GOBIERNO DE ESPAÑA

MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO

FULL ASSESSMENT OF THE POTENTIAL USE OF HIGH-EFFICIENCY COGENERATION AND EFFICIENT DISTRICT HEATING AND COOLING SYSTEMS

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0. INTRODUCTION, CONTEXT AND OBJECTIVES

The scarcity of fossil fuels, energy dependence, the increasing price of fuels, and climate change are some of the main challenges that will face the European Union in energy issues in forthcoming years. In this context, energy efficiency has revealed itself to be a tool that fosters sustainable energy growth and one of the most profitable ways not only to reinforce security of the energy supply, but also to reduce greenhouse gas emissions.

Aware of this, the European Union has published the Energy Efficiency Directive 2012/27/EU (hereinafter the Directive), which creates a common framework for introducing specific actions that promote energy efficiency within Member States.

One of the measures established in this Directive refers to the promotion of heating and cooling efficiency. Article 14 establishes the obligation to notify the Commission with a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling, pursuant to the provisions set out in Annex VIII of that directive. A cost-benefit analysis of the projects assessed and which covers all national territory must be carried out. In those places where the benefits exceed the costs, Member States are to introduce suitable measures to develop efficient district heating and cooling infrastructures.

The State Secretariat for Energy of the MINETUR (Ministry of Industry, Energy and Tourism) in Spain is responsible for transposition of the Directive and for undertaking the assessment of the potential pursuant to the provisions set out therein. The overall aim of the assessment is to analyse the technical and economic feasibility of high-efficiency cogeneration systems and district heating and cooling networks on Spanish territory.

To conduct this assessment, the following stages have been performed:

- Characterisation of the heating and cooling demand in Spain
- Preparation of a heat map that pinpoints energy demand/supply areas
- Compilation of an expert tool to assess the information of the heat map and which processes the information and identifies and evaluates efficient heating and cooling potentials based on the technical-economic analysis of the energy supply available.

In the initial stage of the study, the methodology used in characterisation of the heating and cooling demand of all consumer centres in Spain is described, setting out the sectoral and climate differences.

With regard to the heat map and following the provisions set out in Annex VIII of the Directive, we have identified the following information within national territory:

- Heating and cooling demand points, including:
  - Municipalities and conurbations with a plot ratio of at least 0.3
  - Industrial zones with a total annual heating and cooling consumption of more than 20 GWh
- The district heating and cooling infrastructure
- Potential heating and cooling supply points, including:
  - Electricity generation facilities with annual production in excess of 20 GWh
  - Waste incineration plants
  - Existing cogeneration plants that use the technologies set out in the Directive, as well as the district heating facilities

All of these demand figures and potential district heating and cooling supply points have been integrated into a database from which two differentiated tools have been developed: an initial consultation tool that constitutes the heat map and, secondly, the tool developed for elaboration of the technical-economic calculation of high-efficiency cogeneration potential and efficient district heating and cooling systems.

Lastly, and based on the information listed in the previous section, the tool will be responsible for identifying thermal demands with the potential to introduce efficient heating and cooling systems in order to subsequently analyse the technical and economic feasibility of these.

Based on this we have been able to identify the technical solutions which, using residual heat, renewable energies and cogeneration systems, reveal technical and economic potential for possible introduction. Subsequently, based on the economic potential we calculate the efficient cost potential the combination of the most beneficial technical solutions represent for each system to satisfy the highest percentage of demand.

We should point out that, due to the absence of statistical data on which to base ourselves, we have had to carry out a large number of assumptions in order to characterise the demand for thermal energy. Consequently, the findings obtained in the characterisation of the demand should be considered as an initial approximation to the disaggregated knowledge of demand for heating and cooling in the different sections nationwide. Furthermore, given that demand for thermal energy represents the starting point for the entire subsequent analysis of the technical and economic potential of efficient heating and cooling systems, the final results should likewise be considered as an initial approximation.

Elsewhere, we should also point out that the findings obtained from the economic potential study are highly sensitive to the assumptions considered in their calculation, given both the amplitude of the 2015-2050 time horizon considered as well as the high number of economic and energy variables that intervene in each of the alternatives put forward. The evolution of the baseline itself adds uncertainty to the final results. In this regard, the economic potential should not be understood as a static figure but rather has to evolve, and not only because of the dynamics of the change in the variables that determine it, but also through the introduction of suitable policies for its implementation.

Notwithstanding the foregoing, it is important to stress that the methodology adopted, completed with subsequent studies focused on specific areas of national territory, will enable us to have greater knowledge than we currently have about the real potential available in efficient heating and cooling systems, and this will be of great help in future energy planning processes as it will assist us in taking decisions to optimise the economic resources used.

Before proceeding to carry out a detailed analysis of the methodology employed, below we set out the cogeneration status in Spain.

1. CURRENT STATUS OF COGENERATION AND DISTRICT HEATING AND COOLING SYSTEMS IN SPAIN

In accordance with Annex VIII to Directive 2012/27 on energy efficiency, below we set out the current status of cogeneration and district heating and cooling systems.

1.1. Current status of cogeneration

Law 24/2013 on the Electric Sector, and Royal Decree 413/2014 which regulates the production of electricity using renewable energy sources, cogeneration and waste, classify cogeneration plants into the following groups and subgroups:

- Group a.1. Installations that include a cogeneration power station.
  - Subgroup a.1.1. Cogenerations that use natural gas as fuel if it represents at least 95% of primary energy or at least 65% if the rest comes from biomass or biogas.
  - Subgroup a.1.2. Cogenerations that use petroleum or coal derivatives, providing this represents at least 95% of primary energy.
  - Subgroup a.1.3. Remaining cogenerations that use natural gas or petroleum or coal derivatives and which do not comply with the established consumption limits.
- Group a.2. Installations that include a power station using waste energy from any installation, machine or industrial process not intended to produce electrical energy.

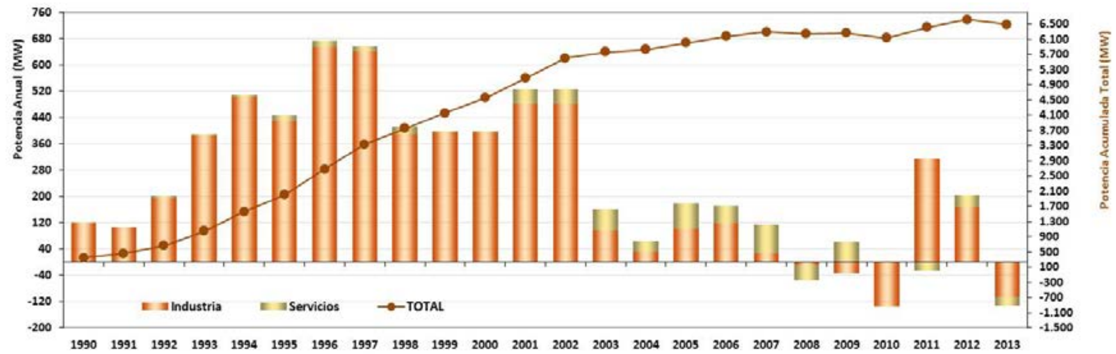
Royal Decree 413/2014 defines a remunerative framework for the sale of electricity fed into the grid, based on the price of the organised electricity market and two additional remunerations:

- Return on investment, a remunerative term per unit of power that enables the investment costs that have not been recovered and which will not be recovered through operating revenue through to the end of the regulatory service life (25 years in the case of cogeneration) to be compensated, for the purpose of achieving the so-called “fair return”. This is updated in each regulatory half-period (3 years).
- Return on operation, a remunerative term per unit of energy which together with the estimation of exploitation revenue tallies with the estimated exploitation costs. This is updated every six months.

The remunerative parameters are for each ‘standard installation’ which typify sets of cogeneration plants that share several technical and administrative features in response to the objective of Royal Decree 413/2014 for cogeneration plants to achieve a fair return during the regulatory 25-year service life. 456 standard installations have currently been defined, without including subgroup a.1.3.

At the end of 2013, cogeneration plants in Spain accounted for **6,486.7 MW** shared among **727 plants**[1]. The historic evolution and installed power in each financial year since 1990 are shown graphically in the Figure 1 attached, which shows how the number of cogeneration plants installed every year in Spain has been growing since 1990, with a considerable number of new projects between 1993 and 2002. The installation of new plants decreased significantly afterwards and there has been no significant activity of new projects in more recent years.

Figure 1. Annual and cumulative installed power of cogeneration plants in Spain.



Source: Journal of cogeneration energy statistics. Year 2013 IDAE (Institute for Diversification and Saving of Energy).

In 2013, electricity generation (on the alternator terminals) of cogenerations in Spain totalled **30,790.9 GWh**, with electricity feed-in of **25,409 GWh**[2] (this last figure does not include cogeneration from renewable sources). This represents a decrease in electricity production of cogenerations with regard to the previous year, although participation in electricity demand is around 10%.

Elsewhere, the Table 1 shows the power figures, number of cogeneration installations and electricity generated (on alternator terminals) in 2013 by sectors of activity. This shows that cogeneration has a major presence in the following areas, which concentrated around 80% of installed power in 2013:

- Agricultural Industry, Food and Tobacco (19.4%)
- Paper and Pulp (19.3%)
- Chemical industry (15.9%)
- Refineries (9.9%)
- Manufacturing of Non-metallic Minerals (7.4%)

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[1] Data from the Journal of cogeneration energy statistics. Year 2013 IDAE (Institute for Diversification and Saving of Energy).

[2] Figures from the National Commission for Markets and Competition (CNMC) on sales of energy under the Special Regime.

Also of note is the high electricity production in the chemicals industry, food, paper and cardboard and refining, which all exceeded 4,000 GWh in 2013.

Table 1. Installed power, number of plants and electricity generated in Spain by cogeneration plants, broken down by activity sectors

Sector of activity		Electrical power (MW)	Number of plants	Electric power (GWh)
Industry	Coking	123.8	5	613.8
	Extraction	95.3	14	502.3
	Solid Fuel Extraction	35.4	5	72.8
	Manufacture Of Other Non-Metallic Mineral Products	478.0	139	1,696.3
	Chemical industry	1,032.5	60	5,264.8
	Agricultural, Food and Tobacco Industries	1,257.1	151	4,709.7
	Paper and Cardboard, Publishing and Printing Industries	1,253.9	78	7,562.4
	Production of Nonferrous Minerals	35.3	6	87.9
	Refineries	641.4	15	4,306.9
	Steel industry	12.1	3	52.4
	Textile, Clothing and Leather	311.5	34	557.0
	Processed Metals, Manufacturing of Machinery and Equipment	122.1	14	448.5
	Other Industrial Branches	414.4	58	1,774.5
Residential and services		630.1	129	2,906.0
Transport and Communication		44.0	16	235.5
TOTAL		**6,486.7**	**727**	**30,790.9**

Source: Journal of Cogeneration Energy Statistics. 2013, IDAE

Next, Table 2 shows the same power figures, number of cogeneration installations and electricity generated (on alternator terminals) in 2013 by technologies. Almost half of the power plants use the **internal combustion engine** (3,120.5 MW), while the presence of **combined cycles** (1,306.8 MW) and **single-cycle gas turbines** (1,221.1 MW) is also significant. Most electricity comes from **internal combustion engines** (around 11,000 GWh), although the production from **combined cycles** (more than 8,000 GWh) and **single-cycle gas turbines** (more than 6,000 GWh) is also relevant.

In relative terms, the dominant technology continues to be the **internal combustion engine**, with 48.1% of installed power, as well as 76.1% of existing installations. This is followed by **combined cycle** and **gas turbine** technologies, which jointly account for 39% of installed power, although the representativeness of these technologies is less in terms of the number of installations (17.6%). The foregoing leads to a larger average size associated with these technologies, in particular in the case of the **combined cycle**, with 38.4 MW of unit power, almost 7 times higher than the average size of installations equipped with **internal combustion engines** (5.6 MW).

Table 2. Installed power, number of plants and electricity generated in Spain by cogeneration plants, broken down by technologies

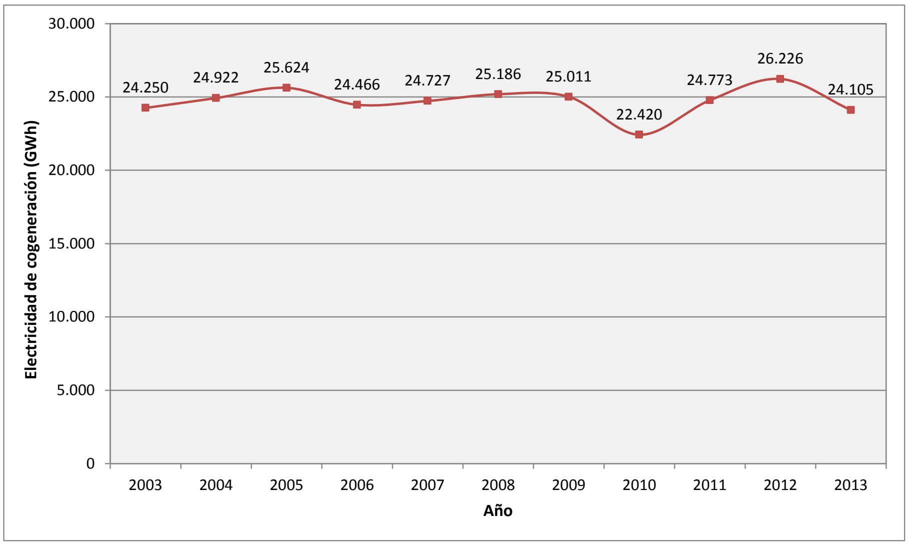
Technology	Electrical power (MW)	Number of plants	Electric power (GWh)
Combined Cycle	1,306.8	34	8,034.6
Internal combustion engine	3,120.5	553	11,455.0
Gas Turbine with Heat Recovery	1,221.1	94	6,882.7
Steam: Back-pressure Turbine	552.8	31	2,714.3
Steam: Condensing Turbine	284.9	13	1,704.3
Various	0.6	2	0.0
TOTAL	**6,486.7**	**727**	**30,790.9**

Source: Journal of Cogeneration Energy Statistics. 2013, IDAE

As regards fuels used by cogeneration plants, **natural gas** continues to be the one used by most installations (more than 80% of electricity production comes from this fuel), although the plants that use **diesel**, **fuel-oil** and **renewable fuels** are also relevant. To a lesser extent there are groups that use coal and by products from oil refining.

Figure 2 shows the evolution of cogeneration electricity of plants in Spain. This figure has been calculated in accordance with the provisions set out in Annex I of Directive 2012/27/EU on energy efficiency.

Figure 2. Evolution of cogeneration electricity from 2003 – 2013



Source EUROSTAT

This shows that cogeneration electricity has not experienced any major changes over the 2003 – 2013 period, which does not tally with what was remarked upon earlier on the scant relevance of new cogeneration plants installed since 2003. However, we expect that with the relatively recent publication of Royal Decree 413/2014 and with future renovation and improvement of efficiency plans for the cogeneration plants in Spain, these figures will experience slight increases. Also within the community framework, we expect a favourable impact on cogeneration associated with Directives 2010/31/EU on energy efficiency of buildings, and 2012/27/EU on energy efficiency. Both directives underline the importance of high-efficiency cogeneration, with an emphasis on covering energy demands of new buildings, in the case of Directive 2010/31/EU, and on district heating and cooling systems, in the case of Directive 2012/27/EU.

Table 3 details the power, number of installations, cogeneration electricity and useful heat of cogenerations in 2013, broken down by technology used. Cogeneration electricity calculated in accordance with Annex I of Directive 2012/27/EU for all plants was 24,105 GWh, while the useful heat contributed by cogenerations totalled 48,570 GWh.

Table 3. Installed power, number of plants. Cogeneration electricity and useful heat for 2013 by technologies.

Complete CHP Plants (global efficiency ≥ threshold)				
Technology	Electrical power (GW_E)	Number of installations	Cogeneration electricity (GWh_E)	Useful heat (GWh_T)
Combined Cycle			0	0
Gas Turbine with Heat Recovery	379	35	2,101	5,562
Internal combustion engine	368	35	1,665	3,459
Steam: Back-pressure Turbine	180	13	768	5,717
Steam: Condensing Turbine			0	0
Other technologies			0	0
SUBTOTAL	**927**	**83**	**4,533**	**14,737**
Plants with part non-CHP (global efficiency < threshold)				
Technology	Electrical power (GW_E)	Number of installations	Cogeneration electricity (GWh_E)	Useful heat (GWh_T)
Combined Cycle	1,307	34	7,508	11,340
Gas Turbine with Heat Recovery	842	59	3,594	7,359
Internal combustion engine	2,753	518	6,024	8,391
Steam: Back-pressure Turbine	373	18	1,001	3,378
Steam: Condensing Turbine	285	13	1,444	3,365
Other technologies	1	2	0	0
SUBTOTAL	**5,560**	**644**	**19,572**	**33,833**
TOTAL	**6,487**	**727**	**24,105**	**48,570**

Source: Compilation using MINETUR - IDAE Statistics. Year 2013

1.2. Status of the district heating and cooling systems

The first census of district heating and cooling grids in Spain took place in October 2011, including grids and micro-grids. As a consequence of the continuation of this work, to date we have identified 270 grids, of which there are data for 247. These grids have a constructed length of more than 310 km and satisfy the energy demand of a surface area of 7,000,000 m², equivalent to the surface area of 93,000 homes.

Of the 247 grids for which data are available, 220 grids are for heat, and only three grids solely produce cold. Consequently, 89% of the grids only produce heat, while 1% only produce cold.

However, the heating and cooling grids are those that have the highest installed power.

- 1,139 MW installed in total.
- 419 MW in heating grids: 37%
- 713 MW in heating and cooling grids: 62%

- 7 MW in cooling grids: 1%

In absolute terms, the installed power is mainly for the supply of heat

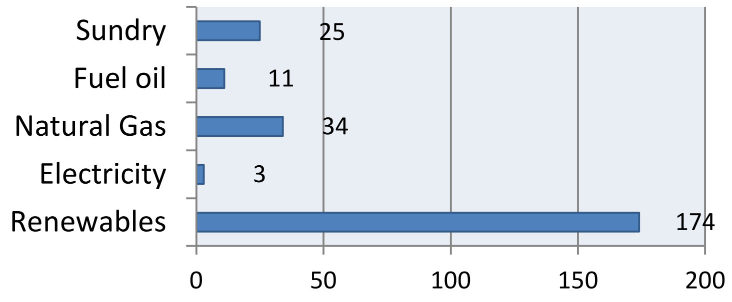
- 814 MW in heat: 72%
- 325 MW in cold: 28%

As regards the distribution of the number of grids by sector of activity to which they provide service, we see that most are in the tertiary sector, 63%, followed some way behind by the residential sector, 19%, while the industrial sector only represents 5%.

However, if we take into consideration the installed power that provides service to each sector, the distribution is as follows: tertiary 33%, residential 15% and finally industry 7%.

As regards ownership of the grids, the percentages of public and private ownership are 51 and 43% respectively, accounting for 94% of the installations. The remaining 6% belongs to joint ventures. However, in terms of installed power, the grids that belong to joint ventures represent 49% of all installed power.

With regard to the type of energy consumed by the grids surveyed, the distribution is as follows:



2. METHODOLOGY FOR PREPARING THE DATABASE ON THE LOCATION OF CONSUMER CENTRES

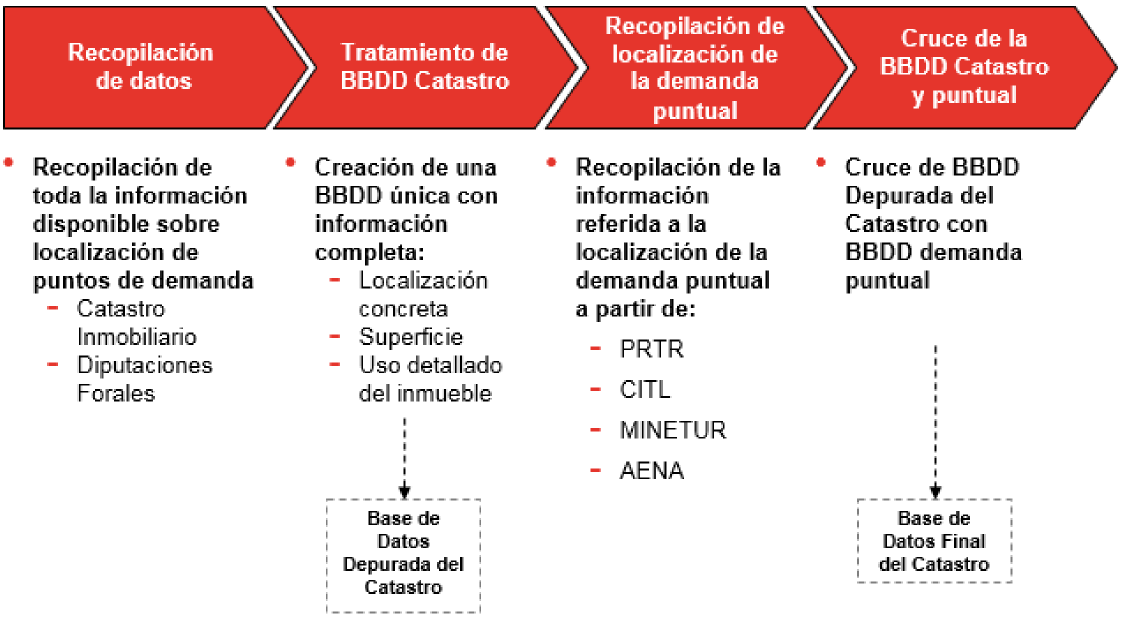
In order to characterise the thermal demand of Spanish territory, given the total lack of official statistics that would allow us to draw different conclusions, we need to obtain the information that allows us to estimate the energy demands of each of their consumer centres.

The main source of information for each of the country's municipalities has been the Land Registry of Spain, while for more singular centres we resorted to other sources (records of CO_2 emissions of the PRTR and CITL, Registry for Production of Electricity under the Special Regime, the National Hospitals Catalogue etc.), which have enabled us to complete the initial information and optimise the calculation methodology. Annex I sets out all of the sources of information used in the study.

Having obtained all the information required, we then process and structure the data, pooling all of the information necessary into a single database (hereinafter, the Final Database of the Land Registry).

Figure 3 summarises the methodology used for the compilation of the Final Database of the Land Registry:

Figure 3. Methodology used for the compilation of the Final Database of the Land Registry



2.1 Data collection

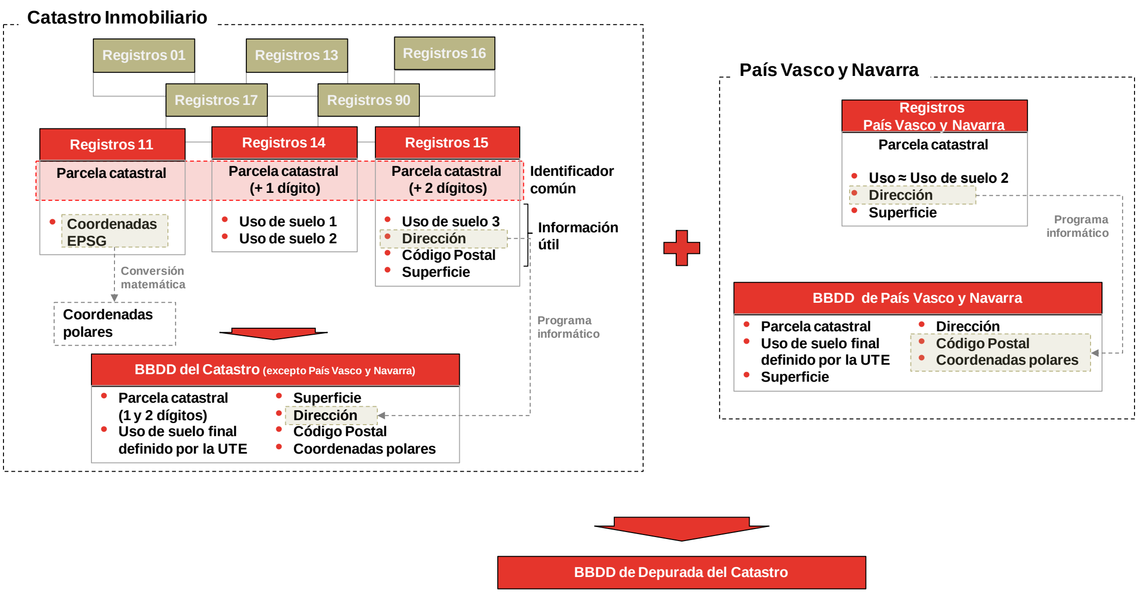
The Land Registry is a subordinate administrative registry of the MINHAP (Ministry of Finance and Public Administrations) which records the urban, rural and special properties. Registration with this registry is mandatory, and therefore all real estate of Spain is on record there except for those properties in the Basque country and Navarre, which have their own powers with regard to the Land Registry. The description of each property includes its physical characteristics, including its land registry reference, location, surface area and activity carried out, information required for subsequent determination and localisation of thermal demand.

