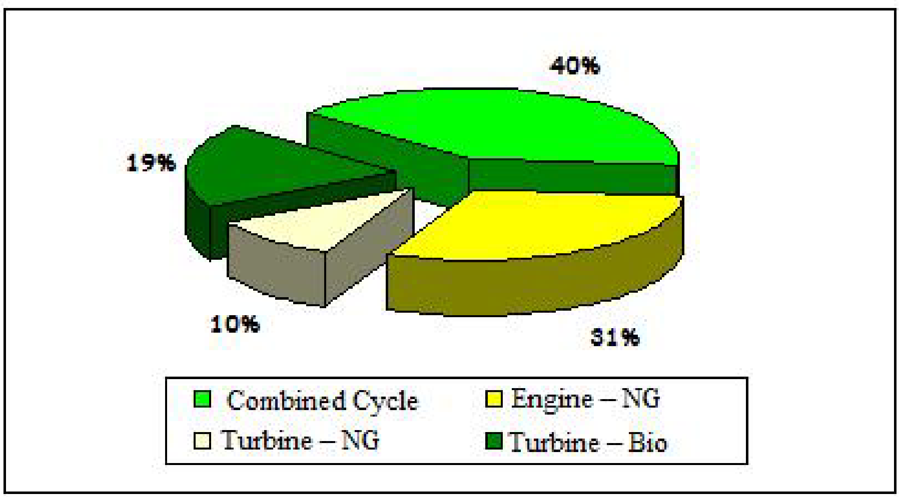


__Figure 3.11__– Breakdown of the installed capacity according to the different technologies in 2020

It is also important to note the existence of the opportunity to make use of residual heat ("Bottom Cycles") through organic cycles, which, despite their marginal presence (1% of the installed cogeneration capacity by 2020), encompasses numerous economically important sectors where there are typically no opportunities for conventional cogeneration. By using the available heat to produce electricity, these bottom cycles do not have specific emissions, as is the case with renewable sources.

Keeping in mind the fact that cogeneration used in the manufacturing industry typically focuses on the energy needs resulting from manufacturing processes, and likewise considering the high degree of existing or planned coverage provided by the cogeneration units that have already been identified, it is believed that the residual potential that has been identified, from 2020 onwards, will be derived from the impact of the potential to attract new manufacturing activities. This will take place both due to the expansion of current activities as well as due to progressive increase of smaller industrial units.

The growing pressure to adopt EU regulations for buildings, accompanied by the constant pressure to increase the comfort indexes associated with human activities will together ensure that this scenario for the potential of high-efficiency cogeneration will be realised, as long as it is accompanied by a sufficiently encouraging legal framework to develop this activity.

Setting out from this principle, the primary energy savings and savings in terms of CO_2 emissions as well as the production of thermal and electric energy were estimated on the basis of the optimistic curve for the national economic potential, presented in the following tables.

Table 3.8 – Estimate of the production of thermal and electric energy and primary energy savings and savings in terms of CO_2 emissions for 2010

	Production of Energy		Savings	
2010	**Electric (MWhe)**	**Thermal (MWht)**	**Primary Energy (TEPs)**	**CO2 (kton)**
Fuel Oil	1473884	2249595	227565	624
Natural Gas	5080686	5911177	575721	1347
Renewable	1363776	6663817	572883	1326
TOTAL	**7918346**	**14824589**	**1376169**	**3297**

Table 3.9 – Estimate of the production of thermal and electric energy and primary energy savings and savings in terms of CO_2 emissions for 2015

	Production of Energy		**Savings**	
2015	**Electric (MWhe)**	**Thermal (MWht)**	**Primary Energy (TEPs)**	**CO2 (kton)**
Fuel Oil	866991	1323291	227565	367
Natural Gas	8356227	9821099	690830	2215
Renewable	1468971	6875937	590932	1429
TOTAL	**10692188**	**18020326**	**1509326**	**4011**

Table 3.10 – Estimate of the production of thermal and electric energy and primary energy savings and savings in terms of CO_2 emissions for 2020

	Production of Energy		**Savings**	
2020	**Electric (MWhe)**	**Thermal (MWht)**	**Primary Energy (TEPs)**	**CO2 (kton)**
Fuel Oil	0	0	227565	0
Natural Gas	11744394	13465156	844406	3114
Renewable	1664333	7708098	662807	1619
TOTAL	**13408727**	**21173254**	**1734778**	**4732**

4 Barriers and Mitigation Strategies

4.1 Introduction

Since cogeneration is an efficient technology, which has matured in technological terms and has clear environmental benefits, it would seem to be highly desirable to ensure its propagation within the Portuguese energy context in all applications in which it is economically viable. However, despite its many advantages - which include primary energy savings and a reduction in CO_2 emissions that are essential to achieving the goals defined in the Kyoto Protocol, the increased reliability and security of energy supplies, fewer losses in the electricity network and increased economic competitiveness by companies - there are various barriers that prevent cogeneration from being used on a larger scale. Some of these obstacles have conditioned the evolution of the installed cogeneration capacity over the course of decades, hindering its expansion, while others are the result of the prevailing socio-economic and political scenario in Portugal and the scientific and technological development that have taken place.

This chapter will provide an overview of the most significant barriers that were identified by diverse agents in the industrial and services sectors, such as investors and self-producers, which hinder the expansion of the installed capacity of cogeneration systems in Portugal. It will also summarise the strategies which could mitigate a number of the obstacles that were identified.

In conformance with point 2 of article 6 of Directive 2004/8/EC, a separate and more comprehensive study has also been conducted entitled **"Study of the Potential for High-Efficiency Cogeneration in Portugal – Identification of Barriers and Mitigation Strategies"**, which contains a more detailed analysis of this issue (Barriers and Mitigation Strategies).

4.2 Barriers to Cogeneration

The following table identifies the various barriers that hinder a greater penetration of high-efficiency cogeneration in Portugal. Each of them has been associated with the respective period when they have an effect, in a forecast extending up to 2020, as stipulated by Directive 2004/8/EC. These periods of effect were considered while preparing the estimates for the development of cogeneration, so as to ensure that the said estimates were more accurate and reflected reality more accurately.

Table 4.1 *– Barriers to the penetration of cogeneration and their periods of effect up to 2020*

		Periods		
Type	**Barrier**	**2008-2012**	**2012-2016**	**2016-2020**
Economic	Price of fuels, particularly NG	■	■	■
	Initial cost of installing a cogeneration system	■	■	
	Conditions for the remuneration of electricity			■
	Continued existence of thermal needs	■	■	■
Technical	Access to electricity and NG distribution networks	■	■	■
	Goal of 10% PES in some industries	■	■	■
	Absence of a distribution network for thermal energy	■	■	■
	Lack of physical space	■	■	
Political	Uncertainties of the EU emissions market		■	■
	Time taken to obtain a licence	■	■	■
	Excessive bureaucracy for environmental requirements	■	■	■
Others	Lack of information	■		
	Inertia of a transformation process within the company	■	■	■

4.3 Mitigation Strategies

In short, the following are the main strategies that have been identified to mitigate barriers:

- Expand and improve the gas supply network
- Publicise the benefits of cogeneration and the resulting advantages
- Reduce constraints with regard to links to the electricity network, more specifically by reinforcing the network and differentiating cogeneration projects from other independent producers in terms of what is an effective injection into the network and the contribution towards the transfer of capacity
- Promote funding systems with public-private capital
- Reduce the bureaucracy for licensing new facilities
- Stable incentives in terms of the regulatory framework and policies

5 Conclusions and Recommendations

Cogeneration was implanted and expanded more significantly between 1991 and 2002. Between 2003 and 2007 there was a widespread consolidation of the efficiency of the existing units and a more moderate expansion of new facilities.

The investment projects currently underway in the industrial sector are expected to expand cogeneration by 2010 by approximately 25% of the installed capacity in 2007. This forecast, which indicates a strong evolution of new cogeneration facilities, will essentially be derived from the application of rules resulting from legislation in effect as of today and will primarily be based on delivering heat, with a limited number of cases in which both cold and heat are produced.

The substitution of the use of fuel in the plants that were installed during the 1990s by natural gas, by converting plants in some cases or by substituting the existing equipment in others, appear as viable technical options as long as this process is duly framed by specific regulations. It has been estimated that the impact of the implementation of this option will not be reflected in the potential for cogeneration, as long as thermal consumption continues to exist.

With regard to the range of primary fuels used to operate cogeneration plants, apart from the aforesaid case of fuel, a strategic role can be played by other sources of heat such as typical renewable sources (biomass, biogas, solar, etc) and sources that use other residual sources of heat (exothermic processes and other sources of heat). None of them are properly addressed in prevailing legislation and, owing to their merits, they should be positively decoupled, in the light of the Directive, based on the argument that the use of renewable fuels for cogeneration should be the subject of positive discrimination since they are associated with significant primary energy savings and reductions in CO_2 emissions.

The expansion of cogeneration, beyond 2010, will require not just the consolidation of the areas of industrial applications but also a greater use in services, including urban areas. This tendency will include a sharp increase in the contribution towards the production of cold, along with the production of heat, by means of trigeneration, associated with a reduction in the average size of the units and a consequent increase in their number.

The higher value of the specific investment associated with trigeneration, which can be extended to other “less conventional” forms of cogeneration with specific applications in some relevant sectors of economic activity (industrial chemicals, cement, glass, etc.) implies higher levels of requirements, which must be kept in mind when drawing up the new regulatory framework that is currently being prepared, in keeping with the real costs of energy supplies, including the costs associated with fiscal requirements.

The meeting of requirements for environmental comfort that typically exist in urban areas or even a multipoint demand, whether simultaneous or otherwise, of cold and heat in industrial processes by means of network accumulation and distribution to a given group of geographically dispersed consumers is a solution that must be considered.

The necessary expansion of cogeneration to urban areas, supported by the natural development of networks to distribute heat/cold, inspired by facilities in Northern Europe, could play a decisive role in the effort to reduce energy intensity and emissions. Keeping in mind IEA recommendation to develop networks to distribute cold to support the penetration of trigeneration systems, legislators must pay renewed attention to this issue in order to promote high-performance projects that are sustainable from an economic point of view.

However, the performance of conventional equipment used to produce cold has been improving progressively (e.g. COPs > 6) and hence it would be advisable to carefully analyse this technology, as compared to cogeneration, in terms of primary energy savings and a reduction in emissions.

The maturing process of other cogeneration technologies, which are less conventional nowadays, or access to other energy sources and the inevitable tendency towards increasingly sophisticated systems to manage and transport energy, could lead, in the long-term, to the use of cogeneration systems with residential applications, should there be economic and environmental advantages.

Making the most of the economic potential of cogeneration is a national plan that is not always compatible with given timeframes and does not always coincide with the interests of the owners of the establishments which consume heat and the dynamics of market realities. In this sense, legislators face the challenge of providing a framework of stimulus measures that will encourage the comprehensive development of the potential for cogeneration in each application while simultaneously creating mechanisms to allow more flexible activities, showing the necessary commitment with a view to achieving the national and EU objectives associated with the expansion of cogeneration.

In an optimistic scenario, in the Industrial Sector it is possible to achieve a reduction in primary energy consumption of approximately 493 ktep/year by 2020, i.e. 81% of the total overall economic potential of 608.8 ktep/year. A potential of 1 377 MWe was identified in the industrial sector, comprising 677 MWe obtained by converting fuel oil to natural gas with the remaining 700 MWe corresponding to the new capacity to be installed. When added to the 1 368 MWe that already existed in 2007, it represents an installed electric capacity of 2 068 MWe by 2020.

A reduction of approximately 116 ktep/year can be achieved in the Services Sector, i.e. 19% of the overall potential for reductions. This sector has the potential to achieve 252 MW of installed capacity by 2020, owing to an increase in this capacity of 221 MWe. This is a very significant increase when compared to the installed capacity that existed in 2007, which was only 31 MW.

***Table 5.1** – Estimated evolution of consumption according to type of fuel for 2010, 2015 and 2020*

Fuel	2007	2010	2015	2020
Fuel	49%	33%	16%	0%
Natural Gas	27%	46%	65%	81%
Renewable	24%	21%	19%	19%

***Table 5.2** – Evolution of the installed capacity for high-efficiency cogeneration according to the different technologies*

Technology	2010	2015	2020
Combined Cycle	23%	32%	40%
NG – Engine	18%	25%	31%
NG – Turbine	6%	8%	10%
FO – Steam Turbine	21%	11%	0%
FO – Diesel Engine	11%	6%	0%
Bio Turbine	21%	19%	19%

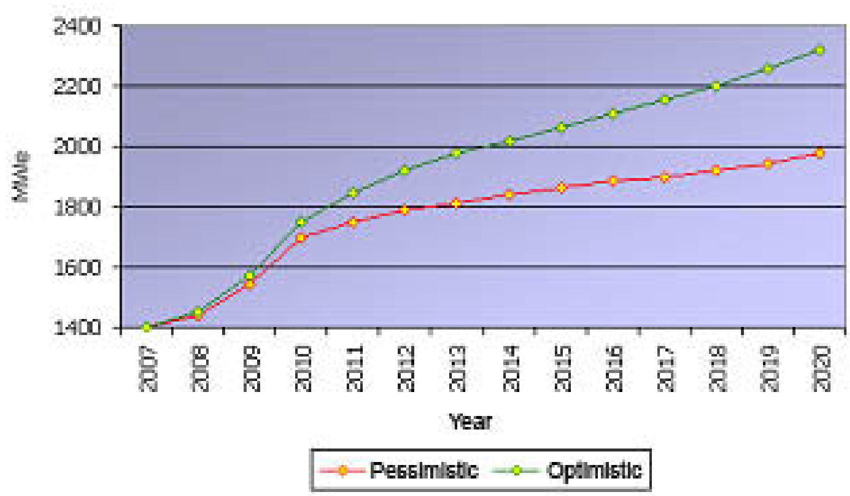


***Figure 5.1** – Evolution of the National Economic Potential for High-Efficiency Cogeneration*

***Table 5.3 –** National Economic Potential in 2010, 2015 and 2020, for the scenarios being considered*

Year	Optimistic (MWe)	Pessimistic (MWe)
2010	1750	1697
2015	2065	1862
2020	2320	1979

Hence, in an optimistic scenario the overall economic potential for high-efficiency cogeneration, for 2020, would correspond to 2 320 MWe of installed capacity. In a pessimistic scenario, the national economic potential reduces to 1 979 MW.

It thus seems possible to be able to achieve in Portugal the goal established by the European Union to produce 18% of electric energy by means of cogeneration before 2020, with very significant benefits for the country in terms of primary energy consumption. The net balance of emissions resulting from the implementation of the added potential that has been identified, already considering the possible elimination of the use of fuel, would translate into an annual reduction of emissions of 4.7 $MtCO_2$/Year.

Current legislation and endogenous incentives for encouraging cogeneration, of which the tariff for selling the electricity produced to the network is worthy of note, have been tools used to increase the installed capacity in cogeneration systems. Notwithstanding this policy of incentives, which can be considered to be positive, there are some aspects that must be improved to promote greater penetration of this technology, which has clear benefits for the country. Thus, as a corollary to Chapter 4, the following recommendations should be considered with a view to overcoming the barriers that have been identified:

- Links to the network should be assessed in a focused manner to ensure a balance between local production and consumption. While carrying out studies to assess the impact on the network associated with the linking of independent producers, this impact should mainly be conditioned by the balance between the production by cogeneration and the local consumption of electric energy by the user(s) of heat.

- Making it compulsory to declare the cogeneration potential associated with each licensing process for a new facility, and the acceptance of the commitment to satisfy this potential, should be a principle that can be adopted by legislators.

- Maintain a framework of stimulus measures aimed at supporting continued efforts to achieve optimum energy and environmental results, with a view to achieving primary energy savings as compared to existing plants, which should incorporate the merits of cogeneration. In particular, the energy produced by means of cogeneration from renewable sources should not be discriminated against as compared to other technologies that produce energy from a similar renewable source, since it is also associated with significant savings of CO_2 emissions.

- The system of incentives should create conditions to provide temporal stability to the promoters of new projects, based on an adequate remuneration for their investments and the European reality. It is especially important to also consider the Spanish framework, given the growing integration of the Iberian electricity markets.

- Create bases within Portugal to produce the equipment used in cogeneration, especially in terms of boiler making.

- Create bases that make it viable to expand renewable cogeneration, making it similar to the support framework established by prevailing legislation aimed at promoting renewable energy from an equivalent source. Given its potential to expand renewable cogeneration, coordinated actions should be promoted in order to encourage the sustainable expansion of chains of economic activities linked to the forestry sector. It is extremely important to promote the forestation of abandoned wastelands that could be used, with a high potential impact on the nation's economic and social development, both directly as well as due to the positive impact on industries in which Portugal is competitive, such as cellulose, agglomerates and furniture.

- Establish clear time frames for the approval of cogeneration projects, providing a simpler and more streamlined licensing process.

- Develop programmes to disseminate information on cogeneration and make available and circulate case studies on success stories in the sectors that have the greatest potential.

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7 Annexes

7.1 Cogeneration Technologies

- Internal Combustion Engines

Having been developed more than a century ago, internal combustion engines use a well-known technology that is available in a range of capacities from 5 kW to 10 MW. There are two types of internal combustion engines, which differ in the way in which the fuel is ignited. The explosion engine or spark ignition engine, which uses the Otto cycle, was invented by the German engineer Nikolaus August Otto in 1867. Internal combustion explosion engines use the 4 stroke Otto cycle known as intake, compression, power and exhaust, depicted in Figure 7.1

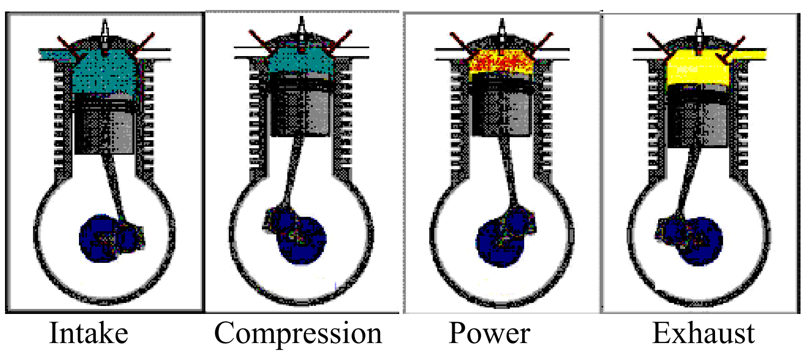


***Figure 7.1** – Four-Stroke Otto Cycle*

In 1892, Rudolph Diesel, another German engineer, developed the Diesel engine or the compression ignition engine. Compression engines use the Diesel cycle, in which, during the intake, when the piston moves downwards, only air enters into the cylinder instead of a mixture of air and fuel. The fuel is later injected into the cylinder near the end of the air compression. By only compressing air it is possible to achieve much higher compression rates (typically 12:1 in explosion engines and 20:1 in compression engines), achieving temperatures that make it possible to ignite fuel.

Both types of engines have been successful in the market and continue to be used widely even today for the most diverse applications. Internal combustion engines can operate with a vast variety of fuels, including natural gas, gasoline and diesel. However, it is also possible to use fuel oil, biogas, LPG, methanol, ethanol and hydrogen. The energy available in the fuel is converted into mechanical energy, available in the engine shaft. The mechanical energy is converted into electric energy by coupling a generator to the engine shaft.

Cogeneration Systems with Internal Combustion Engines

The yield of natural gas engines in cogeneration applications is increased by making use of the thermal energy contained in the exhaust gases, which typically represent between 60% and 70% of the energy contained in the fuel. Most of the waste heat can be used by means of the cooling systems of the piston sleeves, since small quantities of heat are available in lubricated cooling systems. The heat from exhaust gases and cooling systems can be used to produce hot water or low-pressure steam. Thus, using a heat recovery system, it is possible to achieve overall yields of 70% to 80% in systems with natural gas engines. Some industrial applications use the exhaust gases directly for drying or other processes. Generally, the hot water and low-pressure steam that are produced are suitable for low temperature applications, heating spaces and water, for absorption chillers to produce cold water or for cooling and air conditioning.

The exhaust gases of an internal combustion engine have a significantly lower temperature when compared to gas turbines, the temperature of which varies between 300ºC-400ºC. This is why an additional source of heat is often used, either through an additional burner in the exhaust boiler (it being necessary to supply air since the oxygen contained in the exhaust gases is not significant) or by means of an auxiliary boiler.

Yield and Reliability

Internal combustion engines represent a technology that has a proven availability, presenting values between 90 and 98% with suitable maintenance. These engines have yields of between 25% and 45%. In general, diesel engines are more efficient than natural gas engines due to the fact that they function with higher compression rates and a greater lower heating value. In 2010, manufacturers hope to achieve a reduction in fuel consumption and yields of between 50% and 55% in large engines (above 1 MW). The heat recovery capacity of internal combustion engines is relatively low when compared to other technologies. The large units have an average useful lifespan of between 20 to 30 years, while smaller units (below 1 MW) have shorter life spans. They have a high tolerance for successive starts and stops, with start-up times ranging from between 0.5 and 15 minutes. Natural gas internal combustion engines offer lower initial costs, a quick start, have proven reliability, excellent characteristics for load tracking and a significant potential to make use of waste heat.

Emissions and Noise

***Table 7.1** – Emissions from Internal Combustion Engines (kg/MWh)*
Source: NREL

	Natural gas engine without controls	Natural gas engine with a three way catalyst	Diesel engine without controls	Diesel engine with SCR
NO_X	1.00	0.23	9.89	2.13
SO_2	0.00	0.00	0.21	0.21
CO_2	502.58	624.14	649.55	649.55
CO	2.27	1.81	2.81	2.81

Costs and Maintenance

Typical installation costs for internal combustion engines vary from between 400 - 700 €/kW[1]. Since natural gas is cheaper than diesel to produce the same quantity of heat, if the internal combustion engine operates for many hours over the course of the year, the total operating costs of a natural gas engine will be lower. The maintenance intervals range from 500 to 2 000 operating hours for minor maintenance, including oil changes, while it is necessary to undergo more extensive service at intervals of between 12 000 to 15 000 operating hours. The costs involved in maintaining natural gas engines vary from between 0.007 to 0.015 €/kWh and diesel engines from between 0.005 and 0.010 €/kW. [Source: OSEC]. The following tables (Table A.2 and A.3) provide a summary of the main characteristics of this technology as well as the main advantages and disadvantages.

***Table 7.2** – General characteristics of internal combustion engines*

Commercial Availability	High
Range of Capacities	5 kW - 10 MW
Yield	25-45%
Availability	90 to 98%
Fuels	Gasoline, natural gas, diesel
Others	Cogeneration (some models)
Environmental Impact	Necessary to control NOx and CO emissions High noise levels

[1] - Values as of 1 January 2005 [Source: *RETScreen International*]

***Table 7.3** – Advantages and disadvantages of internal combustion engines*

Advantages	Disadvantages
Good yield (up to 45%)	Polluting emissions (mainly NOx)
Low installation costs	Noise
High level of reliability	Need for frequent halts for maintenance
Widely diffused and proven technology	Modest heat recovery capacity
Quick starting time with a good tolerance for starts and stops	Unable to start from zero rpm, unlike the majority of steam engines
Versatility in terms of fuels	
Quick starts (for most models)	
Simple albeit frequent maintenance operations	

- Steam Turbines and Engines

Steam turbines are one of the most versatile technologies used to produce energy and one of the cheapest. These turbines have been used as primary machines in industrial cogeneration systems for many years. The main components of a system based on these turbines are: a source of heat (typically a boiler), a steam turbine, a condenser and a water pump. This system operates on the basis of the Rankine cycle, both in its most basic form as well as in improved versions. The steam turbines do not directly convert the energy of the fuel into mechanical energy, since the gases resulting from burning the fuel do not come into contact with the working fluid, which drains into the interior of the machine and which realises the processes of converting the fuel's energy into axle power. Thus, it is necessary to have a source of high-pressure steam, which can be obtained by burning any fuel or using exhaust gases from another system. This enables a degree of flexibility with regard to the fuel being used and it is possible to use a vast range of fuels such as petroleum derivatives, natural gas, waste or biomass. Steam turbines are high-speed machines, with the steam being channelled at a high speed and pressure to the turbine, turning the blades of the turbine rotor. The remaining energy contained in the steam that cannot be transformed into work remains in the steam discharged by the machine. After passing through the turbine the temperature and pressure of the steam diminish. The unused energy that remains in the steam discharged by the machine is used for heating purposes, significantly improving the overall yield of the cycle.

The electric energy produced depends on the reduction of pressure that the steam undergoes through the turbine before being used for the heating needs of the site. These systems generate less electric energy per unit of fuel than a cogeneration system based on a gas turbine or on an internal combustion engine, although the overall yield of the system can be greater, reaching up to 85% (using fuels with a high calorific value).

Depending on the quantity and quality of the steam necessary and other operating factors of the industrial process there are various steam turbine engines available for cogeneration systems. Most steam turbines used in cogeneration are extraction/condensing or backpressure turbines, however there are recent technologies and processes that will also be examined. Although the extraction/condensing turbines have lower yields, there are some advantages to their use when compared to backpressure turbines. The former provide a good solution for electric energy needs and are used in units in which the need for steam can vary a lot or in industrial facilities where interruptions in the supply of electricity should be avoided.