A total of 15,184 alphanumeric CAT Files from the Land Registry were used: one urban on one rural from each of the municipalities of Spain, with the exception of Navarre and the Basque Country for which the alphanumeric information for each of their municipalities was obtained independently. Having obtained the files required to cover all Spanish territory, the files were independently processed to subsequently unify them in a single database, the Refined Database of the Land Registry, which includes information required for each registration.

2.1.1. Processing of the Land Registry database

The complexity of the Land Registry data format required in-depth processing of the information provided. Below we show an outline of the procedure followed.

Figure 4. Procedural outline to obtain the Refined Database of the Land Registry



The processing is based on the 15,184 CAT files, each of which contains eight different types of registration. Each registration refers to a different land registry level, and therefore has different dimensions. The registrations of these files are as follows:

Table 4. Characteristics of the CAT files

Registration	File characterisation	Useful data for the project
Type 01: Header registration	There is one for the entire file and it makes reference to the file header	-
Type 11: Property Registration	There is one for each cadastral parcel involved	• Cadastral Parcel • Coordinates
Type 13: Registration of Construction Unit	There is one for each constructive unit on each cadastral parcel	-
Type 14: Construction Registration.	There is one for each construction of each constructive unit on each cadastral parcel	• Cadastral Parcel • Use of land 1 • Use of land 2
Type 15: Property Registry	There is one for each property on each cadastral parcel	• Cadastral Parcel • Use of land 3 • Address • Area
Type 16: Registration of the distribution of common elements	There is at least one for each common element that is distributed, whenever it is necessary to specify special distributions	-
Type 17: Registration of crops	There is one for each sub-parcel of crops that exists within the cadastral parcel	-
Type 90: Queue log	There is one for the whole file	-

Source: Land Registry

As shown in *Table* 4, the information required to categorise the Refined Database of the Land Registry and which is set out in Type 11, Type 14 and Type 15 registrations is as follows:

- **Cadastral Parcel**: this is an official identifier of real estate. It comprises an alphanumeric code assigned by the Land Registry so that each property can be unequivocally situated on the cadastral mapping.
- **Use**: this refers to the activity carried out at that property according to the Land Registry (for further detail, see Annex II). Each type of registration may include a different dimension of this activity, from lesser to greater specificity, as follows:
  - Use of land 1 refers to the activity carried out in general (for example "I Industrial").
  - Use of land 2 includes information on the type of building (for example "2.1.3. Manufacturing and storage premises; Storage").
  - Use of land 3 refers to the activity carried out with greater detail (for example "IIM Chemicals industry).

- **Address** associated with the demand point.
- **Coordinates** in EPSG format.
- **Useful floor area** of the real estate.

Among the three registrations mentioned there is a common identifier, the cadastral parcel, the field from which all information of the different registrations has been unified.

The activity carried out at each of the properties on the land registry is catalogued in accordance with three valuation rules, which differ between themselves as regards the level of specificity. So, in general, most properties are sufficiently identified through the use of land 2 and on occasions through the use of land 3. Following these premises, the final list of the 144 uses of land identified can be consulted in the Table 63 of Annex II.

In order to complete the land registry database, it was necessary to include the information on the Basque Country and Navarre. The format of cadastral data in these communities is significantly different with regard to the Land Registry. This made it necessary to prepare four specific procedures, in line with what has been described for the Land Registry, to adapt this information and integrate the 4,000,000 new registrations in the Preliminary Database of the Land Registry. Another ad hoc piece of software was developed that completes the information on the specific location of the demand centres of these provinces.

Both databases, the Preliminary Database of the Land Registry and the databases as a result of processing the information of Navarre and the Basque Country were integrated into a single one (the Refined Database of the Land Registry) with all the information necessary on each of the cadastral references in Spain.

2.1.2 Processing the specific demand database

In parallel with this procedure, we prepared another database that includes a set of consumer centres with high thermal demands that require different treatment. This database includes the following centres:

- Hospital and healthcare centres
- Buildings belonging to the Central Government
- Prisons
- Airports
- Major industries
- Shopping malls

The specific database comprises consumer centres that require a specific calculation methodology to estimate their demands. In general, specific consumer centres are considered to be those associated with large thermal demands and which, consequently, need to be analysed on an individual basis, with the exception of a large part of the buildings belonging to the Central Government where the specific demand is only due to their public nature and the fact that their energy consumption is officially published.

The information in the database varies in accordance with the typology of the consumer centre and we have proceeded to carry out the geographical location of their coordinates through a geo-location computer tool based on the Google Maps API. *Table* 5 shows the information contained on the database for each type of centre.

Table 5: Structure of the specific database[1]

Typology	Information
Hospital and healthcare centres	• Number of beds • Geographical coordinates
Buildings belonging to the Central Government	• Area • Final energy savings • Geographical coordinates
Prisons	• Area • Final energy savings • Number of cells • Number of prisoners • Geographical coordinates
Airports	• Annual traffic • Altitude • Geographical coordinates
Major industries	• CNAE (National Classification of Economic Activities) code • Annual CO_2 emissions • Cogeneration plant availability • Characteristics of the cogeneration plant • Availability of natural gas

[1]*These do not include shopping malls due to the lack of an official record that enables their identification. The process employed for their location is explained in section 3.3 of this document.*

2.1.3 Unification of the refined database of the Land Registry with the specific demand database

Given that the Refined Database of the Land Registry includes virtually all real estate on Spanish territory, the inclusion of each of the consumer centres represents a duplication of this. Consequently, we have proceeded to identify each of the specific consumer centres in the Refined Database of the Land Registry in order to subsequently combine both entries into a single one that contains all of the information, referred to as the Final Database of the Land Registry.

The identification procedure has been carried out using software programmed in mySQL which, based on the geographical coordinates of a specific demand centre, is able to locate real estate within a predefined radius and analyse the information stored for each of these cadastral references (floor area and use of land).

This has enabled us to obtain a single database with which to estimate the energy demands of each consumer centre.

3. METHODOLOGY USED TO CHARACTERISE ENERGY DEMAND

This chapter reveals the methodology used to characterise the energy demand of consumer centres, as well as the subsequent determination of the hourly hot water, heating and cooling demand curves.

To facilitate analysis of the energy demand, we used the classification of the consumer points in two major categories:

- **Direct demand centres:** these are those thermal demand centres with particularly relevant consumption that require individual treatment. At industrial level they include all of the installations that have thermal demands essentially due to productive processes and not to heating and cooling systems. In the case of the tertiary sector, those buildings belonging to the Central Government (including prisons) are considered to be specific consumption centres due to their public nature, along with hospitals, health centres, shopping malls and airports, on considering these to be buildings susceptible to supplying their thermal demand through high-efficiency cogeneration systems. The overall surface area of the direct consumption centres analysed is more than 77 million square metres.

- **Indirect demand centres:** this refers to those points of the tertiary and industrial sector not included in the previous section and which encompass a surface area in excess of 991 million square metres. The totality of the residential sector is also included in this group (24 million dwellings). Due to the large number of consumers that form part of this category, it is impossible to individualise them, and we therefore use a standard demand profile for each sector of activity.

In greater detail, the following groups will be found in both categories:

Table 6. Classification of indirect and direct categories

Indirect category	Direct category
• Demand - Residential sector - Indirect tertiary sector o Offices o Businesses o Health o Sports o Shows o Leisure and hospitality industry o Cultural - Indirect industrial sector	• Demand - Tertiary sector o Hospitals o Prisons o Institutional buildings o Airports o Shopping malls - Industrial sector

In addition to the differentiation between direct and indirect demand, we consider it necessary to set out additional classifications in accordance with climate variations. In this regard, and in general, the energy demand of the consumer centre is very closely related to its location, mainly because of the different heating and cooling requirements in accordance with the climatic zone where it is located. In this report we have established three different climatic zones: North Atlantic, Continental and Mediterranean.

The differentiation of these zones has been based on the "*SECH-SPAHOUSEC project. Analysis of energy consumption of the residential sector in Spain. Final report. (2011)*" in which three climatic zones that characterise Spain are established and the delimitation of these has been obtained based on the average maximum, mean and minimum temperatures of Spanish provinces for the 1997-2007 period. *Figure 5* shows which climatic zone each of the national provinces belongs to.

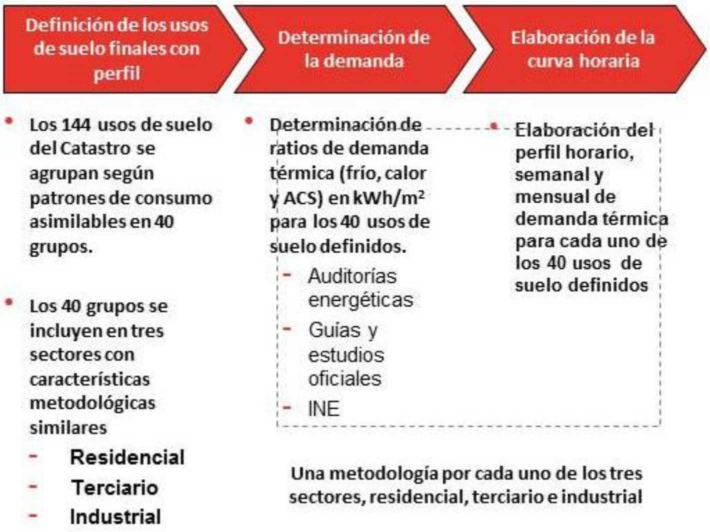
Figure 5. Territorial distribution of climatic zones

Source: SECH-SPAHOUSEC project. 2011

In general, thermal demands of the residential and tertiary sectors are influenced by the climatic zone. However, the industrial sector is not considered to be affected as most thermal demand is due to the productive process, where the climate variable has very little influence.

The following figure shows an outline of the methodology used in characterising energy demand of the energy consumer centres and which will be explained in the following points of the report.

Figure 6. Procedure to determine the indirect demand profiles



3.1. Determination of the final use of land based on which thermal demand is characterised

Energy demand in Spain encompasses a multitude of consumers that can be identified based on land use in accordance with the Land Registry. As shown in *Chapter* 2, having processed the Refined Database of the Land Registry the list of all land uses identified totalled 144. Having studied these independently, many of these were considered to reveal a similar pattern of energy consumption, and we therefore proceeded to group them together to simplify the analysis. This grouping together through similarity gave rise to 40 final land uses, and for each one we calculated their respective ratios of thermal demand and prepared an hourly, weekly and monthly energy demand curve. Below we show the final uses of land as a consequence of the grouping.

Table 7. Final uses of land with an associated demand profile

Id	Use	Id	Use
1	No demand	21	Industry-Agriculture
2	Collective dwellings	22	Industry-Beverage
3	One dwelling buildings	23	Industry-Earthenware
4	Offices	24	Industry-Construction
5	General trade	25	Industry-Quarrying - (Mines)
6	Market or supermarket	26	Industry-Electricity
7	Indoor sports; swimming pools	27	Industry-Chemicals
8	Auxiliary sports	28	Industry-Wood
9	Shows	29	Industry-Manufactured
10	Leisure and hospitality industry with residence	30	Industry-Metal
11	Leisure and hospitality industry without residence	31	Industry-Machinery
12	Health and welfare with residence	32	Industry-Plastics
13	Health and welfare without residence	33	Industry-Paper
14	Cultural and religious with residence	34	Industry-Fishing
15	Cultural and religious without residence	35	Industry-Oil
16	Administrative	36	Industry-Tobacco
17	Prison	37	Industry-Textile
18	Industry	38	Industry-Glass
19	Industry-Farming	39	Service stations
20	Industry-Foodstuff	40	Airports

Furthermore, to facilitate characterisation of demand we established three major consumer groups based on the consumption pattern considered (residential, tertiary and industrial). The demand characterisation employed showed clear methodological differences for each of the defined groups. The 40 different final uses of land were classified in one sector or another based on the following outline:

Figure 7. Demand characterisation of the residential, tertiary and industrial sectors

Patrón de consumo	Afectado por las zona climática	Fuente metodológica empleada	Usos de suelo final *
• RESIDENCIAL	✓	• SPAHOUSEC	• 2 y 3
• TERCIARIO	✓	• Difusa: BBDD • Puntual: BBDD	• 4 - 17 y 39 y 40
• INDUSTRIAL	✗	• Difusa: BBDD • Puntual: BBDD • Balances de energía final	• 18 - 38

** Se han calculado ratios de demanda y curvas horarias específicas para cada uno de los 40 usos de suelo final; la pertenencia a un grupo u otro (residencial, terciario o industrial) sólo define la metodología empleada para dicho cálculo.*

Below we explain the methodology used to characterise the thermal demand of each of the three defined sectors.

3.2. Residential sector

The residential sector encompasses land use 2 (collective dwellings) and 3 (one dwelling buildings) set out in *Table 7* this report. The energy demand of this sector is characterised as being very sensitive to the climatic zone where it is located, due to the heavy influence this has on the overall consumption of dwellings. Furthermore, another factor that is typically important in calculating the thermal demand of a dwelling is the type of dwelling, mainly due to the thermal insulation and the surfaces in contact with the outside. Consequently, we have considered it necessary to draw a distinction between a block dwelling and a one-dwelling building for each climatic zone previously mentioned, and to determine the thermal demand and the hourly curve of each of these.

This sector does not have particularly relevant consumption that requires individualised treatment, and consequently 100% of demand associated with the residential sector has been considered indirect demand.

3.2.1. Demand characterisation of the residential sector

As the main source of information for characterisation of the residential sector we have used the SECH-SPAHOUSEC project "*Analysis of the energy consumption of the residential sector in Spain. Final report"* 2011. The main purpose of this study is the development of a methodology to determine consumption in the residential sector, both at a global level as well as broken down by uses and services. Although this report is based on data from 2010, we consider that the unit results per dwelling remain valid in 2013. The SECH-SPAHOUSEC report breaks down energy consumption between:

- Type of dwelling
  - One-dwelling building
  - Block
- Climatic zone
  - North Atlantic
  - Continental
  - Mediterranean
- Breakdown of energy consumption by household
  - Heating
  - Hot water
  - Cooling
  - Lighting + electricity
  - Others (kitchen)

Average floor area by type and zone

Below we show the SPAHOUSEC data used to determine the consumption ratios of each type of equipped dwelling, by square metre and climatic zone.

Table 8. Annual energy consumption of equipped one-dwelling building by use and climatic zone

Climatic zone	Heating (GJ/ household)	Hot water (GJ/ household)	Cooling (GJ/ household)	Lighting + electrical devices (GJ/household)	Others (cooking facilities) (GJ/household)	Total (less cooking facilities) (GJ/household)
North Atlantic	32.7	9.0	0.1	10.9	1.2	52.7
Continental	49.2	8.9	0.4	10.8	1.5	69.3
Mediterranean	28.6	8.2	0.4	8.7	1.7	45.9

Source: SPAHOUSEC

Table 9. Annual energy consumption of equipped block dwelling by use and climatic zone

Climatic zone	Heating (GJ/ household)	Hot water (GJ/ household)	Cooling (GJ/household)	Lighting + electrical devices (GJ/ household)	Others (cooking facilities) (GJ/ household)	Total (less cooking facilities) (GJ/ household)
North Atlantic	6.7	6.8	0.02	12.1	1.3	25.6
Continental	15.5	7.6	0.3	10.8	1.0	34.2
Mediterranean	4.9	7.5	0.3	7.7	1.7	20.4

Source: SPAHOUSEC

As you can see, the energy consumption data shown in *Table 8* and Table 9 only refer to equipped dwellings; with 'equipped' understood as the availability of the following equipment or energy services: heating, hot water, refrigeration, kitchen, lighting and electrical appliances. In Spain there are dwellings that do not have certain energy services (*Table* 10 *and Table 11*), so in order not to oversize the energy consumption associated with the Spanish residential sector we have reduced the energy consumption of equipped dwellings by type and climatic zone based on the proportion of equipment.

Table 10. Proportion of equipment of one-dwelling buildings

Climatic zone	Heating	Hot water	Cooling	Lighting	Cooking facilities
North Atlantic	91.5%	99.6%	0.3%	100%	100%
Continental	89.4%	99.3%	36.9%	100%	100%
Mediterranean	85.9%	99.7%	67.8%	100%	100%

Source: SPAHOUSEC

Table 11. Proportion of equipment of block dwellings

Climatic zone	Heating	Hot water	Cooling	Lighting	Cooking facilities
North Atlantic	93.3%	100%	1.3%	100%	100%
Continental	97.4%	99.9%	40.3%	100%	100%
Mediterranean	86.3%	100%	66.2%	100%	100%

Source: SPAHOUSEC

Following the recommendations of the European commission guide on preparation of the heat map: "*Best Practices and informal guidance on how to implement the Comprehensive Assessment and the country wide cost-benefit analysis*" we have left out residential consumption referring to "Others (Cooking facilities)" for this report.

The result has given the following ratios of energy consumption by type of dwelling and climatic zone.

Table 12. Annual energy consumption of one-dwelling building by use and climatic zone

Climatic zone	Heating (kWh)	Hot water (kWh)	Cooling (kWh)	Lighting + electrical devices (kWh)	Others (cooking facilities) (kWh)	Total (less cooking facilities) (kWh)
North Atlantic	8,311	2,490	0.1	3,028	333	13,829
Continental	12,218	2,455	38	3,000	417	17,711
Mediterranean	6,824	2,271	81	2,417	472	11,593

Source: SPAHOUSEC

Table 13. Annual energy consumption of block dwelling by use and climatic zone

Climatic zone	Heating (kWh)	Hot water (kWh)	Cooling (kWh)	Lighting + electrical devices (kWh)	Others (cooking facilities) (kWh)	Total (less cooking facilities) (kWh)
North Atlantic	1,736	1,889	0.1	3,361	361	6,986
Continental	4,194	2,109	37	3,000	278	9,340
Mediterranean	1,175	2,083	55	2,139	472	5,452

Source: SPAHOUSEC

According to the use of a dwelling, they are classified as main (occupied most of the year), secondary (second residence or holiday home) and empty. The SPAHOUSEC consumption data only refer to main dwellings, whereby if we apply these consumption ratios to 100% of Spanish dwellings we would be overestimating the final demand of the residential sector in Spain. Consequently, the consumption shown in Table **12** and Table **13** by use and climatic zone was reduced based on the occupation of dwelling ratios specified in the Spanish Institute of Statistics (INE) Population Census of 2011.

Table 14. List of dwellings according to use by climatic zone

Climatic zone	Main dwellings	Secondary dwellings	Empty dwellings
North Atlantic	74.3%	11.8%	13.9%
Continental	72.0%	14.9%	13.1%
Mediterranean	70.9%	15.1%	14.0%

Source: INE

Based on the foregoing data and the average floor area of each dwelling in the corresponding climatic zones (Table 15), we obtained the energy consumption ratio per square metre (kWh/m^2), based on the type of dwelling, use and climatic zone.

Table 15. Average floor area of main dwellings by type and climatic zone

Climatic zone	Floor area of block dwellings (m^2)	Floor area of one-dwelling buildings (m^2)
North Atlantic	82.2	126.7
Continental	84.7	150.6
Mediterranean	88.7	136.8

Source: SPAHOUSEC

To comply with the object of this project, having obtained the energy consumption ratios for each type of dwelling and climatic zone, it was necessary to convert them into demand ratios. To perform this conversion, we applied the average performance of the equipment involved in that particular use, taking into consideration the typical list of energy sources used to provide that service in that climatic zone. Table 16 shows the breakdown of consumption in dwellings, in accordance with the different energy sources and climatic zones considered in the analysis.

Table 16 . Breakdown of consumption based on energy sources and climatic zones

Climatic zone	Technology	Units	Heating	Hot water	Cooling	Lighting + electrical devices	Others (cooking facilities)
North Atlantic	Coal	*TJ*	402	32	0	0	39
	Petroleum products	*TJ*	11,064	4,715	0	0	981
	Gas	*TJ*	6,939	9,225	0	0	3,665
	Biomass	*TJ*	9,229	140	0	0	522
	ST	*TJ*	67	153	0	0	0
	Geothermal	*TJ*	43	33	18	0	0
	Electricity	*MWh*	690,976	621,515	13,867	5,420,096	1,068,284
Continental	Coal	*TJ*	103	8	0	0	35
	Petroleum products	*TJ*	62,870	7,883	0	0	1,980
	Gas	*TJ*	36,123	31,541	0	0	6,105
	Biomass	*TJ*	39,825	1,778	0	0	425
	ST	*TJ*	195	1,173	0	0	0
	Geothermal	*TJ*	145	59	25	0	0
	Electricity	*MWh*	1,697,708	894,273	534,894	14,760,599	2,341,106
Mediterranean	Coal	*TJ*	0	0	0	0	0
	Petroleum products	*TJ*	27,430	14,265	0	0	4,769
	Gas	*TJ*	27,915	24,801	0	0	6,934
	Biomass	*TJ*	50,080	180	0	0	132
	ST	*TJ*	169	4,076	0	0	0
	Geothermal	*TJ*	66	51	64	0	0
	Electricity	*MWh*	2,029,250	2,963,806	851,423	23,932,460	2,162,719

Source: SPAHOUSEC

The performances considered were determined based on specific knowledge of each technology obtained in more than 5,000 energy audits consulted. Table 17 shows the ratio of these returns.

Table 17. Performance by energy sources and climatic zones

Climatic zone	Coal	Petroleum Products	Gas	Biom.	ST	GT	Electricity Lighting	COP	EER
North Atlantic	75%	85%	87%	85%	100%	100%	100%	294%	312%
Continental	75%	85%	87%	85%	100%	100%	100%	289%	292%
Mediterranean	75%	85%	87%	85%	100%	100%	100%	298%	292%

The SPAHOUSEC report does not break down electricity consumption associated with heating and cooling based on the equipment where this is produced. Consequently, and in order to distinguish the electricity consumed in heat pumps from that consumed in other electrical equipment, we established the assumption that electricity consumption would be distributed with the same percentage as the number of heating and cooling items of equipment of each type shown in SPAHOUSEC for each climatic zone.

Based on this information, we determined that of the overall electricity consumption used in heating and cooling homes, the distribution between heat pump and other electrical equipment is as shown below:

Table 18. Ratio of electricity consumption for heating and cooling

	Type of demand	North Atlantic	Continental	Mediterranean
Heat pump	**Heating**	4%	27%	37%
	Cooling	33%	91%	95%
Remaining electrical equipment	**Heating**	96%	73%	63%
	Cooling	67%	9%	5%

Having determined these values, we calculated the energy demand ratios by type of dwelling, use considered and climatic zone and multiplying by the overall floor area of the dwellings of each kind. And for each climatic zone shown in Table 19 we determined the overall demand of the residential sector shown in Table 20, broken down by use and climatic zone.

Table 19. Floor area by use and climatic zone (m^2)

Use of land	North Atlantic	Continental	Mediterranean
Block dwelling	196,660,565	466,525,103	753,465,626
One-dwelling building	122,585,982	401,140,426	595,373,591

Table 20. Broken down thermal demand of the Spanish residential sector

Id	Use of land	Climatic zone	No. of Dwellings	Heating demand (GWh)	Cooling demand (GWh)	Hot water demand (GWh)
2	Collective dwellings	North Atlantic	2,207,335	2,692.4	0.3	2,965.5
		Continental	5,112,033	14,686.2	406.7	7,348.8
		Mediterranean	8,203,409	6,452.1	925.5	11,289.7
3	One dwelling buildings	North Atlantic	891,952	5,211.7	0.0	1,580.9
		Continental	2,832,634	20,691.9	201.9	4,136.7
		Mediterranean	4,404,903	19,205.2	696.1	6,305.1
Total		**-**	**23,652,266**	**68,939.6**	**2,230.5**	**33,626.8**

As a summary of all the foregoing, the thermal demand of the residential sector in 2013 is 104,797 GWh, distributed by final use as follows:

Hot water	**33,627 GWh**
Heating	**68,940 GWh**
Cooling	**2,231 GWh**

3.3. Tertiary sector

Uses pertaining to the tertiary sector are characterised by a thermal demand highly dependent on atmospheric conditions. Consequently, for each use we have determined the thermal demand corresponding to each of the climatic zones defined in Appendix B of the Building Technical Code (CTE). The correspondence between these zones and the three considered in the SPAHOUSEC study is shown in Annex III of this report.

The tertiary sector has centres with a relevant volume of energy consumption that requires individualised treatment and consequently the following have been considered direct demand centres:

- Hospitals and health centres
- Buildings belonging to the Central Government (including prisons)
- Airports
- Shopping malls

Furthermore, all consumers from the tertiary sector that are not included in the previous classification or who, because of their consumption characteristics, are not catalogued as direct, have been characterised as indirect demand. Below, Table 21 shows a summary of all uses of land of the tertiary sector:

Table 21. Uses of the tertiary sector and classification into direct and indirect demand

Id	Use	Direct demand	Indirect demand
4	Offices	✘	✔
5	General trade	✘	✔
6	Market or supermarket	✘	✔
7	Indoor sports; swimming pools	✘	✔
8	Auxiliary sports	✘	✔
9	Shows	✘	✔
10	Leisure and hospitality industry with residence	✘	✔
11	Leisure and hospitality industry without residence	✘	✔
12	Health and welfare with residence	Hospitals	✔
13	Health and welfare without residence	Health centres	✔
14	Cultural and religious with residence	✘	✔
15	Cultural and religious without residence	✘	✔
16	Administrative	Central government buildings	✔
17	Prison	Prisons	✔
39	Service stations	✘	✔
40	Airports	Airports	✘

3.3.1 Demand characterisation of the tertiary sector

- **Hospitals and health centres**

To determine the thermal demands of hospitals and health centres we have based ourselves on the analysis of actual electricity and fuel consumption from energy audits carried out with a set of hospitals.

- **Buildings belonging to the Central Government**

The buildings belonging to the Central Government cover a wide range of edifications of different types, mainly administrative and office buildings, prisons and health centres, as well as properties used for cultural, social or educational purposes.

Every year, the Ministry of Industry, Energy and Tourism publishes an energy inventory detailing consumption of electricity and fuel (natural gas, diesel and propane) for each building.

- **Airports**

As regards airports, the corporation AENA (Aeropuertos Españoles y Navegación Aérea), which is in charge of the management of national airports, regularly publishes environmental management reports in an effort to minimise the environmental impact of its installations. In these reports, special importance is given to the optimisation of energy efficiency, and the evolution of energy demand of buildings is therefore analysed.

By analysing this information we observe patterns of energy consumption and are able to characterise several standard terminals based on their size and passenger traffic. We then use this to establish an analogy with the remaining airports and apply a demand adjustment based on the degrees-day of heating or cooling as appropriate.

- **Shopping malls**

The case of shopping malls is affected by a peculiarity with regard to other direct consumer centres, given that they have been considered as such despite not having a source of specific information that identifies them and provides first-hand data concerning their energy consumption. The reason for this treatment is the high energy consumption of these kinds of centres, which makes it necessary to study the feasibility of cogeneration projects there.

To identify the centres, we have resorted to analysing the buildings catalogued as trade sector by the land registry and have established that all those centres with a floor area in excess of 5,500 m^2 are susceptible to an individual study.

The estimation of energy demands is carried out using the audited consumption at shopping malls located on the Spanish mainland as the reference and which show their energy consumption. These enable us to generate unit thermal consumption ratios adapted to each of the climatic zones considered in the Building Technical Code.

Applying the ratios obtained to the overall floor area of the points of consumption located for each one of the uses analysed, and which are shown in Annex IV of this report, we have obtained the following aggregate demands by climatic zone.

Table 22. Direct thermal demand by use of land of the Spanish tertiary sector

Use of land	Climatic zone	No. of buildings	Heat demand (GWh)	Cooling demand (GWh)
Hospital and healthcare centres	North Atlantic	109	280.7	17.5
	Continental	268	937.3	524.6
	Mediterranean	458	798.3	680.0
Prisons	North Atlantic	11	25.6	1.9
	Continental	40	103.0	35.7
	Mediterranean	56	91.1	86.7
Airports	North Atlantic	8	47.7	5.8
	Continental	14	98.5	146.5
	Mediterranean	28	95.0	241.2
Shopping malls	North Atlantic	92	112	8
	Continental	168	264	187
	Mediterranean	331	236	340
Buildings belonging to the Central Government	North Atlantic	202	24.5	1.7
	Continental	612	226.5	130.7
	Mediterranean	544	72.6	53.7
Total		**2,941**	**3,412.3**	**2,461.7**

3.3.2. Indirect demand characterisation of the tertiary sector

As mentioned in the introduction to this chapter, most consumer centres of the tertiary sector are classified as indirect, given that their energy consumption is not sufficiently representative to be characterised individually. Table 21 shows the uses of land of the tertiary sector to which the indirect demand characterisation methodology explained hereunder is applied.

To determine the thermal demand ratios of the uses of land considered as indirect, we have used information from energy audits for each use of land, classifying these by climatic zone:

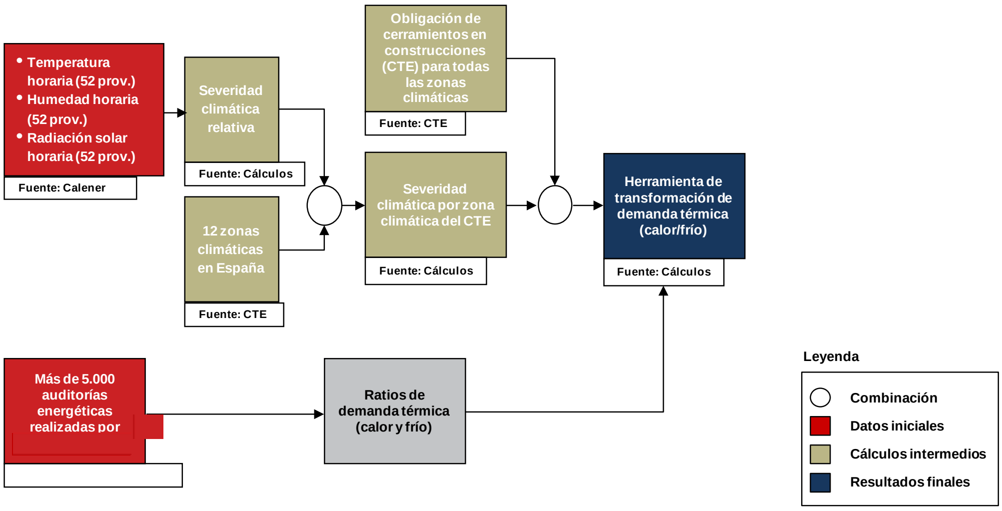
- Energy consumption by floor area unit (kWh/m^2)
- Energy balance (%), divided into:
    - Climate
    - Office IT equipment
    - Lighting
    - Other equipment;
    - Hot water
    - Other

Heating, cooling and hot water may come from different energy sources (fuels and electricity) and the use of one or the other is closely related to the type of building and climatic zone. To reflect the reality of each sector and climatic zone, we carried out an in-depth study of this consumption based on figures from the energy audits. These preliminary steps enable us to establish a range of consumption ratios associated with specific distribution of energy sources for each type of use of land and climatic zone.

The consumption ratios were then converted into demand ratios by applying the performance of the most common equipment in accordance with the type of fuel used and the climatic zone. These values were obtained from the average performance for each use of land of the tertiary sector, using figures from energy audits.

A thermal demand adjustment tool was used for those climatic zones where there were insufficient audits for a certain use of land or where these were not uniformly distributed throughout the corresponding climatic zone. This tool extrapolates the thermal demands for heat and cooling of specific climatic zone of the Building Technical Code (hereinafter CTE) to other climatic zones based on temperature and the degree-day, humidity and solar radiation. Annex II shows the correspondence between the climatic zone used and the sectoral energy monitoring (i.e.) and CTE. Below is an outline on how this tool works:

Figure 8. Performance outline of the Tool for conversion of thermal demands in accordance with the climatic zone



By applying the foregoing ratios to the floor areas for each use of land and grouping by climatic zone, we obtain the following indirect thermal demands in the tertiary sector.

Table 23. Indirect thermal demand by use of land of the Spanish tertiary sector

Use of land	Climatic zone	No. of buildings	Heat demand (GWh)	Cooling demand (GWh)
Offices	North Atlantic	66,227	1,764.8	372.0
	Continental	192,005	19,878.9	4,179.9
	Mediterranean	228,374	6,175.9	1,107.7
General trade	North Atlantic	240,830	1,573.6	613.9
	Continental	380,356	11,036.1	2,939.6
	Mediterranean	775,956	8,632.0	2,652.6
Market or supermarket	North Atlantic	8,154	460.7	813.4
	Continental	19,187	2,135.7	4,204.0
	Mediterranean	26,700	1,863.7	2,836.9
Indoor sports; swimming pools	North Atlantic	1,945	15.2	1.8
	Continental	7,144	215.7	20.9
	Mediterranean	3,857	52.0	5.3
Auxiliary sports	North Atlantic	5,650	9.2	1.3
	Continental	5,149	478.7	35.0
	Mediterranean	6,467	35.4	4.4
Shows	North Atlantic	8,258	36.3	12.2
	Continental	200,269	660.4	149.3
	Mediterranean	152,189	241.9	50.0

Use of land	Climatic zone	No. of buildings	Heat demand (GWh)	Cooling demand (GWh)
Leisure and hospitality industry with residence	North Atlantic	32,710	2,363.4	424.1
	Continental	88,826	5,696.5	1,017.9
	Mediterranean	94,455	5,032.6	385.6
Leisure and hospitality industry without residence	North Atlantic	940	285.1	60.3
	Continental	5,132	2,871.3	617.4
	Mediterranean	5,445	1,526.7	272.4
Health and welfare with residence	North Atlantic	3,503	132.5	29.4
	Continental	10,758	1,181.2	246.2
	Mediterranean	11,244	545.2	99.4
Health and welfare without residence	North Atlantic	2,500	43.5	10.5
	Continental	5,349	416.6	88.4
	Mediterranean	4,981	268.9	43.9
Cultural and religious with residence	North Atlantic	24,750	154.1	25.4
	Continental	46,062	944.8	191.9
	Mediterranean	38,667	586.1	84.9
Cultural and religious without residence	North Atlantic	1,253	306.8	82.8
	Continental	11,600	3,066.8	640.7
	Mediterranean	7,210	1,663.6	262.0
Administrative	North Atlantic	383	430.3	105.6
	Continental	1,447	3,354.4	711.2
	Mediterranean	2,990	1,592.7	281.2
Prison	North Atlantic	66,227	787.8	105.3
	Continental	192,005	647.9	93.0
	Mediterranean	228,374	564.3	56.6
Service stations	North Atlantic	240,830	2.7	0.8
	Continental	380,356	25.0	5.6
	Mediterranean	775,956	24.6	4.8
Total		**4,612,670**	**89,781.6**	**25,948.5**

Table 24 shows the total heat and cooling thermal demand (direct + indirect) of Spain for each use of land defined in the tertiary sector. In general, shops, offices and leisure and hospitality industry with residence are the subsectors that demand more thermal energy of the entire Spanish tertiary sector. The heat demand represents roughly 85% of all thermal demand of each subsector. However, in the case of supermarkets, and because of their specific cooling requirements, the cold demand represents virtually 58% of the total of markets and supermarkets subsector.

Table 24. Thermal demand of the Spanish tertiary sector

Id	Use of land	Thermal demand (heat) (GWh)	Thermal demand (cooling) (GWh)
4	Offices	27,900.2	5,705.0
5	General trade	21,853.2	6,741.7
6	Market or supermarket	4,460.1	7,854.3
7	Indoor sports; swimming pools	282.9	28.0
8	Auxiliary sports	523.3	40.7
9	Shows	938.6	211.5
10	Leisure and hospitality industry with residence	13,092.5	1,827.6
11	Leisure and hospitality industry without residence	4,683.1	950.1
12	Health and welfare with residence	3,875.2	1,597.2
13	Health and welfare without residence	741.8	147.2
14	Cultural and religious with residence	1,689.2	305.5
15	Cultural and religious without residence	5,134.5	1,063.3
16	Administrative	5,506.2	1,153.1
17	Prison	2,219.8	379.3
39	Service stations	52.3	11.2
40	Airports	241.2	393.5
Total		**93,193.9**	**28,409,2**

As a summary of all the foregoing, the thermal demand of the tertiary sector in 2013 is **121,603 GWh**, distributed by final use as follows:

Heating	**85,903 GWh**
Hot water	**7,291 GWh**
Cooling	**28,409 GWh**

3.4. Industrial, agricultural and fishing sectors

The industrial, agricultural and fishing sectors refer to identifiers 18 to 38 (both inclusive) of Table 7. Energy demand of the industrial sector mainly comes from the productive process, and consumption for heating and cooling accounts for very little of the energy total. However, there are appreciable variations in the energy consumption of the productive process depending on the type of industry analysed, and this therefore requires an individualised treatment. As the Land Registry data on location and activity do not make it possible to know those industries that have a productive process, we have considered that those that need to register their CO_2 emissions have energy demands sufficiently large to be treated as direct demand centres.

3.4.1. Direct demand characterisation of the industrial sector

Below we first describe the methodology used to determine the heat demand in industry, and subsequently the one corresponding to the demand for cold.

- **Heat demand**

To determine the thermal heat demand in the industrial sector, we have based ourselves on the registration of CO_2 emissions for 2013. This has been used to develop a calculation methodology supplemented with the information obtained from the land registry and detailed below:

1. Identification, characterisation and location of the industries from the register of CO_2 emissions and their total carbon dioxide emissions. Discrimination of the CO_2 emissions associated with heat generation from those related to process reactions or electricity generation (cogeneration installations).

2. Calculation of the fuel consumption associated with CO_2 emissions due to combustion processes for thermal generation at the installations shown on the record of emissions. Determination of the thermal demand associated with fuel consumption for each installation.

3. Identification of the industries from the record of emissions held at the land registry.

4. Calculation of overall fuel consumption by industrial sectors. Standardisation of these, taking into consideration the final energy consumption shown in the "*Final energy balances (1990-2013)*" for 2013. Readjustment of the thermal demand previously calculated based on standardised fuel consumption.

Below we describe each of the five points that make up the methodology used in determining the direct heat demand in the industrial sector:

I. CO_2 EMISSIONS: OBTAINING AND PROCESSING DATA

The methodology used to calculate the thermal heat demands in the industrial sector is based on estimating this from the carbon dioxide emissions released into the air by each of the industrial complexes shown in the PRTR (Pollutant Release and Transfer Register) and in the CITL (Community Independent Transaction Log) in the combustion processes.

The CO_2 emissions registered both in the PRTR and the CITL for each of the industrial complexes corresponds to the totality of the industry's emissions. Consequently, this includes both emissions from the industrial process as well as those from the combustion processes. For this reason, we analysed the different industrial sectors susceptible to having carbon dioxide emissions due to chemical reactions as a consequence of their productive processes, in order to adjust the CO_2 emissions available in the PRTR and the CITL data and be able to determine those that essentially derive from combustion processes.

The industrial sectors where we identified CO_2 emissions due to chemical reactions and processes other than combustion were: nonferrous metal sector and non-metallic minerals (cement, limestone, ceramic and glass products). Below we detail the adjustments made with regard to the CO_2 emissions obtained from the pollutant emissions registers (PRTR and CITL).

Nonferrous metallurgy sector

Within this industrial sector, the subsector corresponding to aluminium production is the biggest contributor of CO_2 emissions. This is because in the productive process of primary aluminium there is a major amount of carbon dioxide emissions due to the electrolysis of the alumina.

Aware of the tonnes of primary aluminium produced in 2013 by the industries shown in the record of CO_2 emissions, we have been able to calculate the tonnes of CO_2 due to the electrolysis reaction

The CO_2 emissions shown in the record of emissions corresponds virtually to the totality of those calculated. This is logical bearing in mind that the energy consumption to manufacture aluminium is solely electricity and that if there is any fuel consumption this will be reduced and in other processes.

Non-metallic minerals sector

Within this industrial sector, the cement and lime production subsectors generate carbon dioxide emissions through the decarbonation of limestone process. Similar to the cement and lime production processes, the production of ceramic products (bricks, roof tiles, tiles, ceramics, etc.) and glass (hollow or flat) also have CO_2 emissions due to the calcination and smelting processes, respectively.

- During the **cement** productive process, around 60% of CO_2 emissions are generated during the decomposition of the limestone and other materials required to produce Clinker. The remaining 40% of CO_2 emissions are generated through the burning of fossil fuels, carried out to reach the high temperatures in the kiln and associated equipment, such as the dryers.

  Bearing in mind these figures obtained from different bibliographic sources, we have carried out the adjustment of the CO_2 emissions shown in the record by applying the foregoing adjustment factor.

- As regards the productive process of lime, the calcium oxide or quicklime forms when the limestone is heated in order to decompose the carbonates. This is generally carried out in rotary kilns at high temperatures and CO_2 is released in the process. Once we know the chemical reaction, we have been able to determine which percentage of CO_2 emissions corresponds to heat generation required for the process.

  In this way, we determine that 20.76% of CO_2 emissions are a consequence of fuel combustion, while the remaining 79.23% are due to the chemical reaction. This enables us to adapt the CO_2 emissions obtained from the record of emissions.

- The CO_2 emissions due to the **productive process of ceramic products** (bricks, roof tiles, refractory products, tiles, etc.) are the result of the calcination of raw materials, in particular clay, schists, limestone, dolomite and witherite or barium carbonate and limestone as dissolvents.

  The structural ceramics sector is affected by the process emissions of CO_2as a consequence of the decomposition of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) to a lesser extent, during the firing stage, that contains the raw material used in the brick manufacturing process

  Based on the analysis of the data on specific installations from this industrial sector, we obtained a ratio of CO_2 emissions due to the decomposition processes explained previously with regard to overall CO_2 emissions where the emissions due to combustion processes in firing ovens and dryers are included. On average, this ratio is **23.9%.**

- The main raw materials of **glass** that emit CO_2 during the smelting process are: limestone ($CaCO_3$), dolomite Ca, $Mg(CO_3)_2$ and soda ash (Na_2CO_3). The action of these carbonates in the melting of glass represents a complex chemical reaction at high temperatures and must not be compared with the calcination of carbonates to produce quicklime or dead-burned dolomite lime. However, this melting (in the region of 1500 °C) has the same net effects from the standpoint of CO_2 emissions.

  Both in the process of producing hollow glass as well as flat glass there are emissions due to the decarbonation of the lime, dolomite, sodium carbonate and barium carbonate (among others). To calculate the CO_2 emissions due to combustion processes we need to extract the emissions corresponding to the aforementioned decarbonisation processes from the overall emissions of CO_2 obtained from the PRTR and CITL databases.

  To determine this, first of all we obtained the fuel consumption per tonne of glass produced for both flat glass and hollow glass from the "*Guide to Best Available Techniques in Spain of the Glass Manufacturing Sector - Ministry of the Environment*". By applying the corresponding factors of CO_2 emission based on the fuel consumed, we managed to obtain the ratio of CO_2 emissions per tonne of glass produced <u>exclusively due to fuel consumption for thermal generation.</u> Having obtained those ratios, we consulted specific industries in the PRTR where there is information on the overall production of glass and CO_2 emissions and calculated the emissions due to the combustion process and, subsequently, we determined the percentage of emissions corresponding to smelting processes. This has resulted in an average of **41%.**

II. FUEL CONSUMED AND THERMAL PERFORMANCE

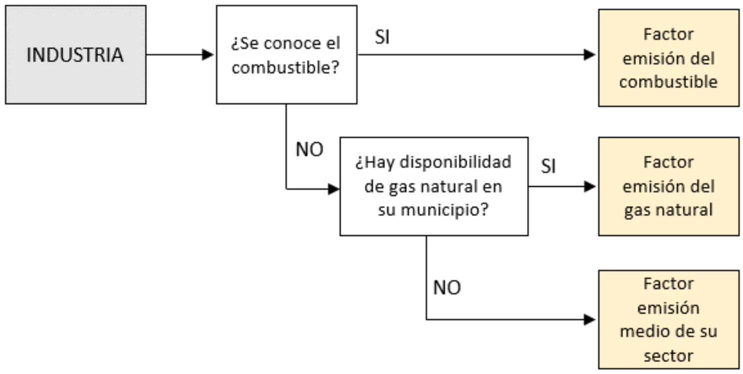
Having determined the CO_2 emissions corresponding to each of the installations shown in the record of emissions, a CO_2 emissions factor related to the amount of energy in the form of fuel consumed has been assigned to each of the industries.

Table 25: Average emission factors in the industrial sector.

INDUSTRY	Emissions factor (tCO_2/MWh)	Emissions factor without NG (tCO_2/MWh)
Extractive (non-energy)	0.2333	0.2631
Food, Beverage, Tobacco	0.2215	0.2707
Textile, Leather and Footwear	0.2087	0.2644
Pulp, paper and print	0.2065	0.2636
Chemicals	0.2108	0.3140
Non-metallic minerals.	0.2671	0.3408
Steel and Smelting	0.2991	0.3312
Nonferrous metallurgy	0.2487	0.3098
Processed Metals	0.2439	0.2834
Transport Equipment	0.2106	0.2579
Wood, Cork and Furniture	0.2301	0.2661
Others	0.2050	0.2633
Petroleum refining	0.2817	0.2817
Agriculture	0.2452	0.2625
Fisheries	0.2615	0.2615

Taking into account that for most industries the fuel consumed was unknown and that, furthermore, the average factors of CO_2 emission by industrial sector was available along with a list of the municipalities in Spain that had a natural gas distribution grid, the process of assigning the emission factor to each industry has followed the process shown below.

Figure 9. Assignment of the CO_2 emission factor of an industry.



Once the CO_2 emission factor had been assigned to each of the industries and once we knew the CO_2 emissions recorded in the PRTR or CITL, we were able to determine the amount of fuel consumed for each industry directly:

$$\text{Fuel consumed}\left(\text{MWh}_{\text{pci}}\right) = \frac{\text{Emissions (ton CO}_2\text{)}}{\text{Emission factor}\left(\frac{\text{ton CO}_2}{\text{MWh}_{\text{pci}}}\right)}$$

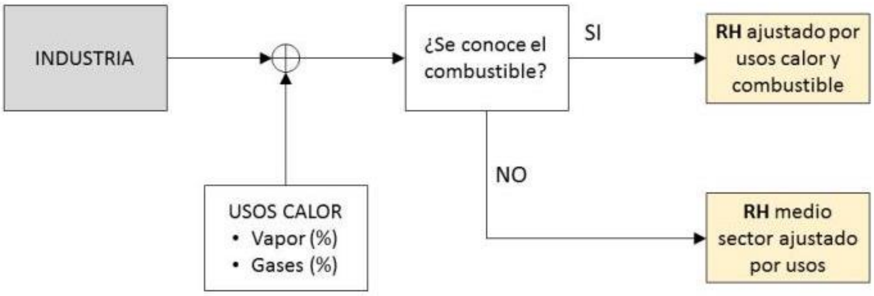
Through the calculation carried out, we obtained all the fuel consumed in each industry. However, in those industries with a cogeneration plant, not all this fuel will be used for thermal generation, and part of it will be used for electricity generation. Consequently, the next step was to discriminate between those industries that have cogeneration plants and those that do not. In this way, for those that do not have cogeneration we have assumed that all of the fuel calculated from the CO_2 emissions is to be used for thermal generation, while in the case of having cogeneration we have assumed that a part will be used for electricity generation.

To identify which industries have cogeneration plants we consulted the Special Regime Register for electricity production to locate a total of 301 companies with cogeneration that declare their CO_2 emissions. Subsequently, depending on whether or not the company had cogeneration, the following methodology was used:

- Industries without cogeneration

In the case of an industry without cogeneration, all fuel calculated is assumed to be used for thermal generation. Given that the reference values of efficiency for separate production of heat does not depend solely on the type of fuel used but also on the type of heat transfer fluid (steam/hot water or direct use of gases), for each industrial sector we considered a percentage of use of the process heat in the form of steam and another percentage in the form of direct hot gases. To determine those percentages we consulted studies and audits compiled in specific industries of the different industrial sectors as well as studies on the characteristic productive processes of each sector.