Cogeneration Systems with Organic Fluids

These systems are normally referred to as Organic Rankine Cycles (ORC). In the system based on a bottoming cycle water is the operational fluid, which evaporates in the thermal recuperator at high temperatures (500ºC or higher). However, when the available heat has relatively low temperatures (80ºC - 300ºC), organic fluids with evaporation temperatures that are lower than that of water can be used (hydrocarbons such as toluene, isopentane, isooctane or silicon fluids), improving the performance of the system and the thermal recuperator. This allows the process to adapt better to a fuel such as biomass with low combustion temperatures.

Organic fluids have four significant disadvantages when compared to water:

- They are more expensive than water and losses of the fluid can result in significant costs;
- Fluids such as toluene are considered to be hazardous materials and must be handled in accordance with safety norms and with specific handling systems, thus increasing the overall cost of the system;
- The thermal stability of some organic fluids is limited;
- Their evaporation at lower temperatures (when compared to water) makes it necessary to use a greater mass of fluid, obliging a greater pumping capacity, resulting in a reduction in the yield.

However, it is also important to note some advantages of organic fluids:

- Their heavier molecular weight results in a reduction in the turbine costs;
- In the case of most organic fluids the absolute value of the inclination of the line separating liquid/vapour and pure steam in a diagram (t,s) is greater than that of water. As a result the rate of condensation inside the turbine is lower.

Cogeneration Systems with Steam Engines

This is an alternative process that, even though it is not very widely disseminated, is a sufficiently attractive technology to be implemented. In this process, the exhaust gases resulting from the combustion pass through a boiler in which the steam is generated. The steam is then sent to the steam engine in which mechanical work is carried out, which is converted into electric energy by a generator. The steam is then taken to a condenser where it releases the heat, which can be used for local heating. The condensed steam is taken up to the operating pressure and is taken to the boiler by means of pumps, thus closing the cycle. However, when combined with steam turbines, this engine produces lower levels of electric power. (Figure 7.2)

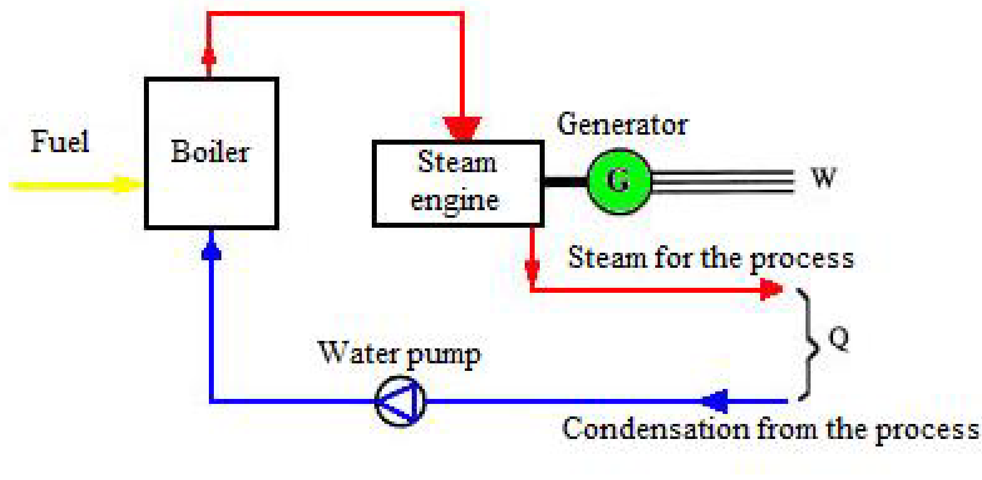


Figure 7.2 *– Cogeneration system with a steam engine*
Source: ITTMD

The operating principle of a steam engine is illustrated in Figure 7.3:

- The steam enters the cylinder until the process of the steam intake is stopped by the controlling piston.
- The steam expands and works on the piston. Once the volume increases, the pressure is continuously reduced.
- When the piston achieves its lowest point it rises, which makes the controlling piston move, allowing the steam to leave the cylinder, beginning the process once again.

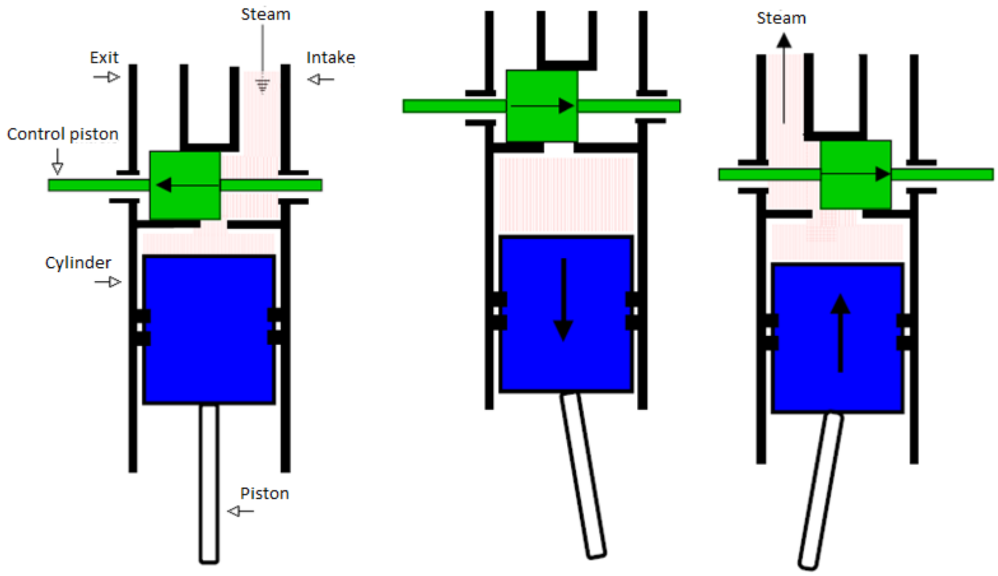


***Figure 7.3** – Operating principle of a steam engine*
Source: ITTMD

This system makes it possible to use practically any fuel (coal, biomass, petrol, etc). When functioning with a partial load, the quantity of steam produced reduces for the same pressure and temperature conditions. The mechanical energy produced and, in its turn, the electric energy produced, also diminishes. Thus, it is important to consider that the unit's greatest yield is not achieved at maximum power but instead just slightly below it. This is an advantage of steam engines if they operate with a partial load, since they function with a yield of 90% of the maximum yield when operating at partial load. On the other hand, this technology requires a great deal of maintenance, produces a lot of noise (up to 95 dbA) and it is hence necessary to resort to soundproofing measures. Such engines can have between 1 and 6 cylinders, each of which has their own controlling piston. Steam engines can achieve a useful lifespan of more than 200 000 hours of service if they are suitably maintained.

Cogeneration Systems with a "Screw Type" Steam Engine

This is an innovative process that is currently being developed, based on the conventional Rankine cycle. This type of technology is derived from the *screw compressor* and is a suitable technology for using biomass in cogeneration systems with a range between 200 and 2 500 kWel. The exhaust gases that result from the combustion process produce steam inside a boiler. The steam enters into this engine, where it is expanded. The steam carries out mechanical work, which, in turn, is converted into electric energy by means of a generator. The steam enters a condenser, where it is condensed, releasing heat that can be used for heating purposes. With the help of a water pump, the condensed steam is placed at the operating pressure and is returned to the boiler, thus concluding the circuit. (Figure 7.4)

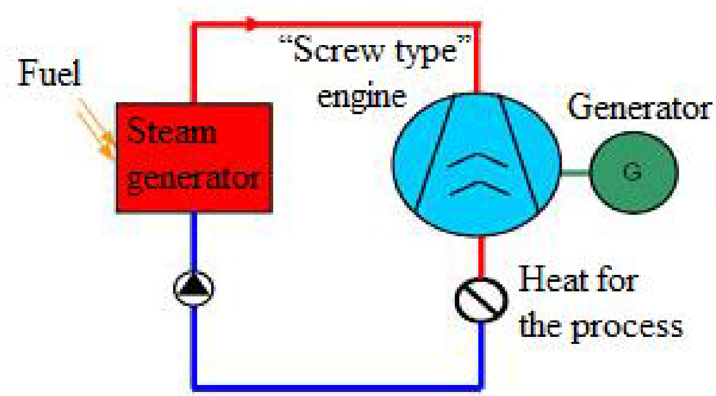
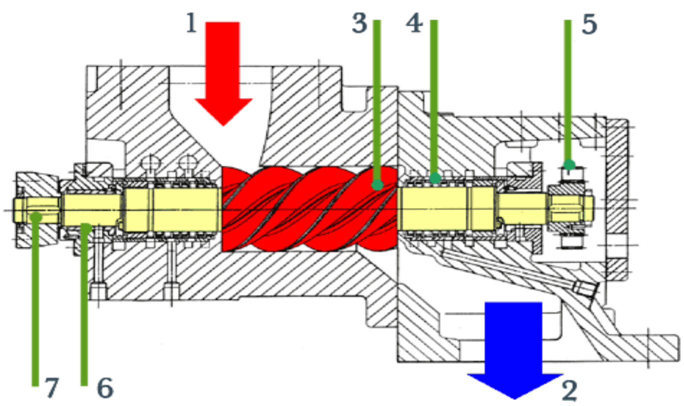


Figure 7.4 *– Cogeneration system based on a "screw type" steam engine*
Source: ITTMD

A "screw type" engine is based on rotary movement. Like piston engines, this type of engine is characterised by a closed operating chamber. The main components of this engine are a "male" rotor, a "female" rotor and a frame, which together form a V shaped operating chamber, the volume of which only depends on the angle of rotation. The volume of the operating chamber changes cyclically, which results in a reduction of the energy content of the fluid in the chamber. The operating principle of this engine is described below:

- A *screw type* engine consists of two spiral rotors linked to each other. The space between them changes cyclically.

- The steam intake is opened, the steam enters the operating chamber, the entry of the steam is closed, due to the continuous movement of the rotor and the steam begins to expand.
- The two rotors are propelled by the process of expansion. The mechanical work is later converted into electric energy by the generator;
- During the expansion process the volume of the chamber continues to increase, reducing the energy content of the working fluid.



1 - Intake of steam	5 - Synchronisation wheel
2 - Output of steam	6 - Drainage bearing
3 - "Male" rotor	7 - Power shaft
4 - Shaft	

Figure 7.5 – "Screw type" steam engine
Source: BIOS BIOENERGIESYSTEME

This type of system makes it possible to basically use any kind of fuel (biomass, petrol, coal, etc.). The engine is controlled by cutting off the quantity of steam that enters the operating chamber, thus reducing the pressure and, in turn, reducing the electric energy produced. Such engines are very compact. They have a long lifespan, good load tracking characteristics and require very little maintenance. When compared with steam engines the necessary foundations for this type of engine do not have to be very strong because the vibrations caused by the rotational movement are not as intense as those produced by translational movement. The latter engines generate a high level of noise (90 dBA), and it is necessary to resort to soundproofing measures.

Yield and Reliability

Currently, in new steam turbines of different outputs it is possible to obtain electric yields of between 40% and 45%. However, in smaller turbines including in industrial applications, the yield varies between 15% and 35%. Steam turbines have a high level of reliability, which can go up to 95% as long as they are maintained in good operating conditions. They are easily available and have a long lifespan (25-35 years). The overall yield of a cogeneration system based on steam turbines is relative high (60%-85%), which reduces slightly when it is operated with a partial load.

Costs and Maintenance

The turbines do not require extensive maintenance and are usually stopped for maintenance once a year. The maintenance costs are about 0.004 €/kWh. [Source: Catalogue]. A disadvantage of this type of turbines is the long start-up time, which takes over an hour. The steam cycles produce a large quantity of heat as compared to the electric power produced, thus resulting in high installation costs in terms of €/kWe. The installation of a steam turbine costs approximately 300 to 900 €/kW[2].

Emissions

As these turbines can function with different types of fuels the emissions differ for each type of turbine, since some fuels have higher emissions than others. The following table shows the average values of emissions, for a steam turbine and coal boiler.