Figure 10. Assignment of the reference thermal performance in an industry without cogeneration.



- <u>Industries with cogeneration</u>

To calculate thermal demand in industries with a cogeneration plant, we referred to the *Cogeneration Energy Statistics Journal. 2013*.

Given that there is no information on the type of technology used at each of the cogeneration installations, in those where the cycle type of the system is known we use its characteristic thermal performance, while for those where this is unknown we will use the average thermal performance of cogeneration plants that belong to the same industrial sector. Table 26 and Table 27 show the calculation values and the thermal performances obtained.

The thermal performance is defined using the following equation:

$$RH = \frac{Net\ heat\ production\ (MWh)}{Total\ fuel\ consumption\ (MWh)}$$

Table 26. Thermal performances of cogeneration in accordance with the technology used[3].

Technology	Electrical power Total (MW)	Gross electrical Production (GWh)	Net Heat Production (TJ)	Fuel Consumption (TJ)	RH
Combined Cycle	1,306.8	8,034.6	40,832.5	100,244.7	0.41
Internal combustion engine	3,120.5	11,455.0	42,665.4	120,948.3	0.35
Gas Turbine with Heat Recovery	1,221.1	6,882.7	46,523.8	95,366.1	0.49
Steam: Back-pressure Turbine	552.8	2,714.3	32,747.8	56,929.2	0.58
Steam: Condensing Turbine	284.9	1,704.3	12,114.6	25,048.4	0.48
TOTAL	**6,486.7**	**30,790.9**	**174,884.1**	**398,536.7**	**0.44**

Table 27. Thermal performance of cogeneration in accordance with the industrial sector[2].

Sectors	Electrical power Total (MW)	Gross electrical Production (GWh)	Net Heat Production (TJ)	Fuel Consumption (TJ)	RH
Coking	123.8	613.8	2,990.2	7,074.6	0.42
Extraction	95.3	502.3	3,373.2	7,007.9	0.48
Solid Fuel Extraction	35.4	72.8	347.3	837.6	0.41
Manufacture Of Other Non-Metallic Mineral Products	478.0	1,696.3	13,503.3	25,930.9	0.52
Chemical industry	1,032.5	5,264.8	28,896.5	64,802.7	0.45
Agricultural, Food and Tobacco Industries	1,257.1	4,709.7	22,330.2	54,971.1	0.41
Paper and Cardboard, Publishing and Printing Industries	1,253.9	7,562.4	51,722.0	115,751.4	0.45
Other Industrial Branches	414.4	1,774.5	7,368.3	19,158.4	0.38
Production of Nonferrous Minerals	35.3	87.9	970.5	1,669.0	0.58
Refineries	641.4	4,306.9	24,827.6	54,254.3	0.46
Services, etc.	630.1	2,906.0	11,433.3	31,104.4	0.37
Steel industry	12.1	52.4	169.8	518.6	0.33
Textile, Clothing and Leather	311.5	557.0	4,043.4	7,957.3	0.51
Processed Metals, Manufacturing of Machinery and Equipment	122.1	448.5	2,309.9	5,356.7	0.43
Transport and Communication	44.0	235.5	599.0	2,141.7	0.28
TOTAL	**6,486.7**	**30,790.9**	**174,884.1**	**398,536.7**	**0.44**

[3] *All figures come from the MINETUR statistics, apart from Thermal Performance which has been calculated based on these statistics.*

III. DETERMINATION OF THE DIRECT THERMAL DEMAND

Having assigned a thermal generation performance to each industry we obtain the thermal demand directly from the fuel consumed by the industry calculated in the previous point:

$$\text{Thermal demand (MWh)} = \text{Fuel}\left(\text{MWh}_{\text{pci}}\right) \cdot \text{RH}(\%)$$

In this way we have a database of consumer centres belonging to the industrial sector with their corresponding associated thermal demands.

- **Cooling demand**

Given that cooling requirements in industry is very heterogeneous in terms of its use, and therefore complex to characterise, we have only considered cooling for the food & drink, pharmaceutical and chemicals industries where the use of this is standard practice and there is information on the most common uses. The most common uses are in cold storage:

- Pharmaceutical industry: Many of the compounds used in this sector need to be kept and stored in strict and stable conditions and at low temperatures. In pharmaceutical industries, the standard temperature intervals in cold chains are between 2 – 8ºC.
- Food industry: Cooling is very extensive in this industry and is particularly important in the meat, fish, dairy and canning subsectors. Most cooling is consumed in cold storage used for preservation, freezing chambers and tunnels and rooms where foodstuffs are worked on and handled.
- Chemical industry: This is a very heterogeneous sector in which the use of cooling varies depending on the activity. It is used in cold storage, reducing temperatures, rapid chilling or cooling tunnels.
- Beverage manufacturing industry: Consumption in this industrial sector basically focuses on refrigeration and chilling of drinks. The most common temperature range is from 2-4ºC down to -4/-5ºC depending on the drink chilling process.

To estimate the cooling demand in the aforementioned sectors we have consulted energy studies and audits in different industries of each one of the sectors selected. Based on the demands for heating, cooling and electricity of the different companies analysed, we have obtained heating and cooling consumption ratios through total electricity consumption for each sector. Given that in most industries the cooling demands are supplied through compression systems (electric chillers), we have considered that all cooling demands are supplied using this type of cooling machines. Consequently, having obtained the average ratios of cooling consumption through electricity for each sector, we determine the cooling demand of each sector by using the electricity consumption data by sectors given in the publication *"Final Energy balances (1990-2013)"*.

Taking into consideration that in this publication the electricity consumption of some sectors where cooling is used is grouped together (chemicals and pharmaceuticals or food and beverage), we have estimated the electricity consumption broken down in each subsector and have subsequently applied the consumption of cooling ratios calculated. The methodology used is shown below:

i. Calculation of the electricity consumption of each industry. We have determined the electricity consumption for each industry (direct and indirect). In the case of direct industries, we have applied the electricity consumption/thermal consumption ratio, while in the case of indirect industries we have estimated their electricity consumption based on heating and cooling needs.

ii. Calculation and standardisation of electricity consumption in each subsector. For each subsector we have calculated the aggregate sum of electricity consumption of all industries using the direct and indirect databases Having calculated the aggregate sum, this has been standardised based on the electricity consumption shown in the "Final energy balances (1990-2013)" for the different sectoral groupings.

iii. Cooling consumption in direct industries. Having determined and adjusted the electricity consumption of each of the industries from the industrial sectors with potential consumption of cooling, we have applied the cooling through electricity consumption ratio corresponding to their subsector to each of them. This allows us to determine the cooling consumption of each direct industry and by adding these together we obtain the total direct cooling demand.

Table 28. Direct thermal demand by type of industry

Industrial sector	No. of buildings	Heat (GWh)	Cold (GWh)
Extractive (non-energy)	19	442.0	n.c.
Food, beverage and tobacco	353	8,996.1	10,147.1
Textile, leather and footwear	23	536.4	n.c.
Pulp, paper and print	99	12,757.3	n.c.
Chemicals	291	29,897.2	4,662.7
Non-metallic minerals.	585	31,196.7	n.c.
Steel and smelting	77	18,642.0	n.c.
Nonferrous metallurgy	47	1,574.4	n.c.
Processed metals	176	1,345.7	n.c.
Transport equipment	41	1,750.4	n.c.
Construction	0	0.0	n.c.
Wood, cork and furniture	11	1,264.2	n.c.
Others	21	361.5	n.c.
Agriculture	13	84.0	n.c.
Fisheries	1	1.1	n.c.
Petroleum refining	14	33,992.8	n.c.
Total	**1,771.0**	**142,841.8**	**14,809.9**

3.4.2. Indirect demand characterisation of the industrial sector

To calculate the indirect demand of each industrial sector studied, we determined the direct energy consumption and compared this with the final energy consumption in the industrial sector for 2013, from the Sectoral Energy Monitoring (SES)

The surplus, if any, was distributed between the industry considered indirect and its demand is determined based on the average RH reference performance which considers the fuel mix of each industrial sector considered in the corresponding Sectoral Energy Monitoring.

Table 29. Indirect thermal demand by type of industry

Industrial sector	No. of buildings	Heat (GWh)	Cold (GWh)
Extractive (non-energy)	2,169	2,618.2	n.c.
Food, beverage and tobacco	73,020	5,299.0	5,906.6
Textile, leather and footwear	9,704	1,342.3	n.c.
Pulp, paper and print	2,666	4,104.2	n.c.
Chemicals	3,932	4,047.7	461.8
Non-metallic minerals.	4,775	373.6	n.c.
Steel and smelting	0	0.0	n.c.
Nonferrous metallurgy	12,409	2,504.1	n.c.
Processed metals	46,468	2,144.7	n.c.
Transport equipment	91,961	0.0	n.c.
Construction	12,695	10,909.1	n.c.
Wood, cork and furniture	37,796	2,645.6	n.c.
Others	95,354	8,030.7	n.c.
Agriculture	522,781	24,357.8	n.c.
Fisheries	1,451	1,039.8	n.c.
Petroleum refining	0	0.0	n.c.
Total	**917,181**	**69,416.9**	**6,368.4**

Total demand of the Spanish industrial sector, considering the direct and indirect demands, is as follows:

Table 30. Thermal demand of the Spanish industrial sector

Industrial sector	No. of buildings	Heat (GWh)	Cold (GWh)
Extractive (non-energy)	2,188	3,060.1	n.c.
Food, beverage and tobacco	73,373	14,295.0	16,053.7
Textile, leather and footwear	9,727	1,878.7	n.c.
Pulp, paper and print	2,765	16,861.5	n.c.
Chemicals	4,223	33,945.0	5,124.5
Non-metallic minerals.	5,360	31,570.3	n.c.
Steel and smelting	77	18,642.0	n.c.
Nonferrous metallurgy	12,456	4,078.5	n.c.
Processed metals	46,644	3,490.4	n.c.
Transport equipment	92,002	1,750.4	n.c.
Construction	12,695	10,909.1	n.c.
Wood, cork and furniture	37,807	3,909.9	n.c.
Others	95,375	8,392.2	n.c.
Agriculture	522,794	24,441.9	n.c.
Fisheries	1,452	1,040.8	n.c.
Petroleum refining	14	33,992.8	n.c.
Total	**918,952**	**212,258.7**	**21,178.3**

As a summary of all the foregoing, the thermal demand of the industrial, agriculture and fishing sector in 2013 is 233,437 GWh, distributed by final use as follows:

Heating 212,259 GWh

Cooling 21,178 GWh

3.5. Total aggregate results

Below we show the results of overall heating and cooling thermal demand of Spain broken down by Residential, Tertiary and Industrial, Agriculture and Fishing sectors.

Table 31. Heating and cooling thermal demand in Spain (GWh)

Sector	Residential	Tertiary	Industrial, agricultural and fishing	TOTAL
Heating + Hot Water	102,566.4	93,193.9	212,258.7	**408,019**
Cooling	2,230.5	28,409.2	21,178.6	**51,818**

We should point out that due to the lack of statistical data on which to base ourselves, we have needed to perform a high number of assumptions to achieve the foregoing results on demand characterisation. Consequently, these findings are highly sensitive to the variation of these assumptions and must therefore be considered as an initial approximation to the disaggregated knowledge of heating and cooling demands in the different sectors nationwide and should be treated with the necessary reservations.

Notwithstanding the foregoing, it is important to stress that the efforts made in the characterisation, completed with subsequent studies focused on specific areas of national territory, and even more so with regard to an energy-measurements-for-statistical-purposes campaign, will enable us to have greater knowledge than we currently do about the real potential available in efficient heating and cooling systems.

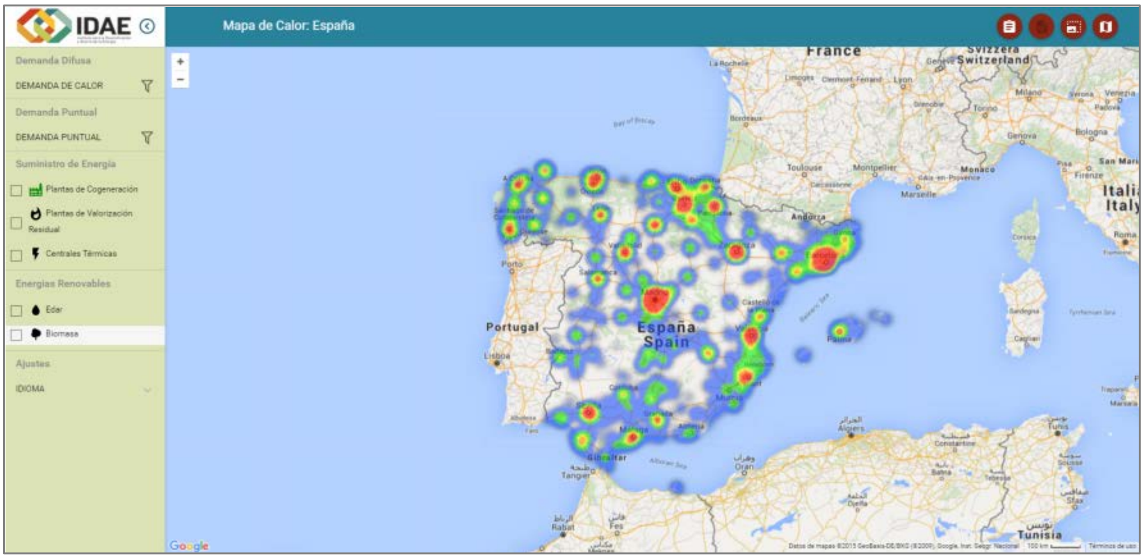
4. CONSULTATION AND DATA UPDATE TOOL

The consultation tool is designed as a secure, easy-to-use and updatable web platform software tool implemented in multi-language (HTML, CSS and JavaScript), which enables both graphic representation of the information from the study into potential as well as its consultation and analysis.

The application will comprise two clearly distinguished modules, a graphic representation map of the information, the consultation tool and a system for analysing the information it contains.

For the application's web environment we have opted for its own domain, which will lend it autonomy, ease of updating and administration. The environment is programmed in *JavaScript* language to guarantee absolute compatibility with the system chosen for the graphic representation of the information (see section 0 of the document) and with the heat map survey application, in order to allow the inclusion of new consumer centres (or to update those that already exist) with prior approval from the system administrator. Figure 11 shows the proposed interface for the application.

Figure 11: Interface of the heat map web application



4.1. Graphic representation map

The visualisation of the information has been carried out using a web mapping application developed on the basis of the API (*Application Programming Interface*) of Google Maps v3.0 which will display all information susceptible to being represented, and allow the visualisation of subsets of information based on filters and layers. The following information is to be represented:

- ***Areas of high building density:*** The main parameter to take into consideration when analysing the technical potential of an efficient district grid is the energy demand that needs to be satisfied and which, according to the guide that interprets Directive 2012/27/EU, must be greater than 130 kWh/m^2 for its installation to be considered as feasible. These consumption ratios are normally obtained in areas of high building density, and consequently this only represents the thermal demand of these areas. The criterion used to identify these zones is through the compilation of a mesh made up of squares measuring 100 metres per side in which the built-on surface area is analysed. Building density will be considered high in those cases in which the plot ratio is greater than 0.30.
- ***Thermal demand:*** Thermal demand is categorised as shown in the following table:

HEAT DEMAND	
Indirect demand	**Direct demand**
Residential	Health and Welfare
Administration	Prison
Offices	Airports
Businesses	Businesses
Sports	Agriculture and fisheries
Leisure and hospitality industry	Food, beverage and tobacco
Health and Welfare	Manufacture of coke and refined petroleum products
Prison	Extractive (non-energy)
Other	Manufacturing of machinery
Industries	Wood and furniture
	Metal Industry
	Non-metallic minerals.
	Paper and print
	Chemicals and pharmaceuticals
	Textiles
	DHC

For the graphic representation of thermal heat demand we have opted for a heat map that will show the energy consumption using a scale of colours, whereby the higher the demand the greater the intensity of the colour that represents it. To improve visualisation, the data can be consulted on a global (aggregate) way or by subsets defined using filters through different sectors of activity and demand type (direct and/or indirect). To improve visibility, in cases of high concentration of demand points, the map shows an icon with a number inside that totalises the direct installations. The demands are broken down on an individual basis as the zoom is increased in order to get more information on each of these.

Figure 12 and Figure 13 show the representation of thermal demand.

Figure 12: Representation of thermal demand and visualisation of the filter bar.

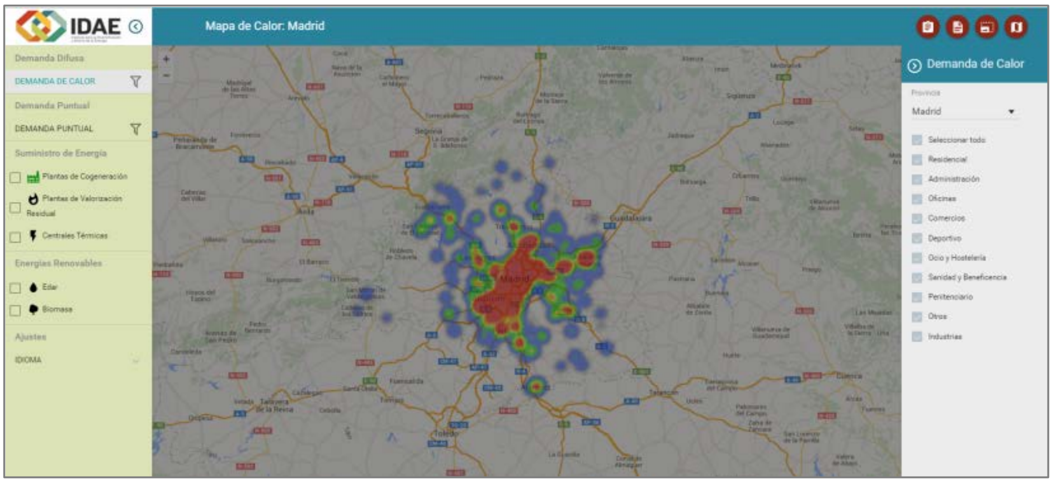
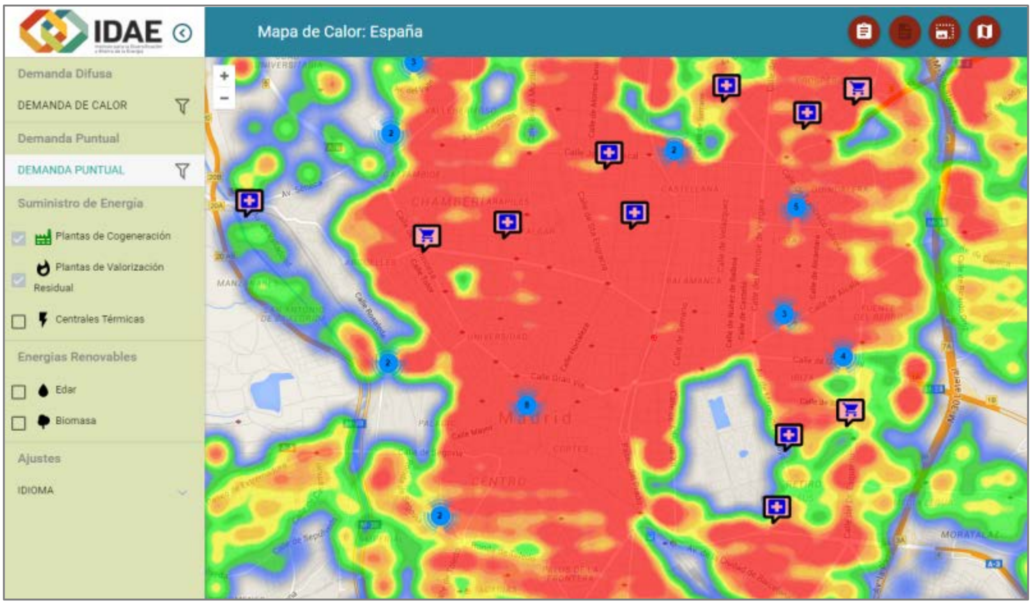


Figure 13: Representation of thermal demand, breakdown of direct demands.



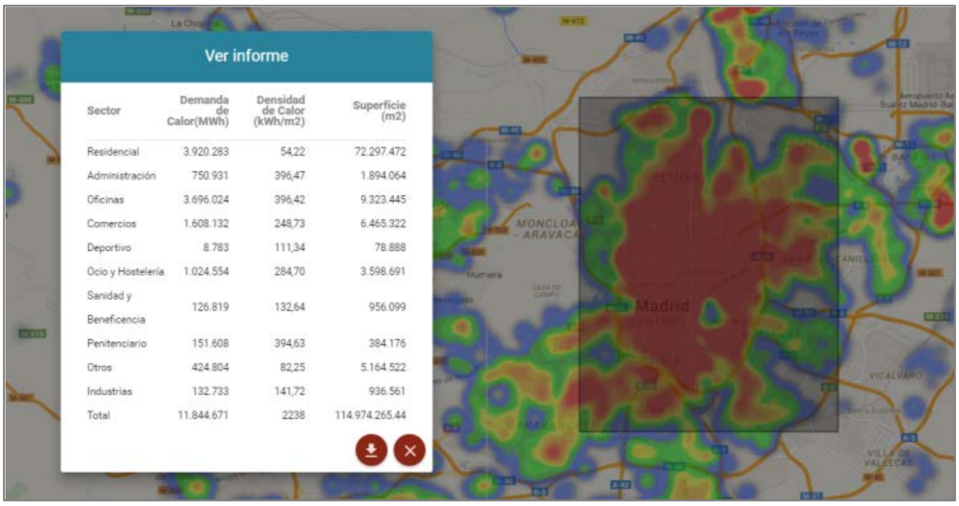
- ***<u>Thermal supply:</u>*** This section will include the points with potential for thermal supply and information about their characteristics. Representation will be through icons that enable the type of centre to be distinguished (**Figure 14)**. In addition to this, their size will vary depending on their power or the amount of heat that they can supply. This heat supply will include:
  - Waste recovery plants.
  - Thermal power plants.
  - Wastewater treatment plants.
  - Residual biomass
  - Solar energy
  - Geothermal energy

Figure 14: Representation of centres with potential for thermal supply.

4.2. Information analysis tool and consultation of results

The function of this tool involves showing detailed information of a specific area of the map selected by the user. The choice of information to be analysed may be delimited by user-defined polygons or all the information concerning one zone may be selected. Reports may be obtained from the subsets showing their demand and thermal supply and a breakdown by different types of consumers. Figure 15 shows the extraction of reports on the heat map.

Figure 15: Webmapping application consultation tool.



5. TECHNICAL POTENTIAL CALCULATION TOOL

The technical potential of efficient heating and cooling systems will be determined through an assessment of thermal demands and their characteristics, and identifying cases in which this would be susceptible to making use of effective technologies, such as cogeneration, residual heat or renewable energies.

In this section we describe the information inputs into the calculation tool, the calculation methodology used to determine the potential of efficient heating and cooling and, lastly, the information outputs of the tool are made clear.

5.1. Information input of the tool

The information inputs of the calculation tool will be based on information contained on the Database that feeds the heat map and through different consultations of the Technical Bases available in the Tool. Depending on the type of information, we consider three different blocks:

a. General information on the consumer centre

Type of consumer centre (Sector)	Tertiary sector/industrial sector
Constructed floor area	m^2 built
Subsector of the consumer centre	i.e. Shopping mall/Paper sector
Geographical location	Polar coordinates of the centre

b. Information on energy demands of the consumer centre

HEAT DEMAND	
Type of heat demanded	Steam/Hot gases/Hot water
Total annual heat demand	MWht/y
Annual hours of heat demand	h/y
COOLING DEMAND	
Type of cooling demanded	Air conditioning/Process
Total annual cooling demand	MWhc/y
Annual hours of cooling demand	h/y

Where:

– *Type of heat/cooling demanded:* For each subsector (industrial or tertiary) there will be an assignment of which cooling and/or heating typology is the most representative. For example, for the paper industry the heat type would be steam and for a hospital it will be hot water (whether for sanitary or heating purposes).

– *Total annual demand of heating/cooling/electricity:* For each direct thermal consumer centre the Database includes its total thermal energy demand for both cooling and/or heating. Their electricity demand is determined on the basis of ratios of electricity consumption in the Technical Bases of the tool.

– *Annual hours of demand:* Once we know the type of direct consumer centre, the cooling/heating/electricity demand hours are made available, as for each subsector (industrial and tertiary) demand curves for each energy types are assigned.

c. Information on the environment of the consumer centre

1.	AVAILABILITY OF WASTE		
2.	Typology	3.	Residual biomass Industrial
4.	Maximum demand that can be supplied	5.	MWh/y
6.	AVAILABILITY OF RESIDUAL FUELS		
7.	Typology	8.	Biogas/others
9.	Maximum demand that can be supplied	10.	MWh/y
11.	AVAILABILITY OF RESIDUAL HEAT		
12.	Origin	13.	Industry/Recovery plant/Power station
14.	Maximum power	15.	MWt
16.	Operating hours:	17.	h/y
18.	Maximum useful heat	19.	MWh/y
20.	AVAILABILITY OF GEOTHERMAL ENERGY		
21.	Typology	22.	Average temperature/Low temperature
23.	Maximum power	24.	MWt

Where:

- *Maximum demand that can be supplied* Maximum thermal demand to be supplied through residual fuels, setting the thermal demand to be supplied in this way at 85% of total demand, thus avoiding thermal oversizing of the installation and using conventional boilers in demand peaks.

- *Maximum power:* Maximum heat supply capacity of the resource based on availability parameters.

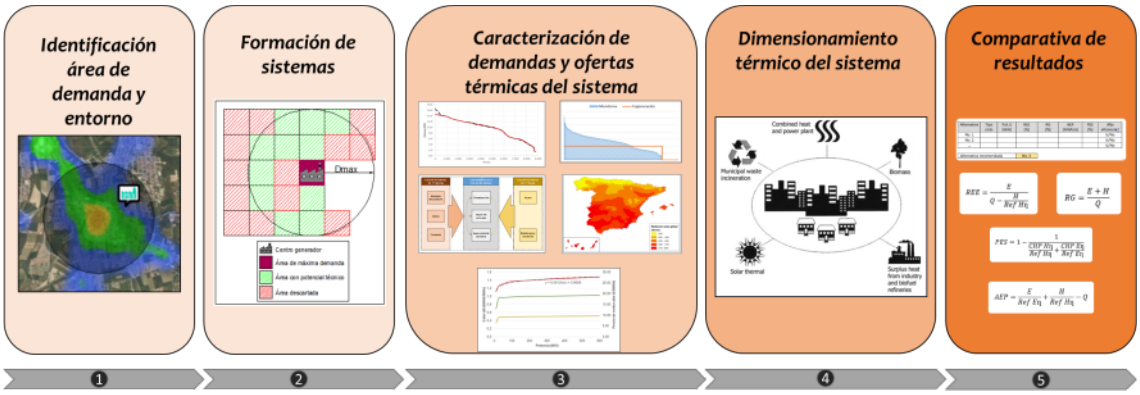
- *Operating hours:* Timing availability of the resource throughout the year.

Based on the geographic location of the consumer centre, the calculation tool will query the Database to obtain the disaggregated information on waste and/or residual fuels within a maximum predefined distance for each case.

5.2. Calculation methodology

Based on the information listed in the previous section, the tool will be responsible for identifying thermal demands with potential to introduce efficient heating and cooling systems in order to subsequently analyse the technical and economic feasibility of these. Next we will describe the process followed by the tool and the technical basis on which this is founded, which is summarised in Figure 16.

Figure 16: Summary of the tool calculation process.



5.2.1 Identification of systems

Within the scope of this study, a system is understood as a grouping of consumer centres of different types, which share demand characteristics, associated with a set of thermal supplies that can fully or partially satisfy this demand.

Within the thermal demands, we draw a difference between:

- *Indirect demand:* Indirect demand comprises those consumer centres that cannot form a system by themselves but which can be grouped to form territorial areas that can be supplied through efficient heating and cooling.
- *Direct demand:* Direct demand encompasses all those consumer centres which, as they are centres with a significant thermal demand, can form a system by themselves or be included as part of larger system. This type includes large industries and large tertiary consumers (hospital and healthcare centres, prisons, large shopping malls and airports).

As regards thermal supply, we can distinguish the following resources:

Residual fuel: This is fuel that is obtained as waste from a process susceptible to being used for thermal generation. The residual fuels considered are: residual biomass, both from industry and agriculture and forestry waste, and biogas from Wastewater Treatment Plants (WWTPs).

Residual heat: This is either heat in the form of hot gases generated in an industrial process, or heat in the form of steam obtained in electricity generation processes.

For the identification of systems, it is necessary to group together the parameters referred to previously. To this end we performed an in-depth analysis of the information contained in the database by drawing up a grid comprising cells measuring 100 metres per side, in which to individually analyse the information of the consumer centres and the suppliers contained in the centres. The process employed follows these steps:

1. ***Locating areas of high building density:*** The technical feasibility of district grids is highly influenced by the density of thermal demand which, in turn, very much depends on the volume of building. The construction of an efficient district heating and/or cooling system will only be considered feasible in areas whose plot ratio is higher than 0.30, thus disregarding any of those cells in which the constructed surface area is lower than 30% of the land area.

2. ***Formation of indirect demand areas:*** Having localised the high-density building cells (*plot ratio* higher than 0.3), we disregard those who demand is lower than 130 kWh/m^2 of land and group together those cells that comply with the two previous requirements.

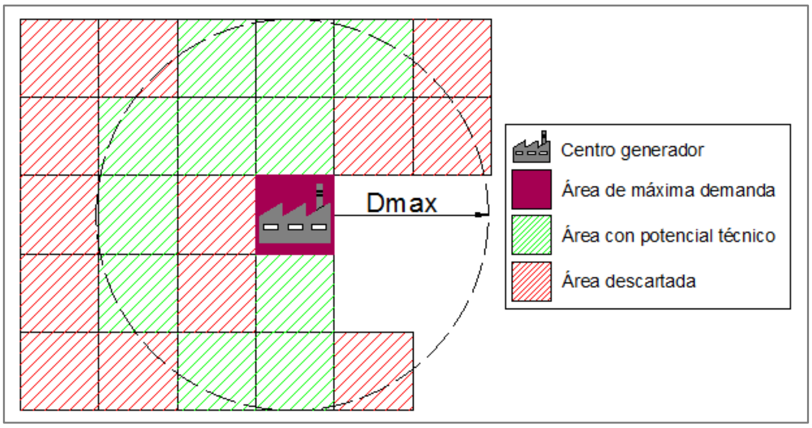
   Firstly, the Tool commences a procedure of grouping together the cells, starting with the cell that has the highest thermal demand of all the territory.

   Once this cell has been located, the Tool establishes this cell as the centre of the first grouping of cells of the territory. The Tool analyses those cells whose centre of coordinates is located at a distance no greater than 1.5 km. Of all the cells located in the area delimited by the radius of 1.5 km, it adds to the grouping of indirect cells all those that belong to the same sector (residential or tertiary) as the origin cell of the grouping and which has not been previously disregarded through failure to comply with the plot ratio of more than 0.3 and those that comply with demand in excess of 130 kWh/m^2.

   Having grouped together all of the indirect demand cells that comply with the restrictions given, it determines the overall aggregate thermal demand of the grouping and if this is equal to or greater than 5,000 MWh it will be considered as a new grouping, or disregarded if it fails to satisfy this requirement. Figure 17 provides a graphic representation of the process used for the formation of systems.

Having analysed the first feasible grouping, taking the origin cell as the one with the largest thermal demand of the territory, the Tool will locate the second cell with the highest thermal demand and carry out the same procedure, taking into account that cells that already represent one grouping cannot form part of a new system. This procedure will be repeated with the remaining cells in descending order with regard to their thermal demand.

Figure 17: Identification of indirect demand areas.



3. ***Inclusion of direct demands:*** Having located the indirect demand areas, these will be grouped with the direct demands located within a distance of less than 5 km from the system. As it is possible that the same direct demand is located in a setting of several systems, priority will be given in accordance with the thermal demands of both the system as well as the direct consumer.

4. ***Formation of individual systems:*** Once all of the systems in the indirect demand area have been formed, individual systems formed by those consumption centres which, due to their distance with regard to the indirect demand areas, can only form systems by themselves will be carried out.

5. ***Analysis of thermal supply availability:*** Lastly, the energy sources available in the environment will be added to the system (see the section on residual heat and fuel). The analysis radius will be 5 km for all resources except residual biomass, which will be 50 km). As with section 3, its distribution will depend on a coefficient (k in this case) which takes into consideration the thermal demand of the system, the thermal supply and the distance between them.

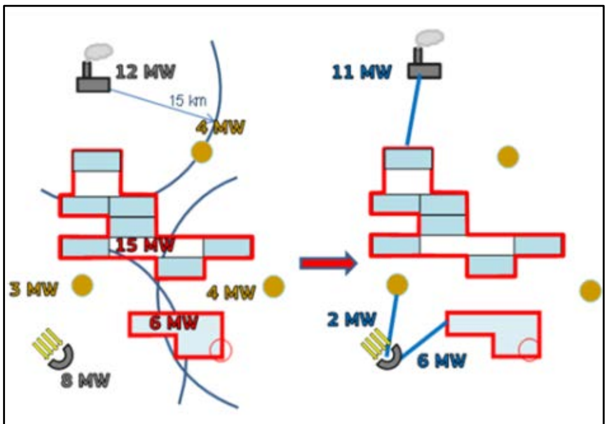
$$k = \frac{H_{resource}}{L \cdot \sqrt{\frac{H_{resource}}{H_{demand}}}}$$

Where:

- $H_{resource}$: Annual available thermal supply
- H_{demand}: Annual thermal demand.
- L: Distance between possible supply of heat and the point or area of thermal demand.

Figure 18 shows how the k factor is calculated for the study of systems based on direct and indirect demands and heat supply sources.

Figure 18: Analysis of thermal supply availability.



Calor residual suministrado	Possible heat consumer	Distance m	Coefficient k
12.000 MWh	15.000 MWh	8	1,677
	4.000 MWh	14,5	0,478
8.000 MWh	15.000 MWh	12,5	0,876
	6.000 MWh	7	0,990
	3.000 MWh	8,5	0,576
4.000 MWh	15.000 MWh	2	3,873
	6.000 MWh	7	0,653

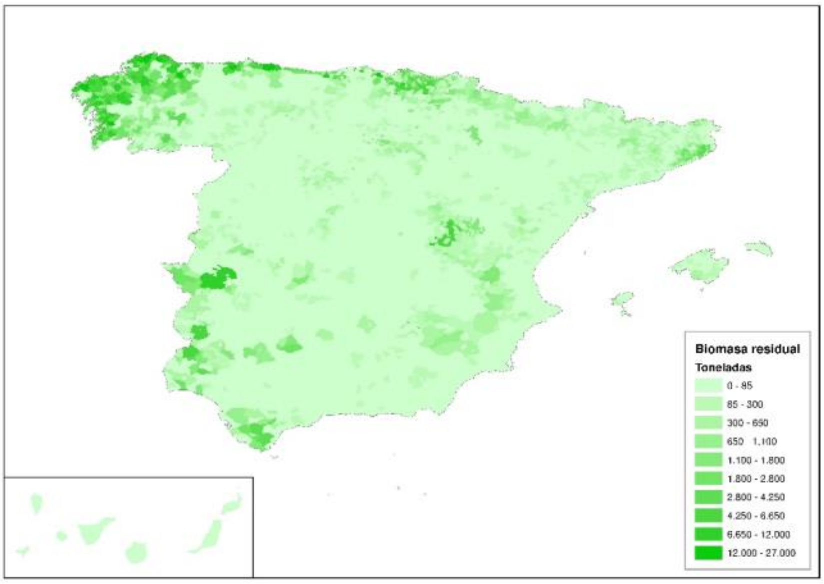
Sources: JRC Science and policy reports

The characterisation of resources available for the thermal supply of systems was carried out as follows:

a. **Residual fuels:** As explained previously, this study has considered residual fuels to be biomass generated as waste from industrial, agricultural and forestry processes, and biogas from WWTPs. Their geographic availability has been determined as follows:

a.1 **Biomass:** This is organic vegetable matter that originates as waste in industrial, agricultural and/or forestry processes. For these last two cases, we will consider the biomass resources analysed in the "2011-2020 Renewable Energies Plan", and processing the information to obtain geographical availability as shown in Figure 19.

Figure 19: Map of residual biomass availability.



For the case of biomass from industrial source, the sectors identified as the main producers are:

- *Wood and furniture sector:* A large amount of residual biomass is produced in the wood and furniture manufacture sector, in the form of wood cut-offs, sawdust, pallets, damaged pieces, etc. The average calorific power with moisture of around 35-40% is in the region of 2,600 kcal/kg.

- *Pulp and paper sector:* The paper industry heads the energy from waste recovery. These wastes come from stripping, shredding, filtering, etc. and includes remains of wood and bark, paper sludge and other organic waste. In general, they have quite a high moisture content, close to 55%, and their average calorific power is around 3,200 kcal/kg.

- *Olive oil sector:* The olive sector also represents a major contribution to the generation of residual biomass. Among the main by products is the olive cake which, despite its high moisture content, has considerable calorific power of around 4,100 kcal/kg on a dry base, and olive stones, which give an ideal fuel due to their reduced moisture content, high calorific power (around 4,440 kcal/kg) and low environmental impact.

- *Other sectors:* There are other industries in which residual fuels are generated and which are susceptible to use in energy recovery but which are not included in this study, either because these are minority industrial subsectors or because the quantity of recoverable waste generated is minimal or difficult to estimate.

Table 32 shows a summary of the factors taken into consideration in estimating the quantities and calorific powers of residual fuels based on the bibliography and on survey results. Only residual biomass for consumption at the centre that generates it will be considered.

Table 32. Residual biomass availability in industry.

Industrial sector	Waste/heat (t/MWh_t)	ICP (kcal/kg)
Wood and furniture	0.0629	2,600
Paper and pulp	0.1173	3,200
Olive oil	0.0746	4,200

a.2 **Biogas:** Residual fuel generated through anaerobic digestion of organic matter, the production of which is undertaken in digesters in which organic matter is deposited to ferment. The generation of biogas is common in several industrial sectors, in the agricultural sector, at wastewater treatment plants (EDARs), at landfill sites, etc. However, as the economic feasibility of using biogas in cogeneration is limited in industry and agriculture, and that the estimate of cumulative waste from landfills is complex, this study will only consider biogas produced at WWTPs.

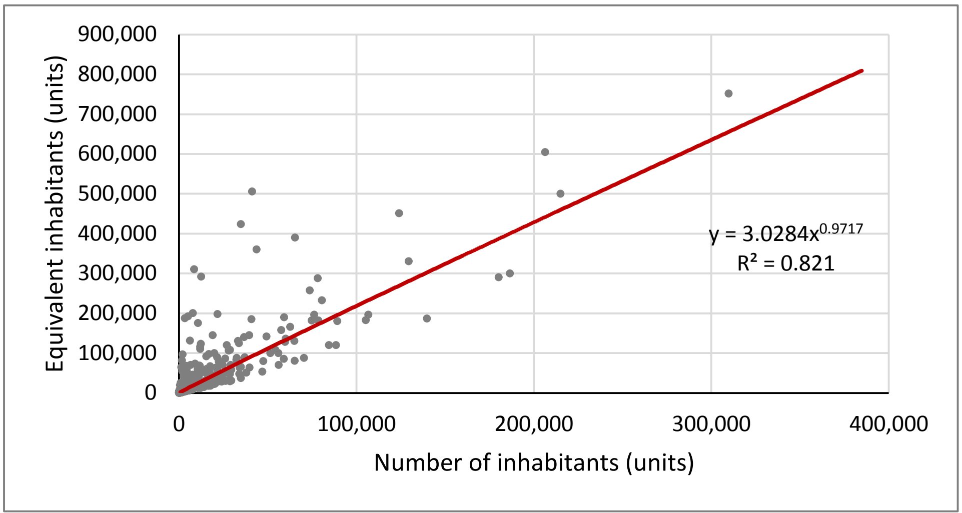
- To estimate the amount of biogas that can potentially be generated by each of the wastewater treatment plants, we have used the available records that include almost all of the existing WWTPs on national territory, for which we have estimated the inhabitants supplied, and for the amount of biogas that can potentially be generated we have considered the analysis carried out in the “Status and potential of biogas generation. 2011 – 2020 ERP technical study” and we have estimated the energy potential per inhabitant for each of Spain’s Autonomous Communities. **Table 33** shows the energy ratios per inhabitant and the overall energy potential.

Table 33. Biogas productions at WWTP by autonomous community.

Province	Biogas generated (KWh ICP/inhab)	Total energy potential (GWh)
Andalusia	20.1	169.8
Aragón	31.9	43.0
Asturias (Principality of)	3.3	3.5
Balearic Islands	100.4	111.6
Canary Islands	6.6	14.0
Cantabria	13.8	8.1
Castilla y Leon	30.2	70.9
Castilla la Mancha	42.1	88.4
Catalonia	53.7	405.8
Valencia (Community of)	87.5	447.7
Extremadura	14.7	16.3
Galicia	23.2	64.0
Madrid (Community of	61.4	398.8
Murcia (Community of)	2.4	3.5
Navarre (Regional Community of)	30.7	19.8
Basque Country	11.8	27.9
Rioja (La)	46.9	15.1
TOTAL	**41.2**	**1908.1**

Although there is no information on all of the WWTPs, we have estimated the number of inhabitants supplied by studying the municipalities in which there is just one WWTP to supply the entire population. In these cases, we draw up a ratio between the inhabitants of the municipality and the equivalent inhabitants of the WWTP which is shown in Figure 20.

Figure 20. Ratio between inhabitants and equivalent inhabitants.



For those cases in which this estimate is not available, we carry out an estimate of the population supplied taking into consideration the population of the municipality and the number of WWTPs that exist in the region. The results obtained are shown in Table 34.

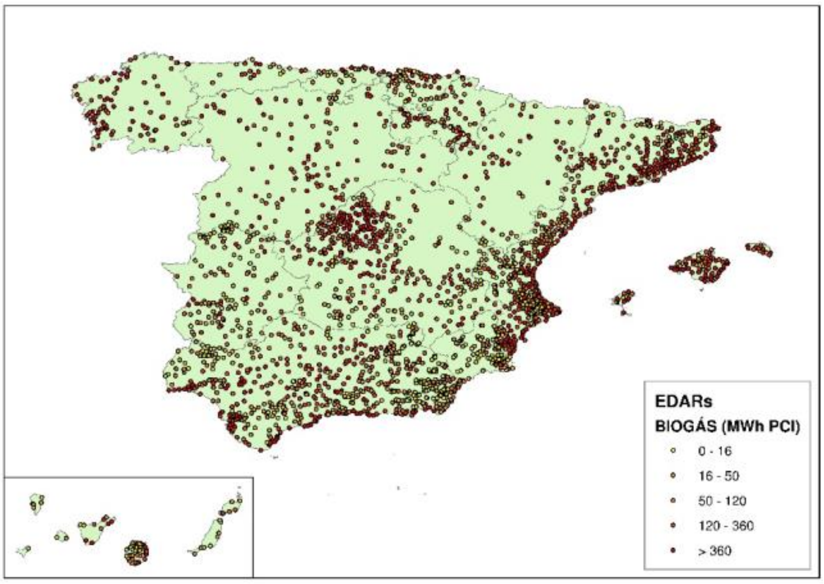
Table 34. Results obtained for the production of biogas at WWTPs.

Autonomous Community	Number of WWTPs	Sum of BIOGAS (MWh ICP)	Total inhabitants	Inhabitants supplied
Andalusia	711	153,331	8,401,567	90.7%
Aragón	57	38,916	1,326,937	91.8%
Principality of Asturias	27	3,237	1,049,754	94.4%
Balearic Islands	100	90,957	1,124,744	80.5%
Canary Islands	85%	11,545	2,128,647	82.4%
Cantabria	45	7,971	585,411	99.0%
Castilla la Mancha	248	59,051	2,062,714	94.7%
Castilla y Leon	133	89,747	2,478,376	86.1%
Catalonia	305	356,319	7,391,133	89.7%
Valencia (Community of)	441	387,342	4,939,550	89.6%
Extremadura	142	14,172	1,091,591	88.0%
Galicia	93	52,758	2,734,915	83.3%
Community of Madrid	106	380,801	6,377,364	97.2%
Region of Murcia	92	3,062	1,463,249	88.3%
Autonomous Community of Navarre	45	18,720	636,638	95.9%
Basque Country	70	21,553	2,164,311	84.2%
La Rioja	25	14,671	313,615	99.7%
General total	**2,725**	**1,704,153**	**46,270,516**	**90.1%**

If technically feasible, we consider that the generation of heat would be carried out at the WWTP itself, and therefore consider that, as in the case of residual heat, the maximum distance between consumer centres and the WWTP is 5 km.

Figure 21 shows the Wastewater Treatment Plants considered.

Figure 21: Map of Wastewater Treatment Plants.



b. ***Residual heat:*** This is either heat in the form of hot gases generated in an industrial process, or heat in the form of steam obtained in electricity generation processes. The technical feasibility of using this residual heat will be determined in accordance with the amount of heat available, its thermal quality and the heat transfer fluid conditions. Use of residual heat depends on a range of factors, including:

- ***Amount of heat:*** For a residual heat installation to be economically justifiable, the thermal demands must be high enough to be able to pay the fixed costs associated with these.
- ***Heat quality:*** One important factor to be considered is the quality of the residual heat, as there is likely to be a large amount of residual energy that cannot be used due to the thermal level at which heat demand is higher than available residual heat. The classification of residual heat in accordance with its quality, which will delimit the way in which it can be used, is as follows:

- *High:* High-quality residual heat will be considered as heat with temperature in excess of 650ºC. Its main advantage is the huge potential for use, such as, for example, to generate steam for industrial processes or electrical generation, preheating of kilns, preheating of combustion air, etc. The main disadvantage is that these temperatures increase corrosion and this requires materials that can stand high temperatures. High-quality residual heat includes steam from incinerators, coking furnaces or the melting of glass, etc. Availability will be highly unlikely, as it is unusual for the centres where this is produced not to use it in order to reduce their thermal level.

- *Medium:* Medium quality residual heat falls within the range of temperatures between 230 and 650ºC. This typology has less potential for use but, on the other hand, it is compatible with the materials employed in the heat exchangers and, on occasions, it is possible to use it for electricity generation. Some examples would include exhaust gases from gas turbines or boilers, or cement furnaces, and it could be used in virtually the same processes as for high thermal levels (generation of steam or electricity, preheating of combustion air, etc.).

- *Low: Its temperature is below 230ºC and it can mainly be used for air-conditioning and to produce hot water for sanitary use, although in a more restrictive way than in the previous cases. These include residual heats such as hot gases from ethylene boilers, condensed process steam, cooling water of motors and compressors, etc.*

· ***Conditions of the heat transfer fluid:*** The type of fluid that transports the residual heat is a determining factor when it comes to establishing the efficiency of its use, because the thermal conductivity is higher in liquids than gases. There are three kinds: hot gases, steam and hot water.

To identify on which occasions these conditions are satisfied we need to analyse the following sectors that could potentially generate residual heat.

b.1 Power stations and E**nergy recovery plants***: Thermal use at power stations and energy recovery plants is addressed as an extraction of steam in the turbine instead of reducing Electrical Performance (EP) and, therefore, a decrease of electricity produced. To discover the thermal power that a plant can give we have supposed that the EP of the installation should not fall below 20% and that the operating hours will correspond to the characteristics of the type of technology of the plant and, in this way, we have simulated several plants for each technology and power range[4]. Elsewhere, we have estimated the sales price of the heat by considering that it is the consumer that makes the initial investment and that the profit margin through the sale of heat is 10%.

b.2 ***Industries:*** Based on a sectoral analysis, we have drawn the conclusion that the industrial sectors that generate residual heat that can be used are the cement sector, the glass sector, the iron and steel production sector, the aluminium production sector and the metallurgy and smelting sector.