[2] - Values as of 1 January 2005 [Source: *RETScreen International*]

***Table 7.4** – Emissions from a steam turbine and a coal boiler*
Source: NREL

	Emissions (kg/MWh)
NO_X	2.54
SO_2	6.08
CO_2	959.35

***Table 7.5** – General characteristics of steam turbines*

Commercial Availability	High
Range of capacities	100 kW - 250 MW
Yield	15-35%
Availability	90-95%
Fuels	Petroleum derivatives, natural gas, coal, waste or biomass, etc.
Environmental Impact	Depends on the type of fuel used

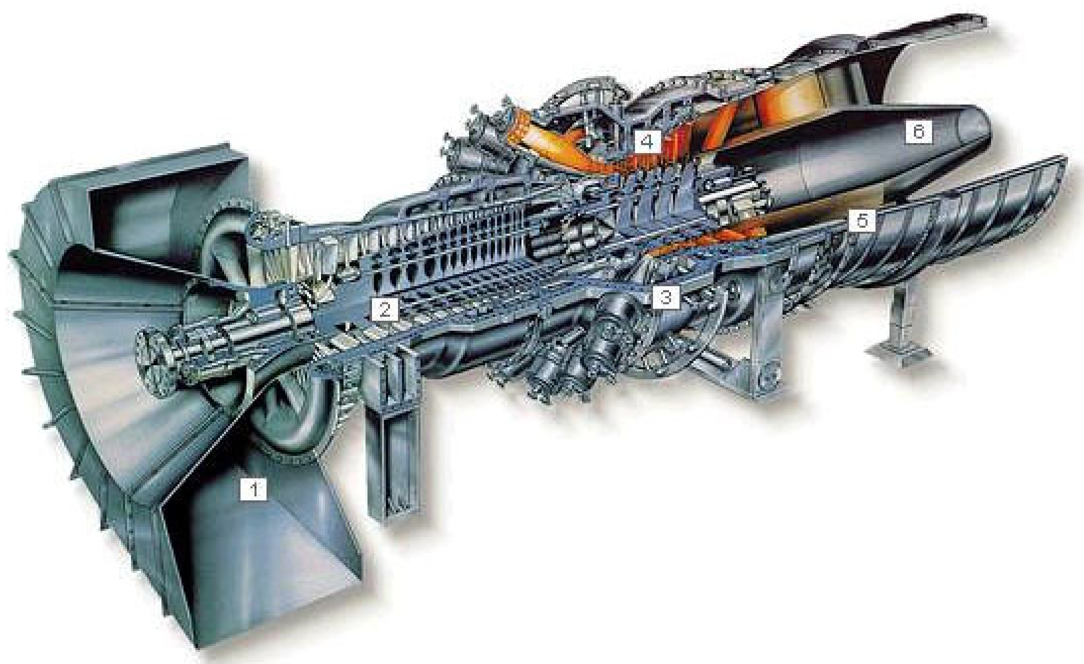
***Table 7.6**– Advantages and disadvantages of steam turbines*

Advantages	Disadvantages
Easily available	Long start-up time
Proven technology	Emission of pollutants (depends on the type of fuel)
Diversity of fuels	Low electric yield
Long lifespan	High initial investment

- Gas Turbines

Regardless of whether they are simple cycle or combined cycle systems, gas turbines are the most widely used technology in recent medium and high power cogeneration systems. They are capable of quick starts and respond rapidly to changes in loads. They offer low costs, a high level of availability, quick and inexpensive maintenance, allow fuels to be changed, provide a high yield on a large scale and produce a high quality heat that can be recovered easily.

A gas turbine consists of a compressor, a combustion chamber and a turbine coupled to a generator. Single-axis turbines have all the components associated with a continuous axis, all of which rotate at the same speed. This kind of architecture is used when variations in the speed of the turbine are not expected. The rotor that operates the generator can be mechanically separated from the rotor that is operated by the combustion gases, thus allowing greater flexibility in the operating speed. (Figure 7.6)



1 - Intake of air
2 - Compressor
3 - Exhaust chamber
4 - Turbine
5 - Exhaust system
6 - Exit for escape gases

Figure 7.6 *– Gas turbine*
Source: Siemens

Since gas turbines produce a large volume of exhaust gases at high temperatures the energy of the exhaust gases can be reused to generate electric energy, through a combined cycle or through a Cheng cycle (steam injection turbines), or for another type of application such as the production of steam for industrial processes by means of cogeneration.

Currently, natural gas is the fuel which makes it possible to obtain the best yield in gas turbines. However, gas turbines can also function with other fuels such as fuel oil, diesel, propane, J-5 (used in aeronautics), kerosene, methane and biogas.

- Combined Cycle

The combined cycle is recommended in situations where the production of electric energy and thermal energy is required in variable quantities, according to the consumption loads or to serve specific markets. The combined cycle is based on a combination of the Brayton and Rankine thermodynamic cycles. Thus, the working fluids operate at different levels of temperature. The cycle with the higher temperature rejects heat, which is recovered and partially or totally used by the lower temperature cycle to produce additional electric (or mechanical) energy, thus increasing the system's electric yield. The Combined Cycle Gas Turbine (CCGT) is the most common solution but it can also be operated with diesel engines. This type of cogeneration process is the most advisable for sites where the demand for electricity is higher than the demand for steam.

Cogeneration Systems with Combined Cycle Gas Turbines

In cogeneration systems which use combined cycle gas turbines, the exhaust gases of the gas turbine are at a relatively high temperature, normally between 450°C and 550°C. Thus, the flux of hot gas can be used in a thermal recuperator to generate steam, which, in turn, serves as a working fluid to operate a steam turbine, generating an additional quantity of energy since the exhaust steam from the turbine is used to provide heat. Hence, the combined cycle has a greater thermal yield than that of the Rankine and Brayton cycles separately. The steam turbine which is used can be a backpressure or condensing turbine. As mentioned before (in open cycle gas turbines) the maximum temperature of the steam which can be achieved (without additional burning) depends on the temperatures of the exhaust gases from the gas turbine, which, as indicated above, is around 550ºC. Additional fuel can be burnt if it is necessary to achieve higher temperatures or pressure, without needing to resort to supplementary air due to the high oxygen content contained in the exhaust gases of the gas turbine. An additional burning of fuel does not just increase the system's capacity but also increases its yield with a partial load. Average annual availability is 77%-85% and useful lifespan is 15-25 years. The following figures show the configurations of cogeneration systems based on gas turbines, using backpressure and condensing steam turbines.

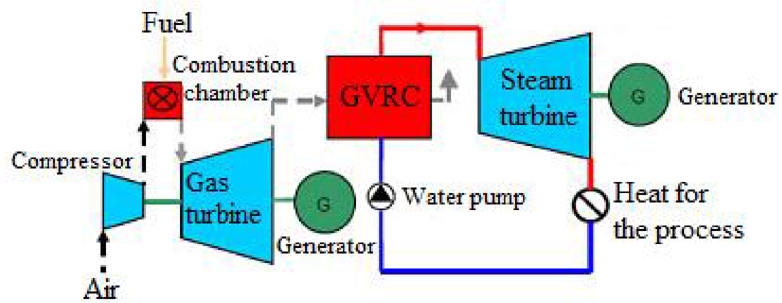


***Figure** 7.7– Combined cycle using backpressure gas turbines and steam turbines*
Source: ITTMD

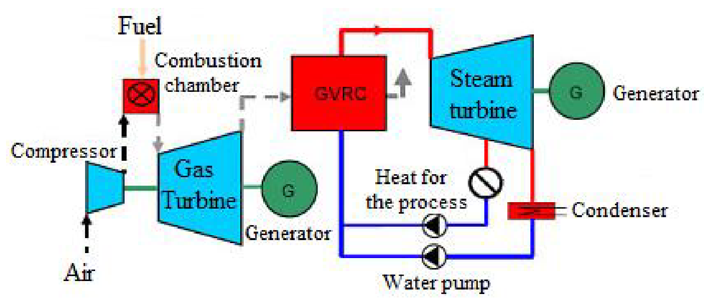


***Figure 7.8** – Combined cycle using condensing gas turbines and steam turbines*
Source: ITTMD

Gas turbines are normally controlled by means of the fuel supply. Steam turbines are controlled by means of the heat recovery boiler, which depends on the gas turbine's exhaust gases. On the other hand, the steam turbine can be controlled by means of a regulatory valve placed in the turbine, thus controlling the pressure of the steam output. The large thermodynamic losses of this kind of a system occur in the thermal recuperator, owing to the large difference in temperature between the cooling curve of the exhaust gases and the heating curve of the steam heating, including vaporisation. This is why double or triple pressure cycles are often used so as to obtain a greater adjustment of the steam curve and the curve of the exhaust gases. A system based on a combined cycle can be quite expensive although it provides a high electric yield. In cogeneration applications this type of system is normally used when a large quantity of electric energy is needed.

Yield and Reliability

The electric yields of gas turbines depend on their capacity and the technology used. Generally, gas turbines have yields of between 20% and 45%. Using the same technology, the yield increases in proportion to the turbine capacity. In cogeneration applications, the exhaust gases can be channelled to a water tank to heat water in residential buildings, to produce steam for industrial processes, etc. In some industrial applications of cogeneration it is possible to achieve overall yields of 80%. These values fall when the turbine is functioning with a partial load, and is approximately 25% lower when the load is 50% of a normal load. The start-up time varies between 2 and 5 minutes. The installation of an open cycle cogeneration system with a capacity of up to 7 MW takes about 9-14 months. For large systems the installation can require up to 2 years. The reliability and annual availability of these systems with gas turbines, burning natural gas, are comparable to steam turbine systems. The lifespan of these systems is around 15-20 years. In combined cycle applications, gas turbines are used as the first cycle, in which the exhaust gases of the gas turbine are used to produce steam in a heat recovery boiler. This steam is later used to operate a steam turbine, thus increasing the overall yield of the system to values of between 70%-88%.

Emissions and Noise

The use of turbines which operate on natural gas to produce electric energy is a good environmental solution, since the process is free from sulphur and ash, which makes it possible to eliminate the ash removal facilities required in other technologies (as is the case in thermal plants running on coal and oil). The most difficult environmental problem in natural gas plants is that of emissions of nitrogen oxides, known as "NOx", since gas turbines have higher levels of NOx as compared to oil or coal boilers, since the relationship between the air and the fuel is greater while burning gas. Unlike in the case of internal combustion engines, in gas turbines the combustion occurs outside the area of the turbine. This fact allows a greater flexibility in terms of reducing NOx emissions. Typically, the emissions of gas turbines are controlled during the combustion process. The levels of NOx emissions for gas turbines without any emissions control devices are approximately 150-300 ppm. After using systems to control these emissions this can be reduced to approximately 6 ppm. The following table shows the levels of NOx emissions for natural gas turbines.

***Table** 7.7 – Emissions of gas turbines*
Source: CEC

	NOx emissions (ppmv @ 15% O_2))
With controls	150-300
With NOx controls	25
NOx controlled with SCR	6

The general impression is that this type of turbine generates high levels of noise, however this is not correct. When used in well-planned plants, noise pollution does not exceed the levels of equivalent steam turbines and is well within the legal requirements. Another advantage of this kind of plant is that it requires less space as compared to other thermal plants.

Costs and Maintenance

The cost of installing such turbines varies between 340 and 1 500 €/kW[3] and it tends to reduce with an increase in capacity. The highest costs occur in small plants. In combined cycle applications, where capacity is higher (tens to hundreds of MW) the cost is in the range of 400 to 900 €/kW. When compared to internal combustion engines, gas turbines

[3] - Values as of 1 January 2005 [Source: *RETScreen International*]

have higher costs for lower capacities, but are less expensive than high-capacity engines. The cost of gas turbines has remained fairly stable, having increased less than 3% in the past three years. Total costs, including the turbine, installation, auxiliary equipment and engineering are 30% to 50% higher than the cost of the turbine itself. The addition of heat recovery equipment increases the turbine costs by 100 to 200 €/kW. Maintenance costs increase with the frequency of start/stop operations. In the case of a turbine which starts every hour, maintenance costs can be triple the costs of a turbine that functions in periods of 1 000 hours. These costs can increase dramatically when it operates with loads that are higher than the nominal capacity. Maintenance costs also depend on the fuel and are higher if they are fuel oil fired. Conventional gas turbines are planned with a modular installation, thus allowing diverse subsystems, such as the burner, the turbine, the compressor, the thermal recuperator, the gearbox or the generator, to be replaced without it being necessary to replace the entire turbine. Owing to the mechanical simplicity and the low lubricant contamination, gas turbines have a high level of reliability. Maintenance costs for gas turbines are typically between 0.004 and 0.010 €/kWh. Energy costs depend mainly on the yield, the capacity and the fuel used. These values vary between 0.05 and 0.15 €/kWh. Generators with gas turbines are available in a vast range of capacities, corresponding to three different types of generators:

Microturbines (from 25 to 500 kW);

- Mini turbines (from 500 to 10 000 kW);
- Large turbines (more than 10 MW).

***Table 7.8** – General characteristics of gas turbines*

Commercial availability	High
Range of capacities	500 kW - 250 MW
Yield	20 - 45%
Availability	90 to 99%
Fuels	Natural gas, fuel oil, diesel, etc.
Environmental impact	Low levels of emissions if equipped with controls; High noise levels.