Cement production

A large amount of heat is consumed in the cement industry in rotary kilns for the calcination of lime and clay to obtain the Portland cement clinker. Depending on the moisture content of the raw materials, the process may be dry or wet (moisture content of around 30 and 40%), with the latter requiring more energy to evaporate the water it contains. The kiln working temperatures exceed 1,500ºC, while their exhaust gases are around 450ºC in cases in which there is no heat recovery. The most common method is for the preheating of raw materials, often through a range of usage stages at different temperatures that reduce the temperature of the exhaust gases to between 200 and 300ºC.

[4] *In the case of combined cycles, we have considered a single range of power due to the fact that the performance variations with regard to such powers are minimal.*

Glass production

The main energy consumption in the glass sector takes place in the kilns used in the melting and refining processes, where the exhaust gases reach temperatures of around 1 300ºC in the event of no heat recovery. The most common heat recovery systems are the regenerators and the recuperators for preheating of the combustion air, although at times it is also used for preheating the raw material to be introduced into the kiln.

Production of iron & steel

The main focal points of residual heat in the iron and steel production sector are the high-temperature kilns for production of sinter, coke, iron and steel. The following are the most important:

– *Coke kilns:* Heat losses take place in the form of coke oven gas, which can be used as a fuel once it has been previously treated, and as exhaust gases at around 200ºC.

– *Blast furnaces:* These are used for the production of pig iron made from iron mineral, coke and lime through a reduction process that takes place at temperatures of around 1,500ºC. Residual heats are found in the form of blast furnace gases that can be used as fuel, and in exhaust gases from Cowper stoves, used for preheating the air introduced into the blast furnace.

– *Basic oxygen furnaces:* Their objective is the refining of pig iron to obtain steel. The process is carried out through the injection of oxygen over the smelted pig iron so that this reacts with the carbon contained in the pig iron and thus performs decarbonation. Use of the energy contained in the exhaust gases is carried out through its combustion in a recovery boiler, or through cleansing, accumulation and use as fuel.

– *Electric arc furnaces:* These are used to produce recycled steel from the electrical fusion of scrap, which produces exhaust gases at temperatures of between 1,400 and 1,900ºC and which are normally used to improve efficiency of the process by preheating the scrap.

Aluminium production

The aluminium industry can be subdivided into the refining of bauxite to obtain primary aluminium and the recycling of aluminium scrap to produce secondary aluminium. The production of primary aluminium is carried out through electrolysis, reaching temperatures close to 1,000ºC and with thermal losses of around 45% on the tank walls, although currently there are no technologies that enable this heat to be used. Furthermore, the production of secondary aluminium requires the fusion of aluminium scrap in order to produce recycled aluminium without losing physical properties. The smelting process is carried out through fusion furnaces, and the most common ones are reverbatory furnaces, rotary furnaces and induction furnaces, where exhaust gases can reach temperatures of between 1,000 and 1,200ºC and account for energy losses of around 60% of the energy input. Although the use of this heat is technically feasible through recuperators and regenerators, it is only profitable in very specific cases, as the maintenance costs are usually fairly high due to problems of corrosion caused by the chlorides and fluorides in the exhaust gases, to the secondary combustion of volatiles in the recuperator and to overheating.

Metallurgy and smelting

The metallurgical sector requires a large amount of energy in the form of heat for the transformation of metal minerals into pure metal and for its subsequent treatment, moulding and processing. Most of this energy is consumed in smelting furnaces that work at high temperatures and involve major energy losses in the form of hot gases at temperatures close to 1,000ºC. The most common way of using this heat is through recuperators that use the exhaust gases to preheat the combustion air or to preheat the metal to be treated, although it may also be used in other ways, such as in air conditioning.

In short, Table 35 shows all of the residual heats identified in industry, their technical features, the percentage ratio between the potentially usable residual heat (H_{res}) and the overall thermal demand (H). It also shows whether there is economic feasibility and technical feasibility to use this heat outside the centre, mainly taking into consideration that part of the residual heat will be used in the industry itself (in general those of high quality).

Table 35: Characterisation of residual heat in industry.

Source	Average temperature	Quality	Carnot efficiency	H_{res}/H	Technical feasibility	Economic viability
Aluminium						
Primary aluminium						
Electrolytic cell	700ºC	High	69%	1.3%	No	No
Secondary aluminium						
Non-recovery	1150ºC	High	79%	51.8%	Yes	No
With recovery	538ºC	Medium	63%	22.9%	Yes	Yes
Steel						
Coke furnace						
Gas	980ºC	High	76%	18.3%	No	No
Exhaust gases	200ºC	Low	37%	6.3%	Yes	Yes
Blast furnace						
Blast furnace gas	430ºC	Medium	19%	0.2%	No	No
Blast furnace exhaust gases						
Non-recovery	250ºC	Medium	43%	12.6%	Yes	Yes
With recovery	130ºC	Low	26%	2.4%	Yes	Yes
Basic oxygen furnace	1700ºC	High	85%	46.3%	No	No
Electric arc furnace						
Non-recovery	1200ºC	High	80%	8.0%	Yes[5]	Yes[4]
With recovery	204ºC	Low	38%	0.6%	Yes[4]	Yes[4]
Glass fusion						
Regenerative	427ºC	Medium	57%	15.8%	Yes	Yes
Recuperative	982ºC	High	76%	42.5%	Yes	No
Oxyfuel	1420ºC	High	82%	26.9%	Yes[4]	Yes[4]
Electric furnaces	427ºC	Medium	57%	14.0%	Yes[4]	No
Direct smelting	1316ºC	High	81%	60.1%	Yes[4]	No
Cement						
Wet process	338ºC	Medium	51%	9.8%	Yes	Yes[4]
Dry process	449ºC	Medium	59%	15.2%		
Preheater	338ºC	Medium	51%	10.5%	Yes	Yes[4]
Precalciner	338ºC	Medium	51%	10.6%	Yes	Yes[4]
Metallurgy and smelting						
Aluminium						
Reverberating furnace	1150ºC	High	79%	52.0%	Yes[4]	Yes[4]
Stack melter	121ºC	Low	24%	4.4%	Yes	Yes[4]
Cupola furnace						
Non-recovery	900ºC	High	75%	31.0%	Yes[4]	Yes
With recovery	204ºC	Low	38%	3.9%	Yes[4]	Yes

[5] *Only in very specific cases.*

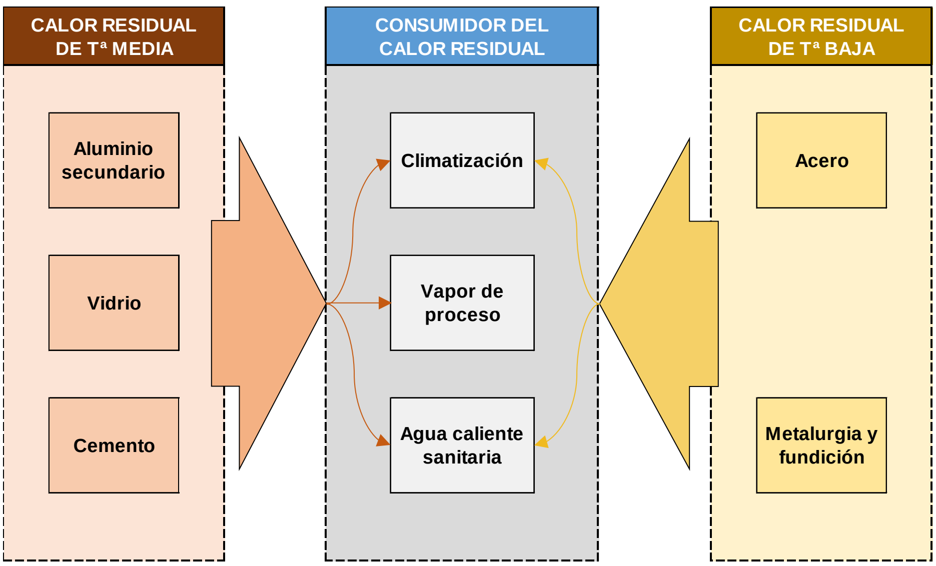
Table 36 shows the calculation values used for the ratio between the potentially usable residual heat (H_{res}) and overall thermal demand (H) taking into consideration that not all processes analysed in Table 35 consume heat in the same proportion, that some of these processes are exclusionary and that others are directly unfeasible, whether for technical or economic reasons. Furthermore, we have considered that high-quality heat is used at the factory itself, whether in full or in part.

Table 36: Calculation basis of residual heat in industry.

Industrial sector	Quality	$\frac{\text{Calor residual útil}}{\text{Demanda térmica}}$
Secondary aluminium	Medium	22.91%
Steel	Low	0.78%
Glass	Medium	6.84%
Cement	Medium	8.17%
Metallurgy and smelting	Low	1.26%

As expected, the residual heats could only be used to supply thermal demands of low temperatures, and there is consequently no need to establish a correlation between the residual heats available and the industrial processes that require them. As it is impossible to perform an individual analysis of each and every one of the industrial processes included in this study, we have defined this ratio in accordance with the main residual heats and processes of each sector, as set out in Figure 22.

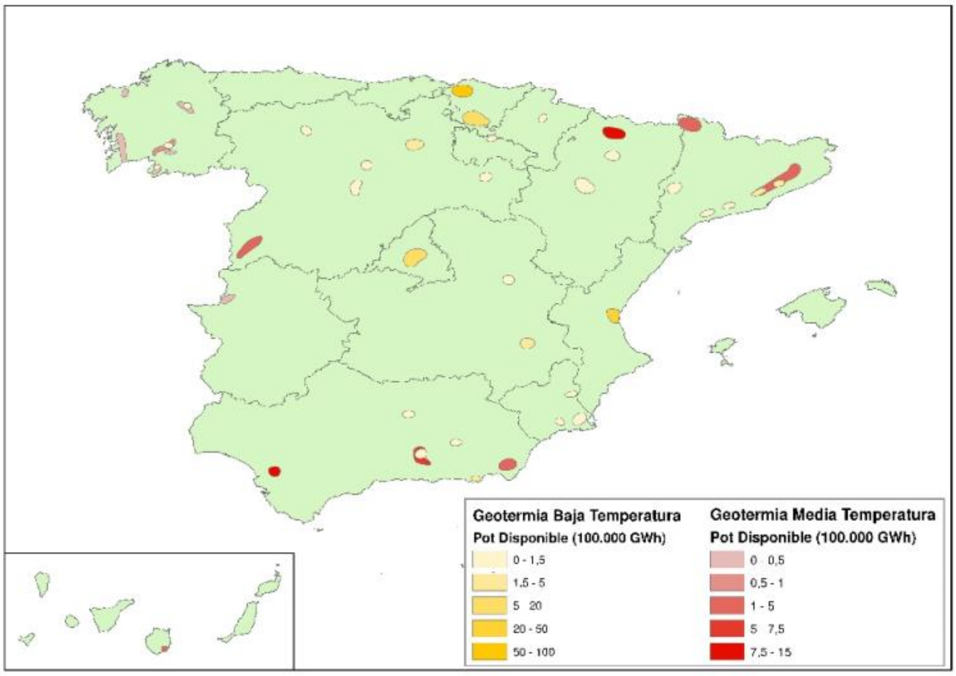
Figure 22: Ratio between industrial residual heat and consumer centres.



The maximum distance considered for the usage of residual heat is **5.0 Km**[6]**.**

c. ***Geothermal energy****:* We consider the direct use of the low-temperature beds for generation of hot water for sanitary purposes, the temperature of which is usually between 30 and 100ºC and at depths of between 1,500 and 2,500 metres; and medium temperature beds for the generation of steam and hot water, with temperatures of between 100 and 150ºC and at depths of between 1,500 and 4,000 metres. The information on geothermal resources has been obtained from the *"2011-2020 Renewable Energies Plan"* (Figure 23).

Figure 23: Distribution of the geothermal beds on national territory.



d. Thermal solar energy*:* Solar energy is an energy source that plays a very important role in energy targets, in particular in hot countries such as Spain. Its efficacy in district heating and cooling systems has been proven and demonstrated on numerous occasions in different projects in Sweden, Denmark, Germany and Austria, and it is usually combined with other technologies and energy sources such as geothermal, biomass, use of residual heat and cogeneration.

[6] *http://www.redciudadesclima.es/uploads/documentacion/b7e75a5a739b40b44fc98ecaad533842.pdf*

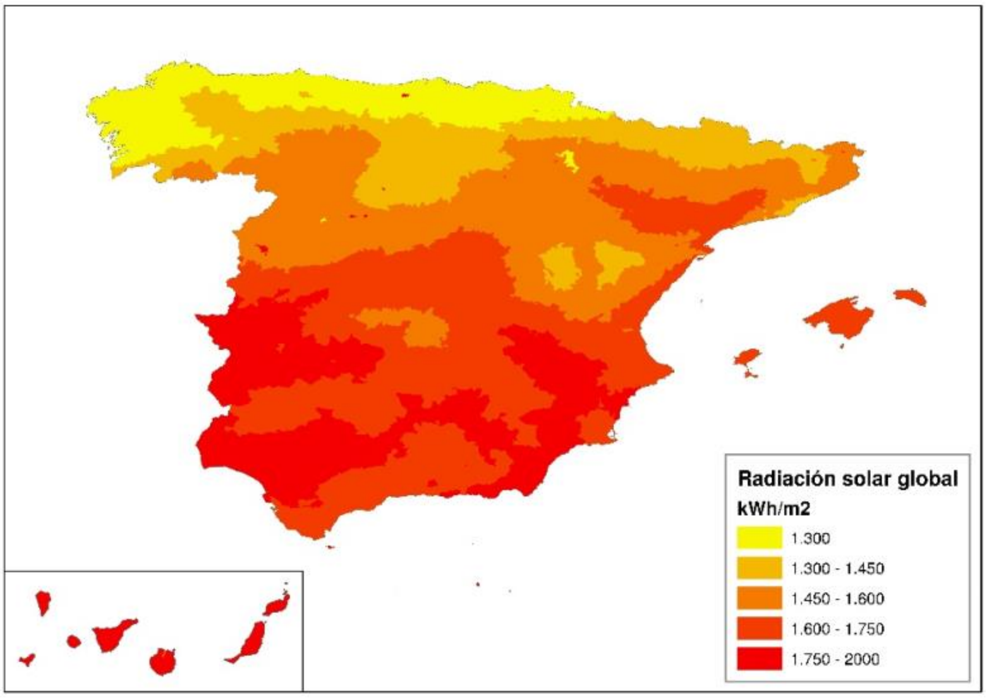
The main obstacle when it comes to building a solar farm is the availability of space on which to site the installation, and the most common way is to build these on the roofs of building or on isolated land specifically designed for its installation. The former option is feasible on very large buildings, especially if the orientation and slope of the roof have been designed for this purpose, while the latter is optimum on rural or isolated terrains where there are large amounts of land available at reasonable prices. In this study we have only considered the latter option, as it enables higher power levels to be installed, and we therefore consider the surface area available with a proportional value of 7.5% of the low building density surface area.

One important factor to bear in mind when it comes to knowing the energy availability of the plant is the global solar radiation of the region where the plant is to be installed, in other words the energy from the sun that reaches a certain surface area. In this study we have considered the values set out in the Building Technical Code for each of the five climatic zones included. These values are shown in Table 37, while their distribution on national territory is given in Figure 24.

Table 37. Solar radiation in accordance with solar climatic zone.

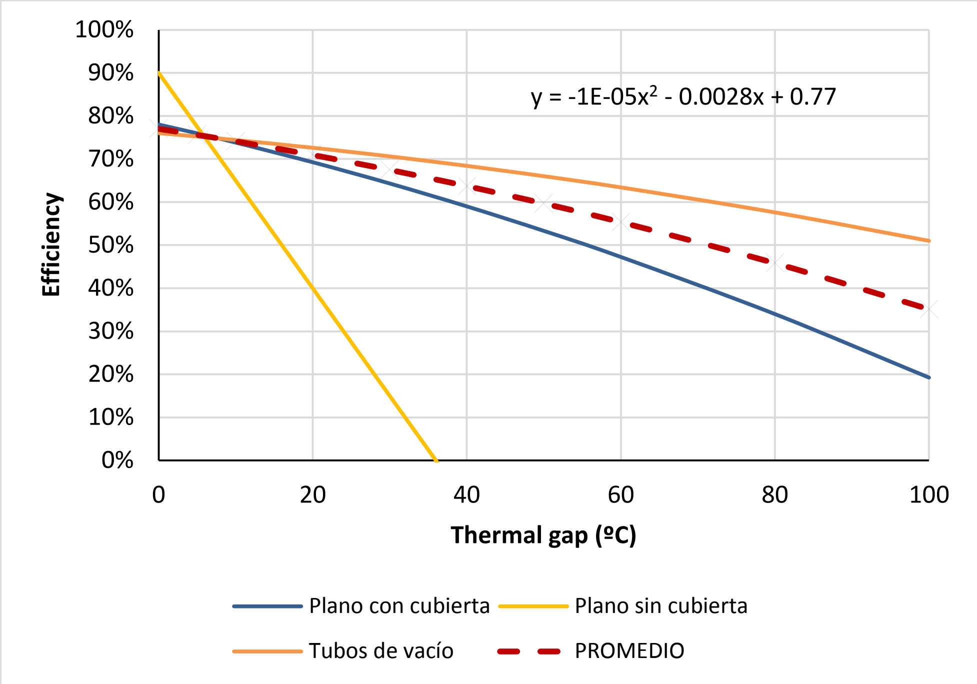
Solar zone	Global solar radiation (KWh/m²/day)	Value used (KWh/m²/year)
I	H < 3.8	1278
II	3.8 ≤ H < 4.2	1460
III	4.2 ≤ H < 4.6	1606
IV	4.6 ≤ H < 5.0	1752
V	H ≥ 5.0	1935

Figure 24. Distribution of solar climatic zones.



As expected, the efficiency of solar collectors varies in accordance with their orientation, angle, typology and thermal gap between the ambient temperature and the heat transfer fluid temperature. Because this study only addresses the possibility of the installation of fairly large solar farms, this presupposes optimum orientation and angling to maximise solar collection performance. As regards the performance of solar collectors, uncovered flat collectors will not be considered, and performance will be calculated in accordance with the thermal gap between the polynomial regression of average efficiencies for covered flat collectors and vacuum tube collectors for the thermal gap determined. Figure 25 shows this regression together with the standard performance values of different technologies.

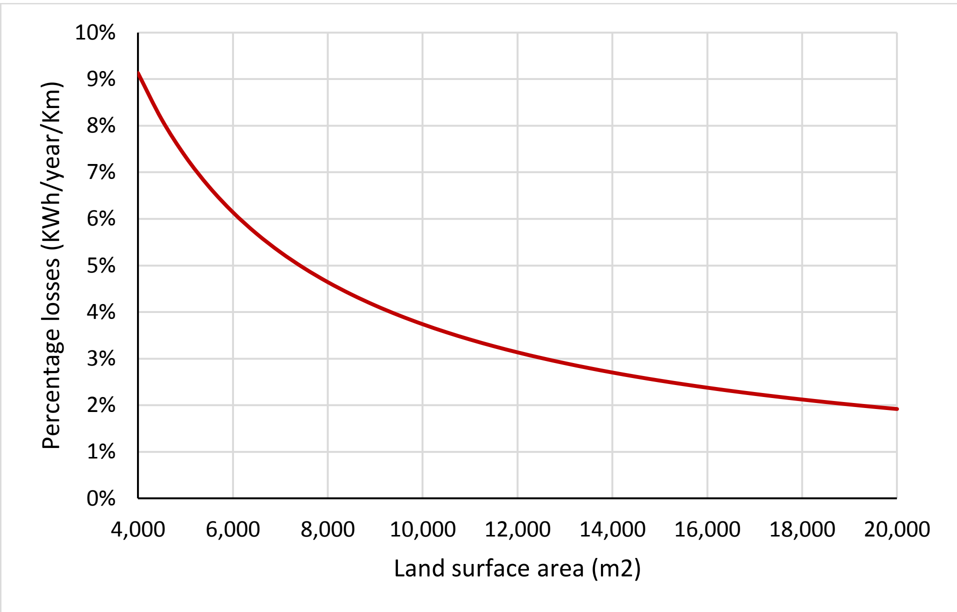
Figure 25. Variation of solar thermal energy efficiency.



Another major factor to bear in mind are the losses produced in the pipes during transport from the solar farm to the consumer centre.

Figure 26 shows the variation of energy losses with regard to the land surface area per kilometre of distance between the collector and the connection point with the distribution grid, considering the value of **3.5 m^2** of terrain per m^2 of collector.

Figure 26. Energy losses on thermal solar panels.



5.2.2 Characterisation of thermal demand and supply

Having identified the system components, we then proceed to calculate the thermal demand of the system and its chronological distribution, and the thermal supply:

- *Characterisation of the thermal demand of the system:* Characterising the non-point thermal demand will take into consideration the surface area of each use of land and apply the unit thermal demand ratio to this. In the case of point thermal demands, these will be calculated beforehand, and their inclusion in the system will therefore be direct.

  Furthermore, it will be necessary to define the thermal consumption method, which will be defined by the sector to which it belongs, and we will also take into consideration that it is possible that not all thermal demand can be supplied through efficient heating and/or cooling systems, such as the case of furnaces. Consequently, for each sector considered we will apply a *"Cogenerational coefficient"* that establishes what proportion of demand can be supplied through these methods. Table 38 shows the parameters used for each sector.

Table 38: Demand characterisation of the tertiary and industrial sectors for heating and cooling.

	HEAT DEMAND		COOLING DEMAND	
	Type	(%) Heat that can be cogenerated	Type	(%) Cooling that can be cogenerated
TERTIARY SECTOR	Hot water	100%	Climate	100%
INDUSTRIAL SECTOR				
Beverages	Steam	100%	Process	85%
Food	Steam	100%	Process	85%
Pharmaceutical	Steam	100%	Process	75%
Chemicals	Steam	100%	Process	75%
Paper	Steam	100%	n.c.	n.c.
Wood	Steam	100%	n.c.	n.c.
Textile	Steam	100%	n.c.	n.c.
Refining	Steam	100%	n.c.	n.c.
Ceramics	Hot gases	40%	n.c.	n.c.
Automotive sector	Steam	90%	n.c.	n.c.
Cement	n.c.	n.c.	n.c.	n.c.
Glass	n.c.	n.c.	n.c.	n.c.
Metallurgy	n.c.	n.c.	n.c.	n.c.
Steel industry	n.c.	n.c.	n.c.	n.c.

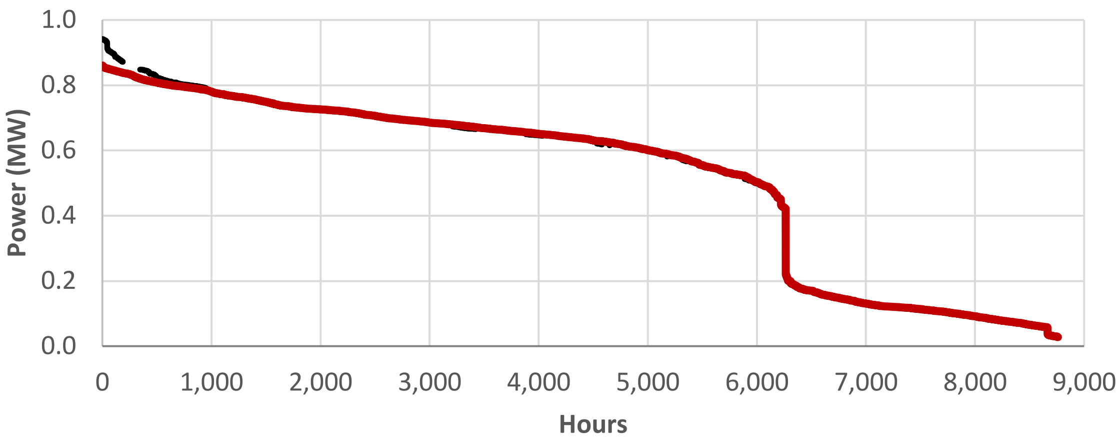
- Chronological distribution of demand: To define the thermal demand of the system we will group together all the consumer centres using a single demand curve (point and non-point) and then add up their thermal demands. With this process we will obtain as many demand curves as types of centres, which can be added together to obtain the hourly demand curve of the entire system. On using identical demand curves for each sector, we will obtain demand peaks that are higher than the actual peaks, and shall therefore apply a simultaneity coefficient to obtain a more realistic maximum demand.

This simultaneity coefficient is not applicable to overall thermal demand, as this would reduce it, and we therefore consider that hourly thermal demands that exceed the resulting peak consume at maximum power and the surplus will be distributed among the remaining hours in proportion to hourly demand.

Once we know the chronological demand curves of the system for each use of land we obtain the global chronological curve by adding these together, which in turn will enable us to size the system.

Figure 27 shows the variation of the demand curve in the case of a set of industries.

Figure 27: Variation of demand peak on the grounds of simultaneity.



- *Characterisation of thermal supply:* Although we have previously identified the availability of thermal resources, it is not always possible to make use of all of these resources through a lack of capacity or because it is not technically feasible. Consequently, the maximum resources are limited in accordance with the different types of resources. The limitations considered for each resource are as follows:

  - **Residual fuels**: For the limitation of biomass and biogas resources we consider that for these resources to be feasible at least the base of the demand curve must be supplied and must not exceed 85% of demand to avoid oversizing of plants.

    Residual heat: Residual heat may only be used during a certain number of hours a year that tally with the operating hours of the plant or industry. To estimate the residual heat that can be potentially used we have considered that the thermal usage is carried out at maximum power during the characteristic operating time of each installation, and never exceeding the hourly demands of the consumer centre.

  - **Renewable energies**: In the case of renewable energies, their usage depends on the availability of the resource and the technical feasibility of this. There are certain particularities for each one of the resources:

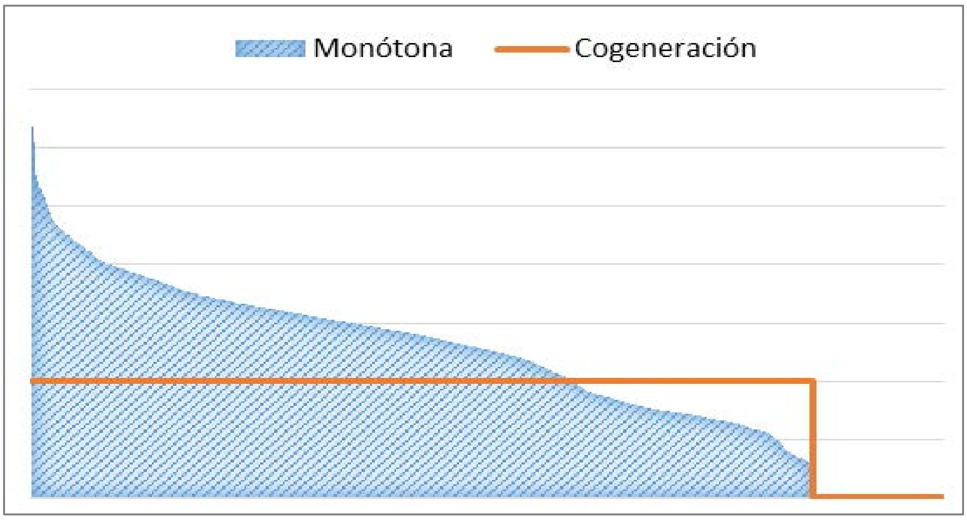
    ***Geothermal energy**:* With this kind of use, we have estimated maximum thermal power for each of the thermal beds considered in the "2011-2020 Renewable Energies Plan", considering their usage over 50 years and restricting the maximum power in some in accordance with the type of bed to avoid unrealistic thermal capacities that are difficult to achieve.

    ***Thermal solar energy**:* In the case of thermal solar energy, the power of the installation is limited to supplying hot water for sanitary purposes, as this allows us to make use of the renewable *source* throughout the year and with stability as regards power consumed that would not occur in the case of sizing it for heating.

  - **Cogeneration**: In the case of cogeneration, we have carried out plant sizing that enables usage of the plant that complies with the minimum thermal supply set out in the European Directive. To this end we consider that cogeneration must at least provide 75% of thermal demand and from among all the technical alternatives calculated we consider that the optimum will be the one provided by a higher Primary Energy Saving that complies with the minimum values of the PPES.

Figure 28 shows a graphic representation of the sizing method used.

Figure 28: Thermal sizing of cogeneration plant.



To analyse the economic viability of developing the technical potential of each resource we need to trace technological solutions that make use of this and which are supplemented with other kinds of technology where necessary. To this end we have put forward a series of supply alternatives based on the resource, and which are as follows:

Centralised alternatives

This study has attempted to prioritise the search for centralised solutions that enable optimisation of system performance and to obtain greater savings of primary energy. We put forward centralised solutions for each resource analysed, which can be grouped together as follows:

– **Use of residual heat**: The usage of residual heat is carried out through a heat recovery boiler from exhaust gases generated in an industrial process. Consequently, the main equipment required to introduce the alternative, including conventional systems where necessary, are as follows:
  - *Recovery boiler.*
  - *Absorption machine (in the event of cooling supply).*
  - *Compression machine (in the event of cooling supply).*
  - *District supply system.*

- **Heat recovery at electricity power plants**: In the case of combined cycles, conventional power stations and waste recovery plants, heat recovery is carried out through steam extraction in the turbine and by recovering this heat through a steam-steam or steam-water exchanger depending on the type of heat required. The main equipment required is:
  - *Heat exchanger.*
  - *Absorption machine (in the event of cooling supply)*
  - *District supply system.*

- **Use of residual fuels**: This case would correspond to use of residual biomass, whether forestry, agricultural or industrial, and to the use of biogas from wastewater treatment plants. In this case the heat is generated using specific boilers that enable the combustion of these types of fuels. The main equipment used is:
  - *Biomass/biogas boiler.*
  - *Absorption machine (in the event of cooling supply).*
  - *District supply system.*

- **Use of geothermal resources:** The use of energy resources is addressed as the direct use of heat in low or medium temperature beds. The installation of this requires the following equipment and facilities:
  - *Extraction and injection wells.*
  - *Heat exchanger.*
  - *Absorption machine (in the event of cooling supply).*
  - *District supply system.*

- **Installation of the thermal solar farm**: The production of heat from solar energy is considered through the construction of a thermal solar farm. The sizing of this kind of farm has been considered to ensure that its operation is efficient for the greatest number of hours possible, and we have therefore restricted its power to that of producing hot water for sanitary purposes. The main equipment and facilities considered are:
  - *Field of solar collectors.*
  - *District supply system.*

- **Installation of a cogeneration plant**: The last case considered is that of building a cogeneration plant that supplies part of the thermal energy demanded. This has been sized to ensure that the thermal supply is at least 75% of the target, to adapt to the parameters required by the European Directive for efficient district heating and cooling systems. The main equipment considered is:
  - *Cogeneration plant.*
  - *Conventional boilers.*
  - *Absorption machine (in the event of cooling supply).*
  - *District supply system.*

Isolated alternatives

Isolated alternatives are, essentially, virtually identical to the centralised alternatives except that they only supply one consumer centre. For this reason, we consider that these centres already possess the equipment necessary to supply their thermal demands and will only require the installation of the equipment and systems to make use of the resources analysed. Below we set out the equipment and installations required in each of the cases considered:

- **Use of residual heat:**
  - Recovery boiler.
  - Absorption machine (in the event of cooling supply).

- **Heat recovery at electricity power plants:**
  - Heat exchanger.
  - Absorption machine (in the event of cooling supply).

- **Use of residual fuels:**
  - *Biomass/biogas boiler.*
  - *Absorption machine (in the event of cooling supply).*

- **Use of geothermal resources:**
  - *Extraction and injection wells.*
  - *Heat exchanger.*
  - *Absorption machine (in the event of cooling supply).*

- **Installation of a cogeneration plant:**
  - *Cogeneration plant.*
  - *Absorption machine (in the event of cooling supply).*

5.2.3 Information outputs of the tool

As a result of calculating the technical potential of the solutions within a system, the tool will allow the user to view the features of each system, including the location (province, municipality and polar coordinates), the constructed floor area of the building or buildings supplied, the thermal heat demand, sanitary hot water and cooling broken down by use of land, and the supply potential of this demand through each of the resources referred to in the previous section.

Table 39 and Table 40 show the structure of the outputs for two of the systems made by the Tool; the former is a system of residential and tertiary sectors, while the latter is a system of the industrial sector.

Table 39: Presentation of the technical findings of the tool for a system of the residential and tertiary sectors

System	Sector	Subsector-Use	Type of demand	Demand (GWh)	Residual heat industry		Residual heat power stations		…
					Technical Solution Potential 1 (GWh)	Technical Solution Potential 2 (GWh)	Technical Solution Potential 3 (GWh)	Technical Solution Potential 4 (GWh)	…
System 1	Residential	**Block dwellings**	Heating						…
			Hot water						…
			Cooling						…
		One dwelling buildings	Heating						…
			Hot water						…
			Cooling						…
	Tertiary	**Offices**	Heating						…
			Hot water						…
			Cooling						…
		General trade	Heating						…
			Hot water						…
			Cooling						…
		Markets or supermarkets	Heating						…
			Hot water						…
			Cooling						…
		Indoor sports	Heating						…
			Hot water						…
			Cooling						…
		…	Heating						…
			Hot water						…
			Cooling						…
		Airports	Heating						…
			Hot water						…
			Cooling						…
Total values of demand and technical potential			**Heating**						…
			Hot water						…
			Cooling						…

Table 40: Presentation of the technical findings of the tool for a system of the industrial sector

System	Sector	Subsector-Use	Type of demand	Demand (GWh)	Residual heat industry		Residual heat power stations		…
					Technical Solution Potential 1 (GWh)	Technical Solution Potential 2 (GWh)	Technical Solution Potential 3 (GWh)	Technical Solution Potential 4 (GWh)	…
System 2	Industrial	Farming industry	Heating						…
			Cooling						…
		Food industry	Heating						…
			Cooling						…
		Agricultural industry	Heating						…
			Cooling						…
		Drinks industry	Heating						…
			Cooling						…
		Earthenware industry	Heating						…
			Cooling						…
		Construction industry	Heating						…
			Cooling						…
		…	Heating						…
			Cooling						…
		Glass industry	Heating						…
			Cooling						…
Total values of demand and technical potential			**Heating**						…
			Cooling						…

5.2.4 Thermal sizing of cogeneration plants

This method of thermal supply will in turn consider a range of sub-alternatives that will be analysed in accordance with the thermal power required and the heat transfer fluid required (Table 41).

Table 41: Alternatives considered in accordance with the heat transfer fluid.

	Type of useful heat demanded			
Type of cycle	Hot water	Water vapour	Hot gases	Cooling
Single Cycle GT				
Single Cycle GM				
Single Cycle Back-pressure ST				
Combined Cycle Back-pressure ST				

GT : ST Gas turbine: GM Steam turbine: Gas motor

The thermal sizing of cogeneration solutions is defined on the basis of their thermal demands so that the tool subsequently determines the electrical sizing of the plant based on this.

Regressions have therefore been prepared between the electrical power of each cycle type and the thermal power supplied (bearing in mind the type of thermal energy demanded). In this way, once we are aware of the thermal power to be supplied by the plant, the type of useful heat demanded and the cycle type, it is possible to estimate the electricity power that the cogeneration plant requires and its characteristic electrical performance. Below we show the regressions obtained for each cycle time:

Single Cycle Gas Turbine

Figure 29: Calculation regression of electricity power in SCGT.

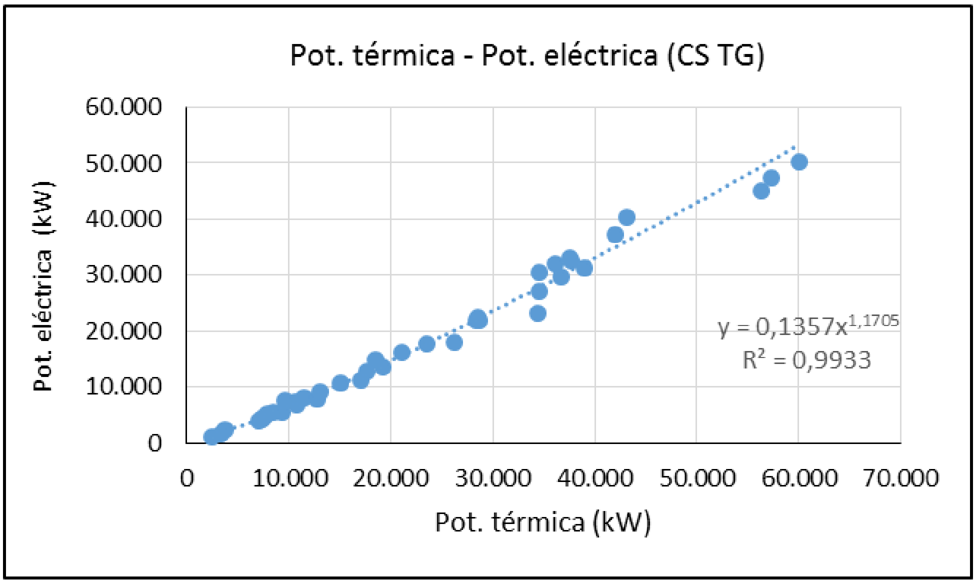
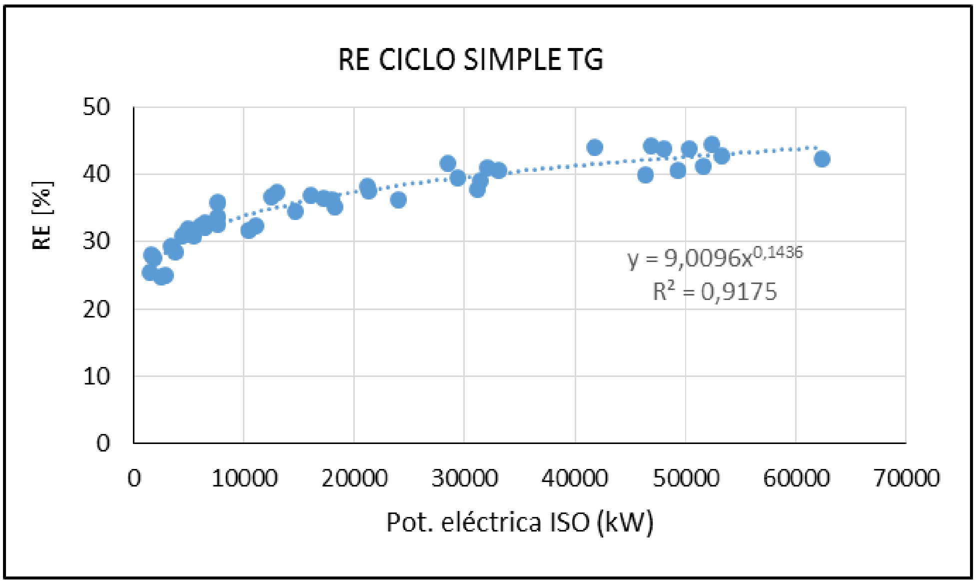


Figure 30: Calculation regression of the electrical performance in SCGT.



Single Cycle Gas Motor

Figure 31: Calculation regression of electricity power in SCGM.

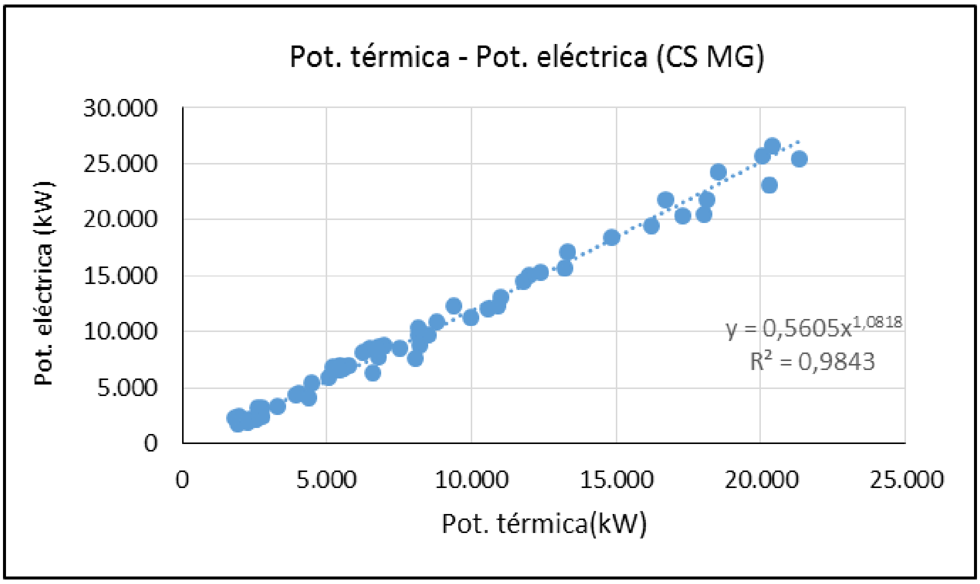
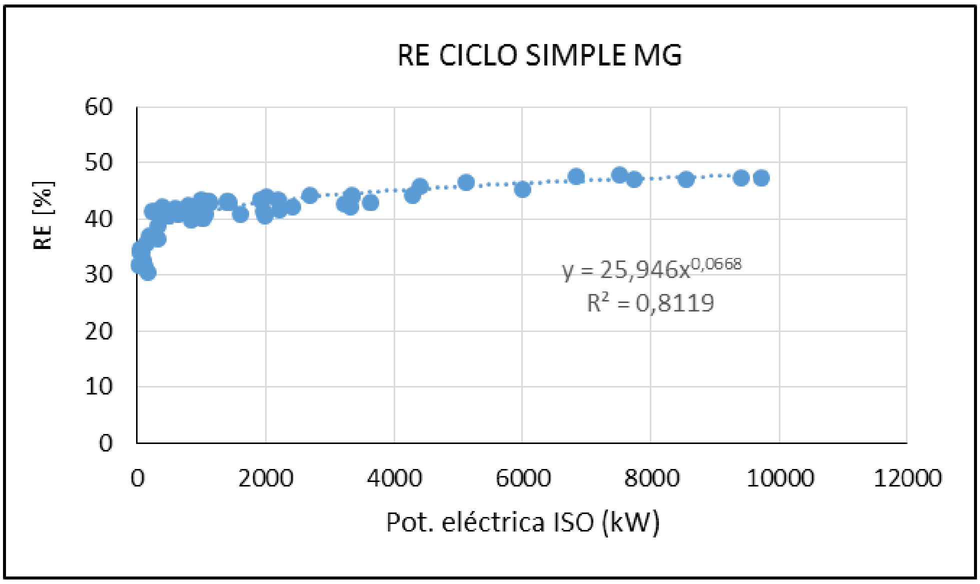


Figure 32: Calculation regression of the electrical performance in SCGM.



Combined Cycle Back-pressure Gas Turbine.

Figure 33: Calculation regression of electricity power in CCBT.

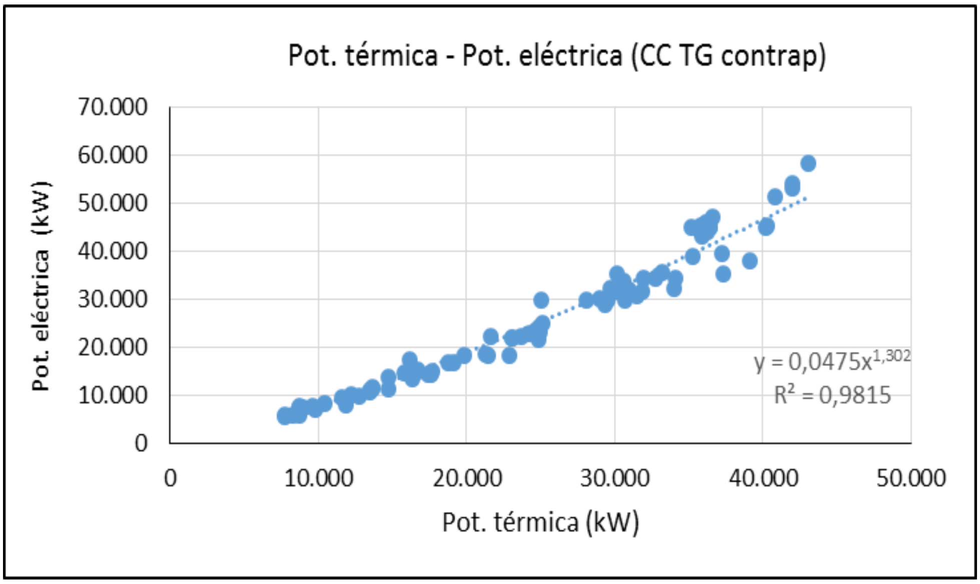
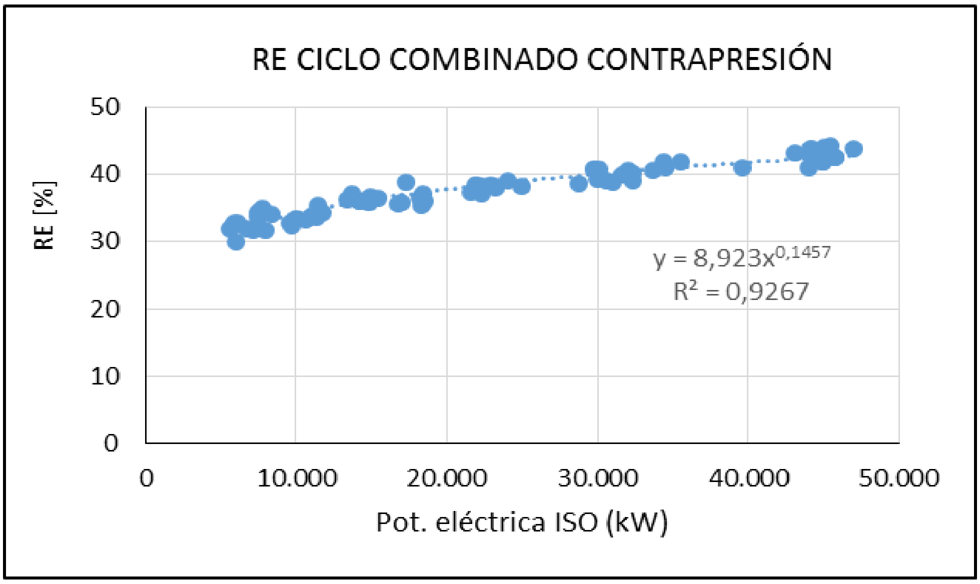


Figure 34: Calculation regression of the electrical performance in CCBT.



Single Cycle Steam Turbine

Figure 35: Calculation regression of the electricity power in SCST.