***Table 7.9** – Advantages and disadvantages of gas turbines*

Advantages	Disadvantages
Low costs in high-capacity systems	Reduced electric yield when functioning in an open cycle
Low installation costs	Low capacity units do not have attractive costs and yields
Good heat recovery capacity	Yields drop with partial loads
High levels of reliability and availability	Very sensitive to ambient conditions (temperature, altitude)
Widely diffused and proven technology	
Quick start-up time	
High capacity density (kW/kg)	
Good load tracking capacity	
Versatility in terms of fuels	
Does not require much maintenance	
Low levels of emissions	

- Microturbines

In recent years, given the new requirements of the market, microturbines have seen great innovation and thus represent an advantageous option for the production of electricity and heat due to their simplicity and the fact that they employ a technology that has already matured, which is capable of producing energy with high levels of quality and reliability and with low levels of environmental emissions, thus making it a very competitive technology. The term "microturbine" generally refers to a system of relatively small dimensions (Figure 7.9) consisting of a compressor, combustion chamber, turbine and electric generator, with a total available capacity of between 25 and 500 kW. The main purpose of the majority of microturbines which exist in the market is to produce electricity, however, they are generally prepared so as to be able to function in micro-cogeneration systems using additional equipment. There are also microturbines created from scratch to function in a cogeneration system. In some (rare) cases the main function of the microturbine is to produce heat. When compared to conventional turbines, microturbines have a lower capacity, a simplified combustion cycle, a lower rate of compression and a smaller rotor axis, with a generator mounted at one of the ends (Figure 7.10).

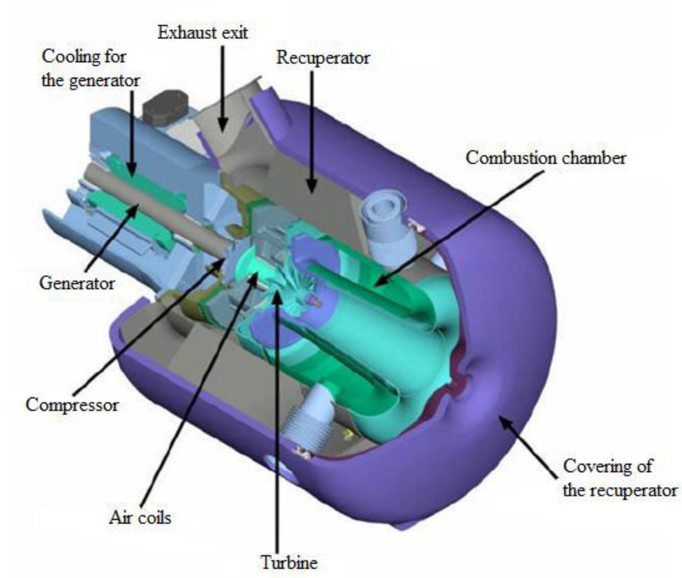
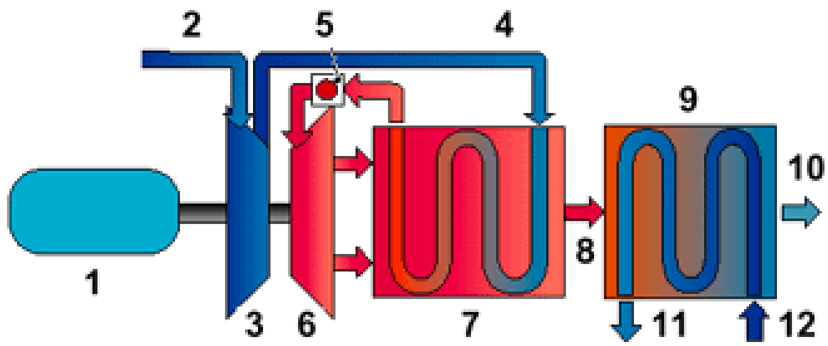


Figure 7.9 *– Cross-section of a microturbine*
Source: Capstone

Figure 7.10 *– Microturbine*

Microturbines function on the same operating principle as conventional gas turbines but include various innovations with regard to the system configuration. One of the main innovations that was introduced, as compared to gas turbines, consists of the adoption of a single shaft on which the compressor, the turbine and the generator are mounted. This single shaft system makes it possible to eliminate the presence of the gearbox used in gas turbines, thus reducing costs, increasing the reliability of the system and reduce (increase?) the intervals between stoppages for maintenance operations, albeit achieving lower yield levels. Another innovation consists of the use of air bearings, which avoids the use of cooling fluids and lubrication (in conventional gas turbines oil is used as a fluid).



1	- Alternator / Generator	7	- Thermal recuperator
2	- Air intake	8	- Escape gases
3	- Compressor	9	- Heat exchanger
4	- Air for the thermal recuperator	10	- Exit of escape gases
5	- Combustion chamber	11	- Outlet for (hot) water
6	- Turbine	12	- Intake of (cold) water

Figure 7.11 *– Drawing of a single shaft microturbine system*
Source: Turbec

Various types of fuel can be used in the majority of microturbines, without any significant modifications needing to be made to the mechanical devices. The fuels that can be used range from fuels with high energy content, such as propane, to gases from composting stations and natural gas. Liquid fuels such as diesel, gasoline or kerosene can also be used and in such cases it is only necessary to make some minor changes to the fuel feed system. However, most microturbines function on natural gas, since this is the fuel with which it is possible to achieve fewer emissions. An additional compressor can be used when the fuel feed pressure is not sufficient. There are solutions in which the compressor and the generator are not directly coupled on the same shaft and in which gearboxes are used in order to allow more flexible operations (Figure 7.12). A greater number of moving parts has a direct impact on the level of wear and tear of the machinery and noise levels during operations.

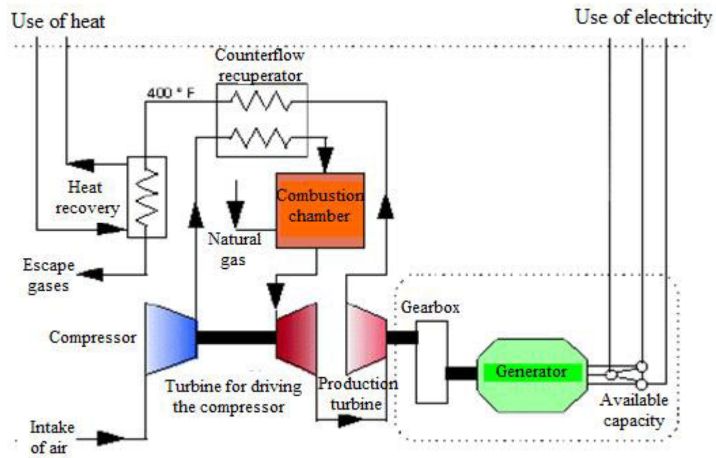


Figure 7.12*– Illustration of a microturbine system with several shafts*
Source: CEEETA

The most recent technical advances indicate the use of ceramic materials, which make it possible to achieve higher temperatures and greater yields. Another subject of research has been the question of how to make thermal recuperators more efficient and capable of withstanding high temperatures. The greatest difficulty is the high cost of the equipment, since microturbines are a relatively expensive technology when compared to conventional technologies. However, manufacturers believe that it will be possible to reduce costs if there is a significant increase in the quantities being produced and an amortization of investments.

Table 7.10 *– Technologies being developed for microturbines*
Source: OMFC

Technologies being developed	Details
More advanced materials for applications involving higher temperatures	• Ceramic materials for the turbines, recuperators and combustion chambers so as to improve yield by operating at higher temperatures • Manufacture metallic components capable of functioning at high temperatures in large quantities, so as to reduce their cost of production
More robust and efficient thermal recuperators	• Improvement of the use of heat • Development of recuperators that maintain the yield throughout their entire lifespan
Low cost natural gas compressors	• Natural gas will be the most suitable fuel due to the low levels of emissions. However, it will often be distributed at low pressure.
More efficient and less expensive electronic control systems	• Increase the yield of microturbines reducing parasite energy losses • Reduce the overall cost of microturbine systems

The start-up time for microturbines is relatively low but is not sufficient to enable them to be used as an emergency generator. However, they can be used to supply electric energy to a facility during prolonged supply failures due to network problems. Microturbines can also be installed with a view to increasing the quality and reliability of the energy of a facility. Microturbines can be used in the residential, commercial and industrial sectors. It is a technology with an extremely small footprint in terms of installation and produces low levels of noise and vibrations.

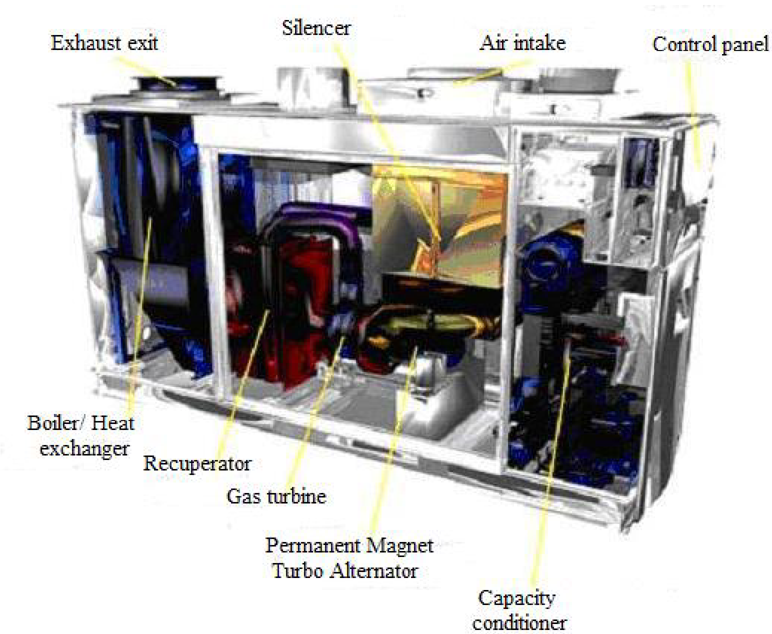


Figure 7.13 *– Microturbine used for cogeneration*

Microturbines can also be used in large-scale plants by using a combination of multiple units and although microturbines normally have capacities that are lower than 500 kW, manufacturers expect to produce microturbines with capacities of up to 1 MW by 2010. On the other hand, most manufacturers recognise that due to the low electric yield of microturbines (up to 20% for systems without heat recovery devices and up to 30% for systems with thermal recuperators), TEXT IS MISSING

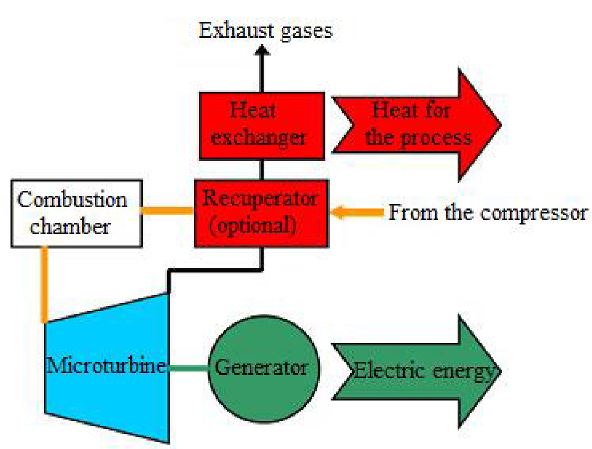


Figure 7.14 *– Cogeneration system based on microturbines*
Source: ITTMD

Yield and Reliability

The electric yield ranges from between 20% and 30% in microturbines fitted with a thermal recuperator. In units without a thermal recuperator this yield can drop to 15%. In cogeneration systems overall yields of 85% can be achieved, depending on the requirements of the heating process. The most recent technological developments indicate the use of ceramic materials in the hot sections of the microturbine, which will make it possible to achieve higher temperatures and consequently result in higher yields. The estimated lifespan of this technology varies between 5 and 10 years depending on its operating cycle. With a limited number of units currently operational there is insufficient information to reach any conclusions on the reliability and availability of microturbines. Although they have not been operational for a sufficiently long time to enable definitive conclusions, microturbines have shown a high level of reliability. Their basic design, with a limited number of moving parts, ensures a high potential for the availability of this kind of system and manufacturers indicate that microturbines will have an availability of 98% to 99%. The use of multiple units or auxiliary units can increase the overall availability of the plant.

Emissions and Noise

Table 7.11 *– Emissions of polluting gases in microturbines*
Source: OMFC

Emissions (natural gas fuel)	Currently	Future (2010)
CO_2	670 - 1,18 g/kWh (Yield of 17%-30%)	
SO_2	Negligible (natural gas)	Negligible
NO_x	9 - 25 ppm	< 9 ppm
CO	25 - 50 ppm	< 9 ppm
PM[i]	Negligible	Negligible

This technology provides noise levels which are lower than those of internal combustion engines. Microturbines offer acceptable levels of noise since there are no emissions of low frequency noise. The noise levels of some of the microturbines available on the market vary between 65 and 85 dBA @ 10 m, however there are some microturbines with 70 dBA @ 1 m.

Costs and Maintenance

The costs of a microturbine vary from between 600 €/kW for larger units to approximately 900 €/kW for smaller units. Many manufacturers sell the recuperator as an optional attachment. Based on the intended application, the client decides whether or not to purchase the recuperator. Purchasing a recuperator adds between 75 to 350 €/kW. The preparation of the site and the installation costs vary significantly from site to site but typically represent between 30% and 50% of the total project costs. However, manufacturers predict that the cost of microturbines will reduce in the future with the expansion of the market.

Owing to the limited experience with this technology and the fact that it has been available only for a relatively short time, there is insufficient information to define requirements in terms of maintenance. However, owing to the fact that microturbines have significantly fewer moving parts, manufacturers believe that these units are more reliable and will require less maintenance than conventional combustion engines. According to manufacturers, it is expected that the first operating units will require more frequent unexpected interventions but as the technology matures, annual operations should be sufficient and most manufacturers indicate maintenance intervals ranging from 5 000 to 8 000 hours. A general overhaul (with the substitution of the rotor) is necessary every 20 000 – 30 000 hours depending on the manufacturer and the operating cycle. Maintenance intervals, as well as current maintenance costs for microturbines, are based on estimates due to the limited data that currently exists, which hinders identifying precise timeframes. These costs have been estimated at being between 0.004 – 0.012 €/kWh.

***Table 7.12** – General characteristics of microturbines*

Commercial availability	Some availability (only some manufacturers)
Range of capacities	25 - 500 kW
Yield	20 - 30% (with a thermal recuperator)
Availability	98 to 99%
Fuels	Natural gas, kerosene, diesel, gasoline, biogas, etc.
Environmental impact	Low levels of noise; Low levels of emissions

***Table 7.13** – Advantages and disadvantages of microturbines*

Advantages	Disadvantages
Fewer moving parts	Modest electric yield
Low weight and volume	Very sensitive to ambient conditions (altitude and temperature)
High yield in cogeneration	Low tolerance for start and stop operations
Low level of emissions	
Operate with diverse fuels (including fuels with a low calorific value)	
No vibrations	
Less noise than internal combustion engines	
Long intervals between maintenance	
Easy to install	
Do not require cooling liquids or lubricants	

Fuel Cells

A fuel cell is a static device that converts the chemical energy available in a hydrogen rich fuel directly into electric energy and thermal energy by means of an electrochemical process, with a high yield. The fuel cell does not have moving parts and functions in a similar manner to batteries. A fuel cell consists of an electrolyte and two electrodes, a porous anode and a porous cathode, covered by a catalyser.

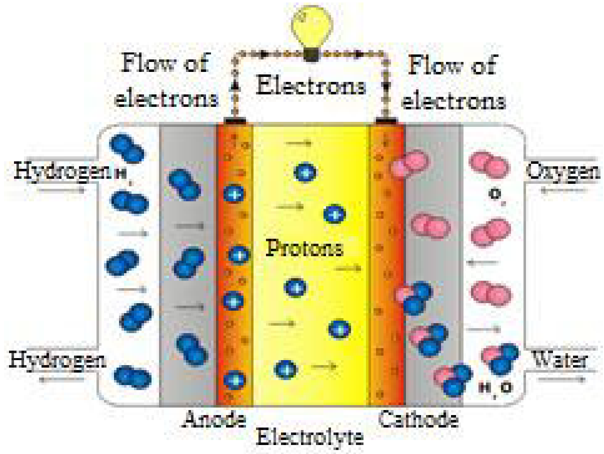


Figure 7.15 *– Operating principle of a fuel cell*
Source: Planetaclix

Figure 7.15 illustrates the operating principle of a fuel cell:

- The hydrogen is transported to the anode where it is oxidised in the catalyser and the electron is separated from the proton;
- The electrons on the anode side of the fuel cell cannot pass through the electrolyte to the cathode. They have to pass through the electric circuit to reach the other side of the fuel cell. The movement of these electrons generates a continuous electric current;
- The protons are transported from the anode to the cathode through the electrolyte;
- In the cathode, the oxygen reacts with the electrons coming from the external electric circuit and the hydrogen ions coming from the electrolyte, obtained as a final product of the reaction of water.

In order to obtain useful levels of electric power diverse fuel cells have to be linked in series, forming a battery of fuel cells. A fuel cell battery can be configured with various groups of cells linked in parallel and in series so as to obtain the intended voltage, current and power. Thus, a system of fuel cells has the advantage of being modular and can hence be constructed for a wide range of electric capacities, ranging from mWatts to MWatts.

Types of Fuel Cells

Fuel cells are mainly characterised by the type of electrolyte they use, the necessary catalyser, the temperature at which the cell functions, the necessary fuel and other factors. These characteristics influence the applications for which fuel cells are most suitable. There are five main types of fuel cells, which are currently at different stages of technical and commercial development, each of which has their own advantages, limitations and potential applications:

- Protonic Exchange Membrane Fuel Cell (PEMFC);
- Phosphoric Acid Fuel Cell (PAFC);
- Molten Carbonate Fuel Cell (MCFC);
- Solid Oxide Fuel Cell (SOFC);
- Alkaline Fuel Cell (AFC).

***Table 7.14**– Advantages and disadvantages of the main types of fuel cells*

Types of fuel cells	Some applications	Advantages	Disadvantages
PEMFC	● Transport ● Power plants ● Cogeneration ● Small portable applications	● Quick start-up ● Solid electrolyte reduces corrosion and management problems ● Low temperature	● Expensive catalyser ● Very sensitive to impurities in the fuel
PAFC	● Cogeneration ● Power plants ● Transport	● Yield of 85% in cogeneration	● Platinum catalyser ● Low current and capacity ● Large size/weight
MCFC	● Cogeneration ● Power plants	● Flexibility in terms of fuel ● High yield ● Cheap catalyser ● Variety of catalysers	● High temperature causes corrosion and ruptures of the components of the fuel cell
SOFC	● Cogeneration ● Power plants	● High yield ● Solid electrolyte reduces corrosion and management problems ● Flexibility in terms of fuels ● Variety of catalysers ● Low temperatures ● Quick start-up	● High temperature causes corrosion and ruptures of the components of the fuel cell
AFC	● Transport ● Space technology	● Rapid cathode reaction ● High performance	● Sensitive to impurities ● High cost to remove impurities

Cogeneration systems with Fuel Cells

Fuel cells release considerable quantities of heat while functioning, which can be used to produce hot water or steam. When the quantities of heat and/or the temperatures of the exhaust gases are low, they can be used to produce hot water or low-pressure steam. On the contrary, in the case of high temperature cells, it is possible to use the heat released in the exhaust to produce high-pressure and high temperature steam, which makes it suitable for producing electricity in a combined cycle system and higher yields can be achieved. A system based on solid oxide fuel cells provides a large quantity of waste heat, which is ideal for cogeneration applications or to produce additional energy based on the bottoming cycle. Units of around tens of MWatts can be combined with a gas turbine – steam turbine in a combined cycle in which the hot gases released by the fuel cell will operate a gas turbine. After passing through the gas turbine they then pass through a thermal recuperator producing steam which can be used in thermal processes or to produce additional energy through a steam turbine. This conceptual application can be seen in Figure 7.16.

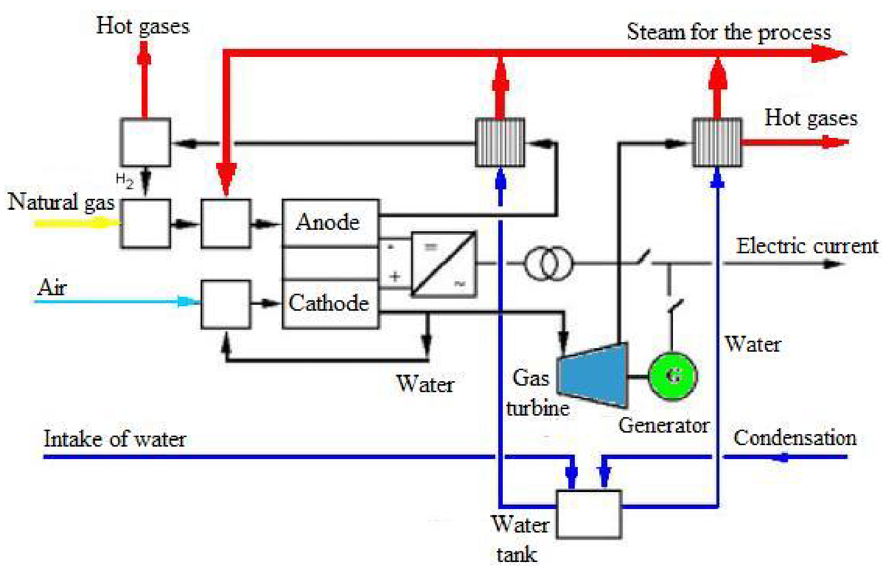


Figure 7.16 *– Cogeneration system with SOFC for use in the tertiary or industrial sectors*
Source: EDUCOGEN

Yield and Reliability

In contrast to combustion engines, in which (maximum) theoretical yield is determined by the Carnot cycle, the thermodynamic yield of fuel cells is decided by the quotient between the energy released by the reaction and the enthalpy of the reaction and usually surpasses 90%. In practice, electric yields of between 40% and 60% are obtained. When the operating temperature of the cell is high enough, the heat produced can be used (cogeneration) and the total yield can vary between 80% and 90%. Figure 7.17 compares the electric yield of fuel cells with conventional equipment used to produce energy.

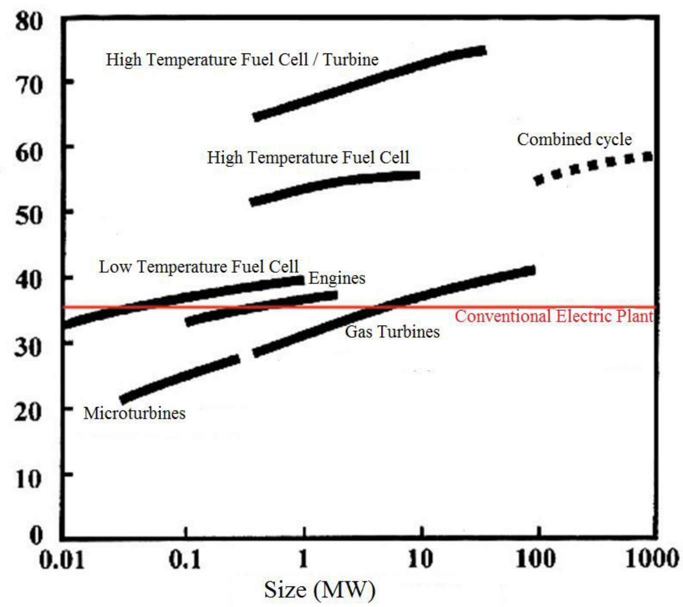


Figure 7.17 *– Comparative yield between the different fuel cell technologies and other conventional technologies*

Although fuel cells are considered to be a device requiring little maintenance, their technical immaturity and low market penetration limits their application in distributed generation. More than 200 commercial PAFC fuel cell units are being carefully observed so as to ascertain their reliability. These units were recently analysed over a 12 month period, achieving a reliability of 89%. This performance indicates that fuel cells can achieve high levels of reliability, even in applications with a high load factor. The simultaneous use of various units for a single facility can increase reliability at said facility. Studies carried out in recent years reveal that the use of 3 to 5 fuel cells, operating in parallel and oversized to supply 120% of the capacity required for a load, can offer a reliability of 99.99%, which is a satisfactory figure for certain applications. A system of generating electric energy to function locally, which uses fuel cell modules of 200kW at the "ONSI Corporation" was developed more recently by the Sure Power Corporation and has managed to supply energy with a reliability of 99.9999%. This system uses natural gas as a fuel for the cells.

The system manages to operate continuously in a regime of the maximum transfer of power using redundant units to supply electric energy, which improves the reliability of the plant. This unit can be placed in the open air and does not require any kind of cooling operation. A probability study carried out by "MTechnology" in collaboration with the Department of Nuclear Engineering at MIT to determine the reliability of a facility installed by the Sure Power Corporation, which is being installed in the First National Bank at the Omaha Technology Center, revealed that this unit used to produce electric energy by means of fuel cells achieved a level of reliability of 99.999997%. This value has never been achieved by any other unit used to produce electric energy that has been marketed to date.

Emissions and Noise

In stark contrast to the combustion of fossil fuels, fuel cells have a minimal impact on the environment. Fuel cells use a clean fuel – hydrogen – and hence produce clean energy. Moreover, as there is no combustion, only negligible NOx emissions are generated. The NOx and SOx emissions of a fuel cell are virtually nil. However, the problem currently lies in obtaining hydrogen, since in the reforming processes, a sub-product of the reaction is CO_2. This is the main cause of the greenhouse effect (around 55%). Nevertheless, the high yield of fuel cells can help reduce the emissions of this gas when compared to the emissions of combustion processes. On the other hand, in the reforming processes the emissions are derived from a chemical reaction and not from combustion and hence the emissions, even in the case of carbon dioxide, are lower than those of a classic power plant that produces energy. A system of natural gas based fuel cells could reduce CO_2 emissions by 60% when compared to a traditional fuel oil based system used to produce electric energy. The noise levels are also far lower than those of a traditional combustion system and fuel cells can easily be used in an urban environment.

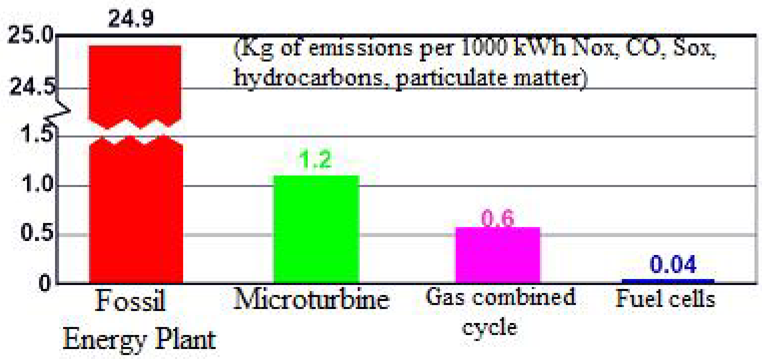


***Figure 7.18**– Emissions of pollutants*

Costs and Maintenance

The total costs (of the equipment and the installation) can vary significantly according to the type of installation, the geographic area, the market competitiveness, the specific needs of each site, etc. From the point of view of costs, each individual system and each manufacturer influence the role of each subsystem. The fuel cell itself can represent approximately 25% to 40% of total equipment costs, the fuel processor from 25% to 30%, the thermal management subsystem can represent between 10% and 20%, the electronic power subsystem from 5% to 15% and the auxiliary subsystems between 5% and 15% (water management subsystem, etc.). The typical total costs for this technology vary between 2 500 – 5 000 €/kW[4]. The high initial costs are one of the barriers to the implementation of this technology, although costs have tended to diminish. It is expected that in coming years these costs will reduce substantially. Table 7.15 provides an estimate of total costs for the different technologies analysed with regard to 2010.

[4] - Values as of 1 January 2005 [Source: *RETScreen International*]

***Table 7.15** – Total costs for the diverse technologies in the year 2010*

Cell	PEMFC	PAFC	MCFC	SOFC
Typical construction	Plastic, metal	Steel	Titanium	Ceramic
Expected price (€/kW)	1 400 - 2 500	1 700 - 2 200	1 500 - 2 600	1 500 - 2 500

The costs of maintaining a fuel cell vary according to the type of fuel used, the size and the maturity of the technology. It is expected that fuel cells will require minimum maintenance. The fuel supply system and the fuel processor will need to be inspected and maintained periodically, on an annual basis. The fuel cell itself does not require maintenance throughout the course of its lifespan. The costs of maintaining fuel cells typically vary from between 0.003 and 0.015 €/kWh (the costs of replacing the fuel cells have not been included here). While the fuel cell system as a whole has a considerable level of durability (manufacturers aim to achieve 40,000 operating hours) the fuel cell itself typically needs to be replaced every 5 years and the cost of this replacement is 0.04 €/kWh. The following tables provide a summary of the main characteristics of the different types of fuel cells as well as their main advantages and disadvantages.

***Table 7.16** – Main characteristics of fuel cells*

Cell	PEMFC	PAFC	MCFC	SOFC
Electrolyte	Polymer membrane	Concentrate of phosphoric acid held in a matrix of silicon carbonate	Molten salt carbonate, chemically inert, stabilised in a base of lithium aluminium oxide	Ceramic material
Self-processing of fuel	No	No	Yes	Yes
Operating temperature	65- 85ºC	190-210ºC	550-650ºC	800-1000ºC
Electric yield of the cell (simple system without cogeneration)	30-33%	35-40%	42-50%	45-55%

Fuel	Natural gas, hydrogen, propane, diesel	Natural gas, biogas, propane	Natural gas, hydrogen	Natural gas, hydrogen, biogas, fuel oil
Range of capacities	3-250 kW	100-200 kW	250 kW -10 MW	1 kW-10 MW
Environmental impact	Low emissions (approximately zero)			
Commercial availability	Available	Available	Some Availability	Some Availability

***Table** 7.17– Main characteristics of fuel cells*

Advantages	**Disadvantages**
High combined yield	Very high initial costs
Low emissions and noise levels	Require very pure fuels
Easy to install and does not have moving parts	Lack of experience with maintenance and a lack of specialised labour
High potential for cogeneration applications	The technology is still mainly being tested
Modular installation allows a vast range of capacities	
Good capacity for load tracking	
Allows a variety of fuels to be used	
Technology with a high potential for development	

7.2 Projected Growth of Economic Sectors (REN)

Foodstuffs		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	1,07%	1,08%
2007	2,97%	2,64%
2008	5,46%	4,56%
2009	8,27%	6,73%
2010	11,29%	9,01%
2011	14,40%	11,23%
2012	17,67%	13,43%
2013	21,13%	15,71%
2014	24,84%	18,11%
2015	28,74%	20,68%
2016	32,78%	23,36%
2017	36,96%	26,02%
2018	41,20%	28,64%
2019	45,47%	31,17%
2020	49,72%	33,62%

Ceramics		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	5,06%	2,09%
2007	9,55%	4,28%
2008	13,66%	6,56%
2009	17,44%	8,89%
2010	20,98%	11,21%
2011	24,34%	13,39%
2012	27,74%	15,51%
2013	31,30%	17,69%
2014	35,14%	20,00%
2015	39,25%	22,48%
2016	43,57%	25,09%
2017	48,11%	27,70%
2018	52,76%	30,27%
2019	57,47%	32,75%
2020	62,18%	35,17%

***Table 7.18** – Annual growth of the Gross Added Value for two scenarios (Left: Food; Right: Ceramics)*

Cork		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	6,01%	3,46%
2007	11,31%	6,63%
2008	16,13%	9,62%
2009	20,55%	12,51%
2010	24,69%	15,26%
2011	28,64%	17,81%
2012	32,61%	20,26%
2013	36,76%	22,74%
2014	41,19%	25,36%
2015	45,90%	28,17%
2016	50,82%	31,10%
2017	55,96%	34,01%
2018	61,21%	36,88%
2019	66,52%	39,65%
2020	71,82%	42,32%

Tanning		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	7,20%	4,76%
2007	13,42%	8,85%
2008	19,01%	12,52%
2009	24,09%	15,90%
2010	28,85%	19,05%
2011	33,39%	21,92%
2012	37,94%	24,65%
2013	42,67%	27,41%
2014	47,70%	30,31%
2015	53,01%	33,40%
2016	58,55%	36,62%
2017	64,30%	39,82%
2018	70,17%	42,96%
2019	76,08%	45,98%
2020	81,96%	48,88%

***Table 7.19** - Annual growth of the Gross Added Value for two scenarios (Left: Cork; Right: Tanning)*

Packaging		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	4,66%	3,17%
2007	9,03%	6,17%
2008	13,22%	9,06%
2009	17,20%	11,88%
2010	21,03%	14,59%
2011	24,73%	17,11%
2012	28,48%	19,53%
2013	32,39%	21,98%
2014	36,56%	24,56%
2015	40,97%	27,32%
2016	45,57%	30,19%
2017	50,35%	33,05%
2018	55,24%	35,87%
2019	60,17%	38,59%
2020	65,09%	41,21%

Wood		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	6,01%	3,46%
2007	11,31%	6,63%
2008	16,13%	9,62%
2009	20,55%	12,51%
2010	24,69%	15,26%
2011	28,64%	17,81%
2012	32,61%	20,26%
2013	36,76%	22,74%
2014	41,19%	25,36%
2015	45,90%	28,17%
2016	50,82%	31,10%
2017	55,96%	34,01%
2018	61,21%	36,88%
2019	66,52%	39,65%
2020	71,82%	42,32%

Table 7.20 - *Annual growth of the Gross Added Value for two scenarios (Left: Packaging; Right: Wood)*

Metalworking		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	4,78%	2,79%
2007	9,18%	5,51%
2008	13,33%	8,19%
2009	17,23%	10,84%
2010	20,94%	13,41%
2011	24,51%	15,81%
2012	28,11%	18,13%
2013	31,88%	20,48%
2014	35,91%	22,96%
2015	40,19%	25,61%
2016	44,67%	28,39%
2017	49,34%	31,16%
2018	54,12%	33,88%
2019	58,96%	36,52%
2020	63,79%	39,07%

Paper		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	5,56%	3,73%
2007	10,62%	7,12%
2008	15,33%	10,30%
2009	19,74%	13,33%
2010	23,93%	16,21%
2011	27,96%	18,87%
2012	32,04%	21,42%
2013	36,28%	24,00%
2014	40,80%	26,72%
2015	45,58%	29,61%
2016	50,56%	32,63%
2017	55,75%	35,64%
2018	61,04%	38,59%
2019	66,38%	41,43%
2020	71,71%	44,17%

Table 7.21 - *Annual growth of the Gross Added Value for two scenarios (Left: Metal Working; Right: Paper)*

Petrochemicals		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	2,62%	1,86%
2007	5,56%	3,96%
2008	8,73%	6,24%
2009	11,95%	8,64%
2010	15,19%	11,05%
2011	18,41%	13,36%
2012	21,71%	15,60%
2013	25,18%	17,89%
2014	28,89%	20,31%
2015	32,82%	22,90%
2016	36,91%	25,60%
2017	41,18%	28,28%
2018	45,54%	30,93%
2019	49,95%	33,48%
2020	54,37%	35,96%

Chemicals		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	3,75%	2,66%
2007	7,51%	5,32%
2008	11,27%	8,01%
2009	14,93%	10,71%
2010	18,49%	13,35%
2011	21,95%	15,83%
2012	25,46%	18,23%
2013	29,11%	20,66%
2014	33,02%	23,21%
2015	37,15%	25,94%
2016	41,48%	28,78%
2017	46,00%	31,60%
2018	50,64%	34,38%
2019	55,37%	37,06%
2020	60,12%	39,65%

***Table 7.22** - Annual growth of the Gross Added Value for two scenarios (Left: Petrochemicals; Right: Chemicals)*

Services		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	0,00%	0,41%
2007	1,15%	1,52%
2008	3,09%	3,13%
2009	5,51%	5,08%
2010	8,21%	7,20%
2011	11,08%	9,31%
2012	14,12%	11,42%
2013	17,36%	13,61%
2014	20,84%	15,93%
2015	24,49%	18,42%
2016	28,27%	21,00%
2017	32,17%	23,57%
2018	36,13%	26,10%
2019	40,12%	28,55%
2020	44,08%	30,93%

Steel		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	6,24%	3,95%
2007	11,65%	7,47%
2008	16,52%	10,70%
2009	20,94%	13,74%
2010	25,04%	16,58%
2011	28,91%	19,16%
2012	32,78%	21,61%
2013	36,79%	24,08%
2014	41,07%	26,68%
2015	45,61%	29,45%
2016	50,35%	32,35%
2017	55,30%	35,24%
2018	60,36%	38,09%
2019	65,48%	40,84%
2020	70,58%	43,50%

***Table 7.23** - Annual growth of the Gross Added Value for two scenarios (Left: Services; Right: Steel)*

Textiles		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	6,28%	4,23%
2007	11,85%	7,96%
2008	16,93%	11,38%
2009	21,63%	14,58%
2010	26,05%	17,58%
2011	30,29%	20,33%
2012	34,56%	22,96%
2013	38,99%	25,62%
2014	43,71%	28,40%
2015	48,69%	31,38%
2016	53,89%	34,48%
2017	59,29%	37,56%
2018	64,80%	40,59%
2019	70,35%	43,50%
2020	75,88%	46,31%

Glass		
	Growth GAV	
	Optimistic	Pessimistic
2005	-	-
2006	5,06%	2,09%
2007	9,55%	4,28%
2008	13,66%	6,56%
2009	17,44%	8,89%
2010	20,98%	11,21%
2011	24,34%	13,39%
2012	27,74%	15,51%
2013	31,30%	17,69%
2014	35,14%	20,00%
2015	39,25%	22,48%
2016	43,57%	25,09%
2017	48,11%	27,70%
2018	52,76%	30,27%
2019	57,47%	32,75%
2020	62,18%	35,17%

Table 7.24 - *Annual growth of the Gross Added Value for two scenarios (Left: Textiles; Right: Glass)*

7.3 Analysis of the surveys carried out in the industrial sector

After eliminating the records which were repeated in the database compiled at the Directorate-General for Energy and Geology, there were a total of 305 valid responses to the questionnaire sent to the industrial sector. There was still some incoherent data in the resulting set, with the identification of heat producing equipment for which there was no record of consumption, as well as innumerable incomplete records, which did not list any consumption for the production of heat and hence could not be used to estimate the potential for cogeneration. In all, only 148 questionnaires could be used for the estimates and the rest were only used to characterise barriers to cogeneration identified by respondents and to complement the existing information, especially with regard to some less documented economic activities.

Of the set of 305 questionnaires from the industrial sector, 8 facilities were identified as already using cogeneration. However, consumption data was not provided in two cases or they could not be identified as being potentially substitutable by cogeneration.

The resulting data obtained from the survey for the 142 cases, without cogeneration and with sufficient data, has been summarised in the following table. It is especially important to note the potential that exists in some less well-known sectors: wholesale trade in intermediate goods (storage of fuels), the extraction of sand and clay, the tobacco industry, abattoirs, the preparation and preservation of meat and meat-based products. In other sectors there is potential for small cogeneration units, which, even if they are not economically viable without support, can be made feasible and, due to the high number of some small industries, can contribute decisively towards achieving the national energy goals. The inclusion of absorption chillers to produce industrial cold could also, in some cases, increase the viability of these cogeneration units, although it was not possible to estimate this effect with the available summary data and the data which was collected in the course of this study.

In overall terms, the installation of the total estimated cogeneration capacity would cover 109% of the electric capacity contracted by these units and 56% of the installed electric capacity, from which it can be deduced that these units would then become suppliers.

Barriers to cogeneration, identified by the respondents:

1. Legal aspects and the availability of a point to link to the electric network
2. Bureaucracy and the slow pace of legal processes
3. High investment costs
4. Lack of availability of capacity in the electric network
5. Little need for heat
6. There is no state support for the installation of a cogeneration unit
7. Lack of information / dissemination
8. Operating period (number of operating hours) / seasonal use
9. Cost of natural gas (indiscipline and instability of the price of gas)
10. Natural gas is not available in the gas-duct that supplies the company
11. High maintenance costs
12. Dispersion of equipment that consumes thermal energy
13. Lack of technical viability
14. Lack of economic viability
15. Amortization of the investment (investment with a long period of return)
16. Declining production from year to year
17. The economies of scale for this sector of activity (15110)
18. Infrastructure is not prepared / adaptation of existing systems to new technologies
19. Irregular consumption and production plan
20. Legislation of the current tender to attribute electric capacity to biomass-fed thermal power plants (it is compulsory to have a high electric yield)
21. Lack of information/ dissemination of the technology
22. Absence of technical viability
23. Lack of training to ensure smooth operations

7.4 Analysis of the surveys carried out in the services sector

After eliminating the records that had been repeated in the database compiled at the Directorate-General for Energy and Geology, there were 148 valid responses to the questionnaire that was sent to the services sector. There was still some incoherent data in the resulting set, with the identification of heat producing equipment for which there was no record of consumption, as well as innumerable incomplete records, which did not list any consumption for the production of heat and hence could not be used to estimate the potential for cogeneration. In all, only 67 questionnaires could be used for the estimates and the rest were only used to characterise barriers for cogeneration identified by the respondents.

Amidst the set of the 148 responses in the services sector, 4 facilities were identified as already using cogeneration. However, it was possible to use the data in a manner that was coherent with the rest of the survey process in only one such case. In two cases consumption data was not supplied. Moreover, the consumption indicated undoubtedly corresponds to the consumption of the cogeneration unit, since there was no indication of real heat needs and it was not credible that the heat needs for the respective sector of activity (education) correspond to the heat produced by the installed cogeneration unit (10 MW).

The data obtained from the surveys for the 67 cases with sufficient data has been summarised in the following table. It is important to note the potential that exists in the sectors of hospitals, swimming pools (classified with the activity code of “social activities” and “sports activities”), museums and theatres, as well as the hotel sector, “retail commerce in non-specialised establishments” (malls) and higher education, although in the latter cases it is essential to carry out a detailed analysis of the “trigeneration” option, even because in some of them it was impossible to disassociate consumption for heating and for cooling. In overall terms, the installation of the total estimated cogeneration capacity would cover 12% of the contracted capacity and could satisfy about 5% of the consumption of these facilities, assuming a use of capacity of 6000 hours, thus contemplating some inevitable wastage of heat.

Barriers to cogeneration, identified by the respondents:

1. Lack of physical space to install equipment
2. Lack of funding for the investments
3. Absence of a gas distribution network
4. The interconnection point was denied during the Preliminary Information Request
5. Old facilities and economic barriers
6. Initial investment / money for investment
7. Absence of economic viability
8. Little need to use heat
9. The return on investments as compared to the size of the project and the associated risk
10. Absence of a thermal energy distribution network
11. Absence of centralised production of thermal energy
12. Need for investments prior to cogeneration
13. High maintenance costs and the reliability of the equipment is less than traditional equipment
14. Lack of information/dissemination of the technology
15. Absence of technical viability
16. Lack of training to ensure smooth operations

7.5 How the survey was implemented

Industrial Sector

The objective of the survey was to obtain data that could complement the characterisation of the diverse economic sectors in terms of the potential for cogeneration, seeking to obtain additional information on energy consumption, the use of heat that could be supplied by cogeneration and estimates of the capacity to be installed.

A preliminary analysis of the survey responses made it possible to identify cases in which there could be potential for cogeneration, soliciting data about the consumption of heat in a form that could be supplied by a cogeneration unit, such as ambient heating, laundries or hot water for sanitary purposes, in the services sector, and drying or other processes in the industrial sector. The survey also requested data about the fluids used to transport heat, to ascertain whether they were compatible with cogeneration. The installed capacity of existing thermal equipment, as well as electric capacity and consumption served as the basis for the other conclusions.

The data regarding thermal consumption that was obtained for the main heat-producing equipment made it possible to approximately estimate some points on the thermal load duration curve, which serve to indicate the capacity to be installed. It is a well-known fact that a cogeneration unit becomes viable if it functions for at least 4500 hours. The thermal capacity taken from the load duration curve at 4500 hours is thus a good indicator of the capacity to be installed, after employing a ratio between the recoverable thermal capacity and the electric capacity generated, suitable for the cogeneration unit to be installed.

In order to carry out this analysis, some specific functions were used in Visual Basic, using Microsoft Excel as an auxiliary tool, so as to systematically process all the cases.

Firstly, after standardising the names of the fuels and the definitions of the units, the study calculated the thermal consumption in a common unit of energy – kWh - for the sake of convenience. Secondly, based on the information provided, the duration of the thermal consumption was estimated, which was used as the basis for calculating average capacities, and thus the capacity for a duration of 6 months, i.e. an estimated operating duration of approximately 4500 hours per year for the producing system. Based on this thermal capacity and on the electric and thermal yields common to cogeneration units, the electric capacity to be installed was estimated.

Services Sector

A similar approach was used in the case of the services sector. However, the specific use of heat for climate control systems made it possible to estimate the capacity for 4500 hours on the basis of diagrams detailing typical daily, weekly and annual consumptions, adjusted to the indicated monthly consumption. These standardised diagrams resulted in a possible annual diagram for average hourly capacities, from which the thermal capacity for a duration of 4500 hours was obtained.

Example 1 – *Example of the survey used in the industrial sector*

AVALIAÇÃO DO POTENCIAL DE COGERAÇÃO DE ELEVADA EFICIÊNCIA EM PORTUGAL
- INDÚSTRIA -

- Instalação:
- Sector Industrial/Produtos fabricados:
- Código da Actividade Económica: Nº Contribuinte:
- Morada:
- Regime de laboração: nº. de turnos 3 horas de funcionamento/ano 2200

1 - Consumo de electricidade

Potência instalada: 1.380 kVA Potência contratada: 690 kW
Tensão de ligação à rede (MT/AT/MAT): 0 kV

Ano	Potência em Horas Ponta (kW)	Consumo de energia activa (kWh)				
		Horas Ponta	Horas Cheias	Horas Vazio Normal	Horas Super Vazio	Total
2006	290	300.997	708.228	761.345	0	1.770.570

2 - Consumo de energia térmica (produção de água ou ar quente, calor, vapor, etc.)

2.1 - Utilização final do calor produzido:

		Temperatura (ºC)
- Aquecimento de água	☐	
- Processo de secagem	☑	100
- Aquecimento de	☐	
- Outro	☐	

2.2 - "Fluido de transporte" do calor para essa utilização/grandeza característica (°C, bar, etc.)

- Vapor bar - Água quente: ºC - Ar quente: 800 ºC

- Queima directa ºC - Outro: *esp. unidade*

2.3 - Equipamento produtor de calor:

		Nº. de unidades	Potência total	Unidade
- Caldeira(s)	☐			
- Queimador	☑	2	6000	kW
- Outro	☐ *especificar*			

2.4 - Consumo de energia do(s) equipamento(s) gerador(es) de calor em 2006; regime de utilização
(gás natural, GPL, fuelóleo, gasóleo, electricidade, etc.)

	Combustível	Unidade	Custo unit.
Equip. 1:	gás natural	m3	
Equip. 2:			

Mês	Consumo Mensal Equip. 1 m3/mês	Equip. 2 /mês	Utilização de equipamentos com necessidade de calor (sim/não)
Janeiro	62.768		
Fevereiro	20.336		
Março	21.792		
Abril	80.152		
Maio	68.324		
Junho	35.189		
Julho	27.152		
Agosto	95.845		
Setembro	49.683		
Outubro	17.805		
Novembro	18.652		
Dezembro	14.123		
Total	511.821	0	

Dias da semana com utilização de equipamentos com necessidade de calor (sim/não)	
2ª Feira	Sim
3ª Feira	Sim
4ª Feira	Sim
5ª Feira	Sim
6ª Feira	Sim
Sábado	Sim
Domingo	Não

- Horário diário de utilização do(s) equipamento(s) com necessidades de calor

	Manhã	Tarde	Noite
Das:	0	8	16
Às:	8	16	24

3 - Possui sistemas de arrefecimento/refrigeração ? Não (Sim/Não)

Utilização: Tipo (chiller, etc.):
Fluido de transporte: Temperatura de trabalho: °C
Potência frigorífica: kW Regime de laboração: ± h/ano

4 - Possui sistemas de Cogeração ? Não (Sim/Não)

Já considerou a hipótese de instalar um sistema de Cogeração ? Não (Sim/Não)
(apenas se respondeu **não** à questão 4)
Se **sim,** qual a utilização para a energia térmica da Cogeração ?

Que barreiras identificou no seu sector de actividade para a instalação da Cogeração ?

Consumos baixos.

Data do preenchimento:
Responsável pelo preenchimento:
Cargo:
Contacto preferencial: *(tel., e-mail, etc.)*

Example 2 – *Example of the questionnaire used in the services sector*

AVALIAÇÃO DO POTENCIAL DE COGERAÇÃO DE ELEVADA EFICIÊNCIA EM PORTUGAL

- SERVIÇOS -

- Instalação:
- Código da Actividade Económica: Nº Contribuinte:
- Morada:
- Area coberta total (soma dos pisos): 29000 m²
- Area total climatizada: 29000 m²
- Nº de ocupantes: 1800
- Horário de funcionamento: 08h às 20h
- Regime de funcionamento semanal: Sim
- Possui sistema de gestão de energia? Sim

Centros Comerciais - colocar número de lojas
Hospitais - colocar número de camas
Hoteis - colocar número de quartos

1 - Consumo de electricidade

Potência instalada: 4,630 kVA Potência contratada: 3,650 kW
Tensão de ligação à rede (BT/MT) 0,4/10 kV

Ano	Potência em Horas Ponta (kW)	Consumo de energia activa (kWh)				
		Horas Ponta	Horas Cheias	Horas Vazio Normal	Horas Super Vazio	Total
2006	20,341	2,472,072	6,393,500	3,205,547	2,002,373	14,073,492

2 - Consumo de energia térmica (produção de água ou ar quente, calor, vapor, etc.)

2.1 - Utilização da energia térmica para:

		Temperatura (ºC)
- Aquecimento de água	☑	50
- Lavandaria	☐	
- Aquecimento ambiente	☑	55
- Outro	☐	

2.2 - Equipamento produtor de calor:

			Nº. de unidades	Potência total	Unidade
- Caldeira(s)	☐				
- Queimador	☐				
- Outro	☑	*Bombas de Calor*	3	1795	kW

2.4 - Consumo de energia do(s) principais equipamento(s) gerador(es) de calor em 2006
(gás natural, GPL, fuelóleo, gasóleo, electricidade, etc.)

	Combustível	Unidade	Custo unit.
Equip. 1:	Electricidade	kWh	
Equip. 2:			

Mês	Consumo Mensal	
	Equip. 1 kWh/mês	Equip. 2 /mês
Janeiro	122,453	
Fevereiro	152,994	