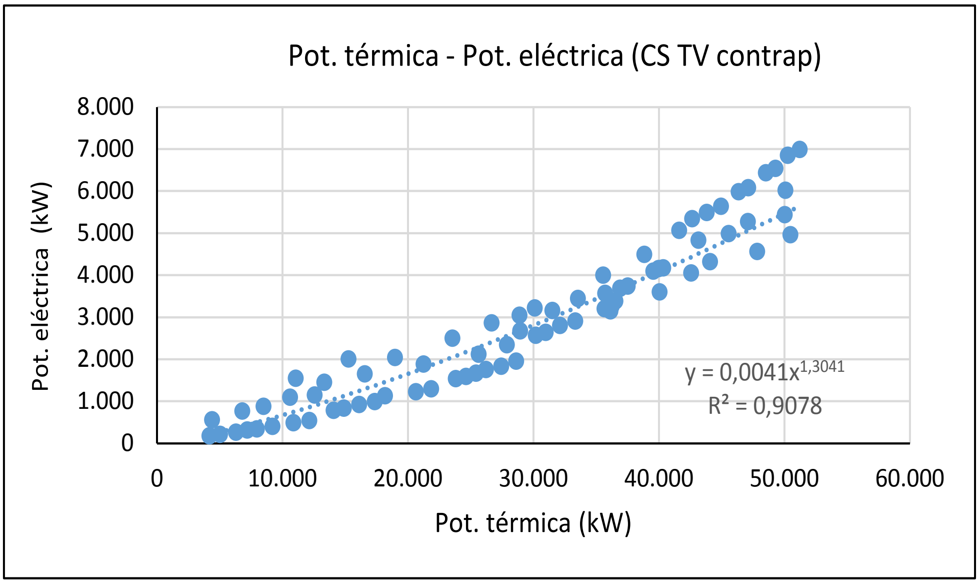
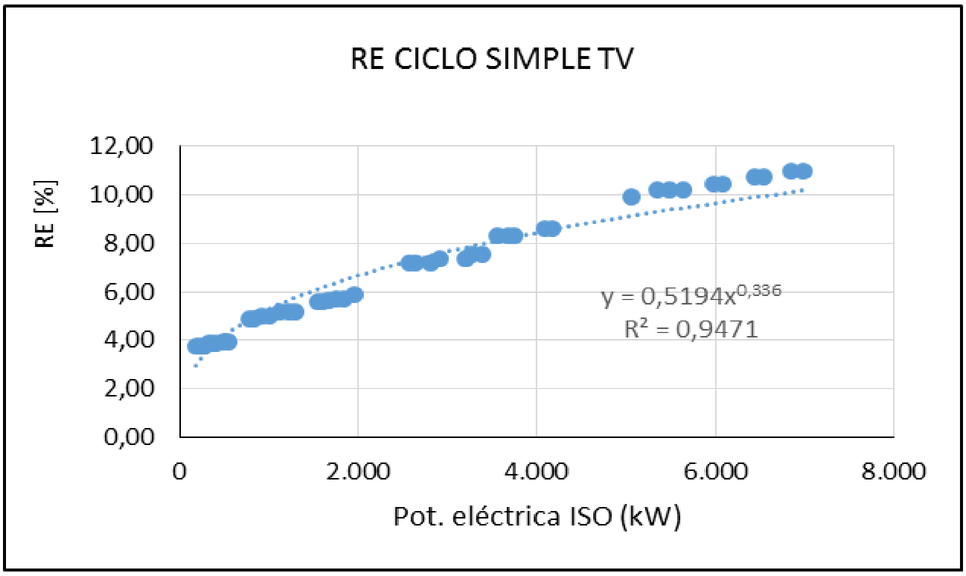
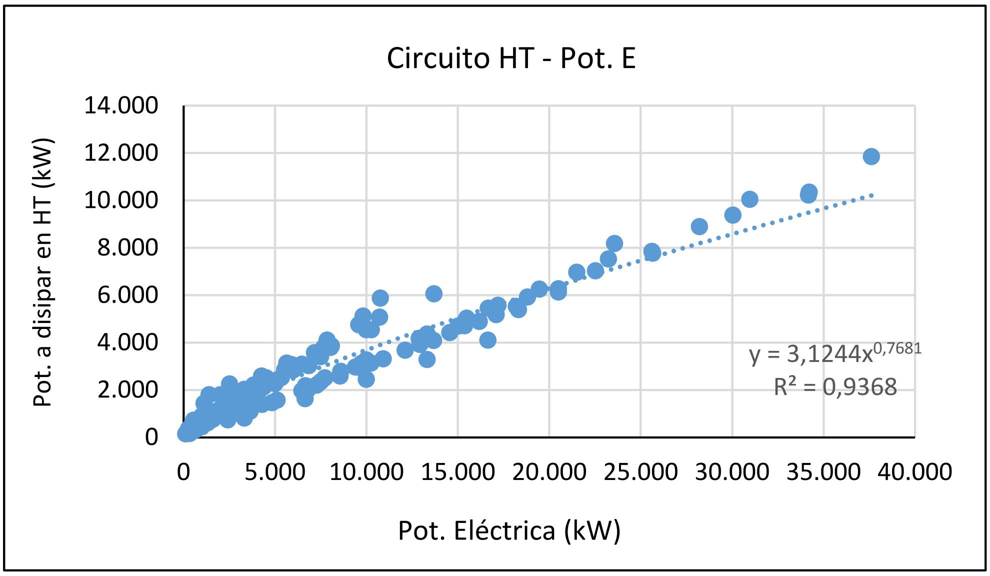


Figure 36: Calculation regression of the electrical performance in SCST.



In the alternatives in which cooling energy is to be supplied as secondary energy with a Single Cycle Gas Motor it will be necessary to determine the thermal power to be dissipated in the motor generator for the purpose of knowing the cooling power it is feasible to supply. To determine this power we will use the regression obtained using the analysis of the data corresponding to different manufacturers' brands and models. The list obtained is shown below.

Figure 37: Calculation regression of the dissipating heat in motor generators.



Lastly, to determine the different performances for each of the alternatives (EEE and OE) and to determine the PES (Primary Energy Saving) and the PPES (Percentage Primary Energy Saving), the Tool will incorporate the reference values Ref E and Ref H for separate production of electricity and heat.

Below we set out the characteristics of the sub-alternatives analysed in each of the supply options:

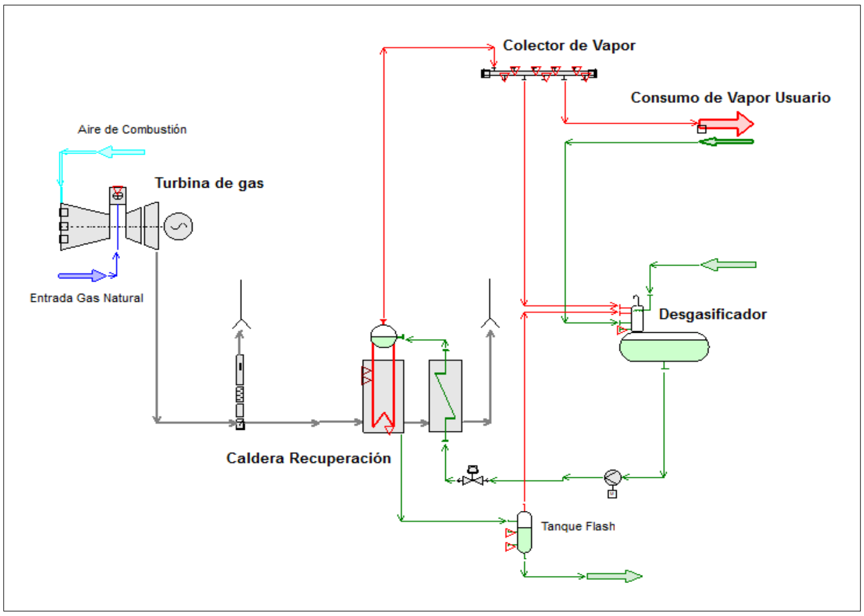
- **Option 1: Supply of heat only**

The first option analyses the different kinds of technologies that enable only the heat demands of the system to be supplied, while the cooling demands are supplied in full using compression machines. The alternatives are as follows:

Alternative 1: Single cycle gas turbine

One example of this kind of solution is the one shown in the diagram represented in the [text missing] and will be subject to analysis in cases in which the electricity power that needs to be installed is higher than 5 MWe and for any type of heat transfer fluid. Moreover, we will study the possibility of introducing post-combustion burners to optimise the performance of the installation.

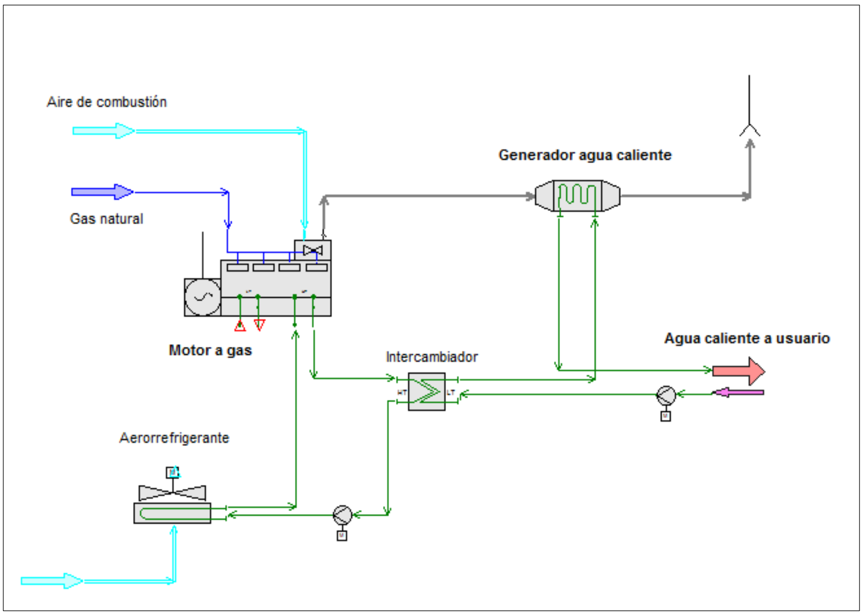
Figure 38: Diagram of a single cycle gas turbine to supply steam.



Alternative 2: Single cycle gas motor

One example of the installation of a single cycle gas motor can be seen in the diagram of [text missing] and will be analysed for any kind of heat transfer fluid and using generators that have individual electricity power of at least 15 MWe.

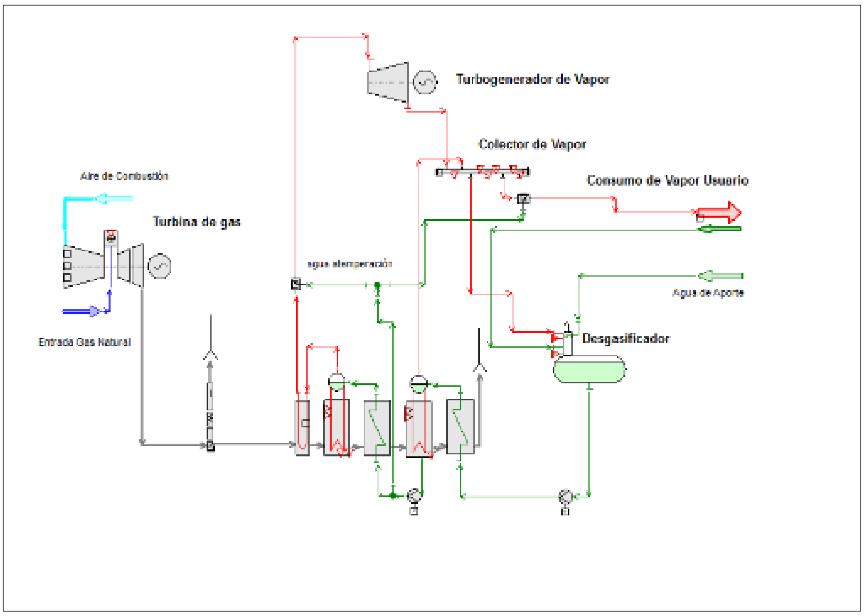
Figure 39: Diagram of single cycle gas motor



Alternative 3: Combined cycle back-pressure gas turbine

This kind of its alternative is shown in the diagram of [text missing] and will be considered for use in cases in which heat is demanded in the form of steam and when the electricity power exceeds 10 MWe.

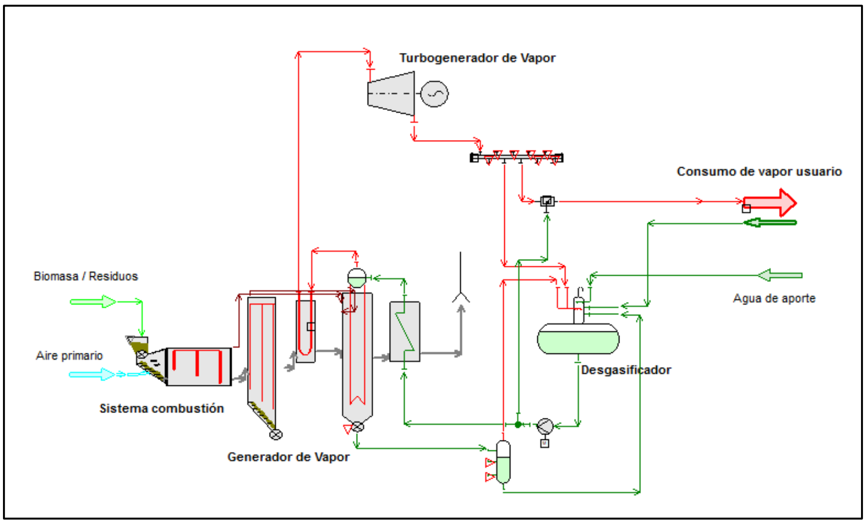
Figure 40: Combined cycle back-pressure gas turbine



Alternative 4: Single cycle with steam turbine

This will be analysed in cases in which there is a demand for steam and the electricity power of the installation exceeds 10 MWe. Figure 41 shows the diagram of the alternative.

Figure 41: Single cycle with steam turbine.



Alternative 5: Single cycle with micro gas turbine

This alternative has the same characteristics and calculation basis as *Alternative 1*, except that the electricity power is never higher than 1 MWe and, as well as natural gas, it considers making use of residual fuels. Figure 38 shows the diagram of the alternative.

Alternative 6: Single cycle gas motor with power of less than 1 MW

This alternative has the same characteristics and calculation basis as Alternative 2, except that the electricity power is never higher than 1 MWe and that, as well as natural gas, we will analyse using residual biogas. Figure 39 shows the diagram of the alternative.

- **Option 2: Supply of heating and cooling**

This option sizes the plant to cover heat demands and also to generate cold using absorption machines. The sub-alternatives put forward are identical to those of option 1, except that the demand curve used for the sizing is the one resulting from adding the heat demand curve and the heat required to produce cold using single- or twin-effect absorption systems in accordance with the type of heat demand.

The performances of the cooling machines are taken into consideration based on the heat transfer fluid, considering that twin-effect absorption machines will be used when the demand is for steam, whose COP is 1.15, and single-effect absorption machines will be used when the demand is for hot water, as these use a COP of 0.70.

- **Option 3: Supply of heating and cooling as a byproduct**

This considers the thermal sizing of the plant solely for the supply of heat, and part (or all) of the cooling demand will be supplied through the excess heat available. This kind of alternative only advises cogeneration cycles based on gas motors, where the hot water of the refrigeration circuit of the sleeving is used to generate cold through single-effect absorption machines.

For each of these sub-alternatives, we will obtain the main parameters that characterise them from an energy standpoint, using the technical bases shown below as the reference:

- *Equivalent Electricity Efficiency (EEE)*

Equivalent electricity efficiency will be determined using the following formula:

$$EEE = \frac{E}{F - \frac{H}{Ref\ H}}$$

Where:

- *E: Electricity generated and measured on busbars.*
- *F: Consumption of fuel both from cogeneration as well as any post-combustion devices that exist.*
- *H:* Production of useful heat or useful thermal energy.
- *Ref H:* Reference value of performance for separate heat production.

- *Primary Energy Saving (PES)*

The primary energy saving is defined using the following equation:

$$PES = \frac{E}{Ref\ E\eta} + \frac{H}{Ref\ H\eta} - F$$

Where:

- *E: Electricity generated and measured on busbars.*
- *F: Consumption of fuel both from cogeneration as well as any post-combustion devices that exist.*
- *H:* Production of useful heat or useful thermal energy.
- *Ref Hη: Efficiency reference value for separate heat production.*
- *Ref Eη: Efficiency reference value for separate electricity production.*

- *Percentage Primary Energy Saving (PPES)*

The primary energy saving is defined using the following equation:

$$PES = 1 - \frac{1}{\frac{CHP\ H\eta}{Ref\ H\eta} + \frac{CHP\ E\eta}{Ref\ E\eta}}$$

Where:

- *PES: Energy-saving as an integer.*
- *CHP Hη: Heat efficiency of the cogeneration production defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.*
- *Ref Hη: Efficiency reference value for separate heat production.*

- *CHP Eη: The electrical efficiency of the cogeneration production defined as annual electricity from* cogeneration divide*d by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.*

- *Overall efficiency (OE):*

  The overall efficiency will be determined using the following formula:

$$OE = \frac{E + H}{F}$$

  Where:

  - *E: Electricity generated and measured on busbars.*
  - *F: Consumption of fuel both from cogeneration as well as any post-combustion devices that exist.*
  - *H:* Production of useful heat or useful thermal energy.

- *Electricity Efficiency (EE)*

  The electricity efficiency will be determined using the following formula:

$$EE = \frac{E}{F}$$

  Where:

  - *E: Electricity generated and measured on busbars.*
  - *F: Consumption of fuel both from cogeneration as well as any post-combustion devices that exist.*

6. PRESENTATION OF TECHNICAL POTENTIAL RESULTS

The process for identifying systems has located a total of **3,565** systems whose thermal demand would total **135.7 TWh** of heat, and **24.6 TWh** of cold with 6% of this energy demand corresponding to the residential sector, 38% to the tertiary sector and 56% to the industrial sector. Figure 42 and Figure 43 show the distribution of these systems on Spanish territory.

Due to the absence of statistical data on heat demand, we have assumed, as remarked upon in previous chapters, certain assumptions in order to calculate this. Consequently, the findings obtained in the characterisation of the demand should be considered as an initial approximation to the disaggregated knowledge of demand for heating and cooling in the different sections nationwide. Furthermore, given that demand for thermal energy represents the starting point for the entire subsequent analysis of the technical and economic potential of efficient heating and cooling systems, the final results should likewise be considered as an initial approximation.

Notwithstanding the foregoing, it is important to stress that the efforts made in the characterisation, completed with subsequent studies focused on specific areas of national territory, will enable us to have greater knowledge than we currently do about the real potential available in efficient heating and cooling systems.

Below we set out the disaggregated results of the technical potential for it each of the energy solutions studied.

Figure 42: Distribution of heat demand of the systems

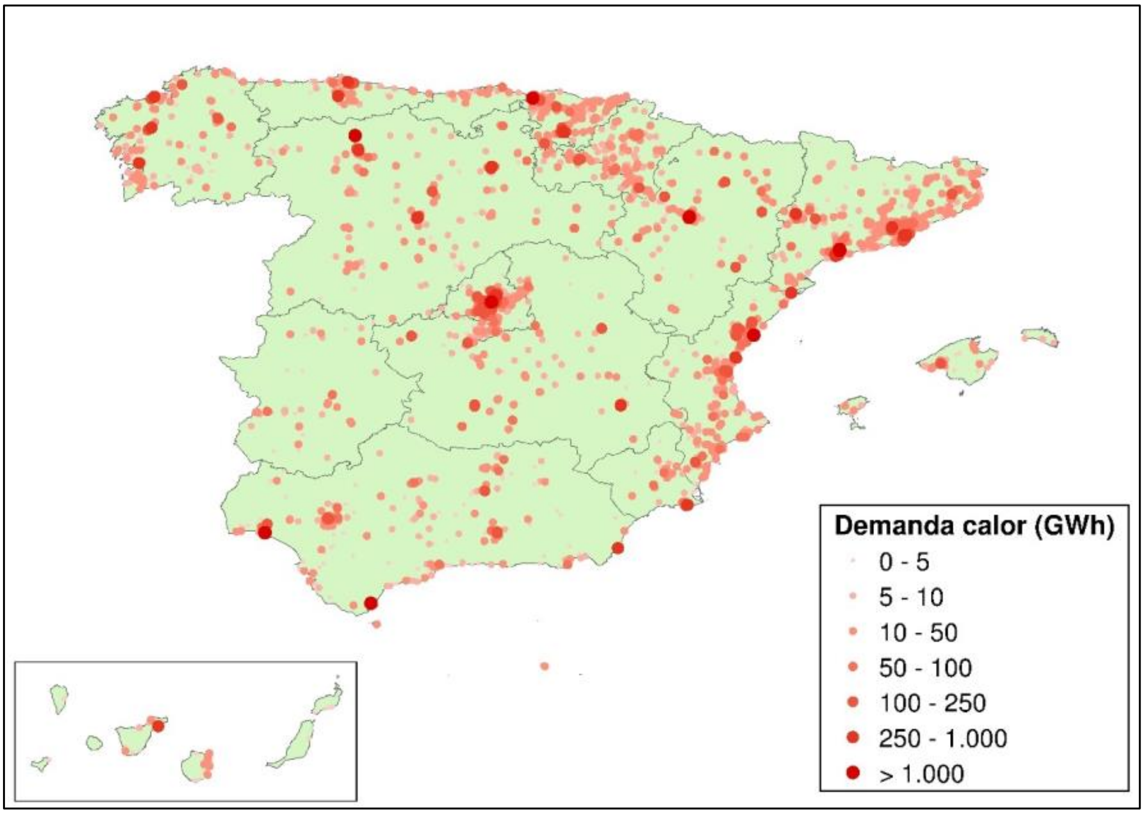
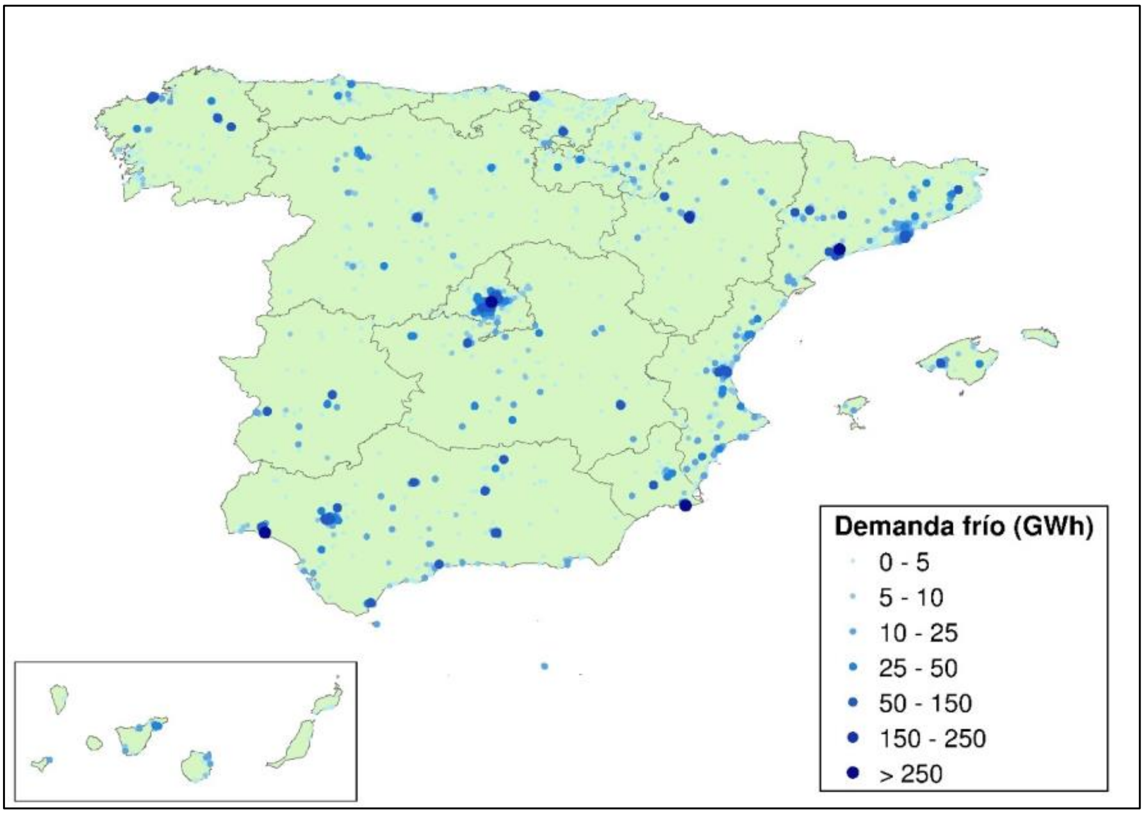


Figure 43: Distribution of cold demand of the systems



Below we set out an individualised analysis of the technical potential of each of the district heating and cooling systems.

6.1. Technical potential of residual heat from industry

Residual heat from industry as low potential for being used in the country in centralised thermal supply systems. The main reasons are the reduced thermal contributions with regard to the investment required and the long distances between the points of supply and the consumer centres. We have identified a total of **402** systems with potential for using residual heat and which represent a total of **4.1 TWh** of heating and **0.2 TWh** of cooling.

The following table disaggregates the heating and cooling potential provided through the use of residual heat from industry in the residential, tertiary and industrial sectors.

Table 42: Technical potential of residual heat from industry

Sector	Use	Residual Heat From Industry Use of direct heat Cooling absorption machine Technical potential (MWh)
Residential sector	*Heating*	18,955
	Hot water	18,362
	Cooling	834
Tertiary sector	*Heating*	185,635
	Hot water	24,265
	Cooling	90,178
Industrial sector	*Heating*	3,806,294
	Hot water	-
	Cooling	79,510
TOTAL	***Heating***	**4,010,885**
	Hot water	**42,627**
	Cooling	**170,522**

The geographic distribution of the systems that could potentially use residual heat from industry is shown in Figure 44 and Figure 45.

Figure 44: Geographic distribution of the potential for heat recovery from industry

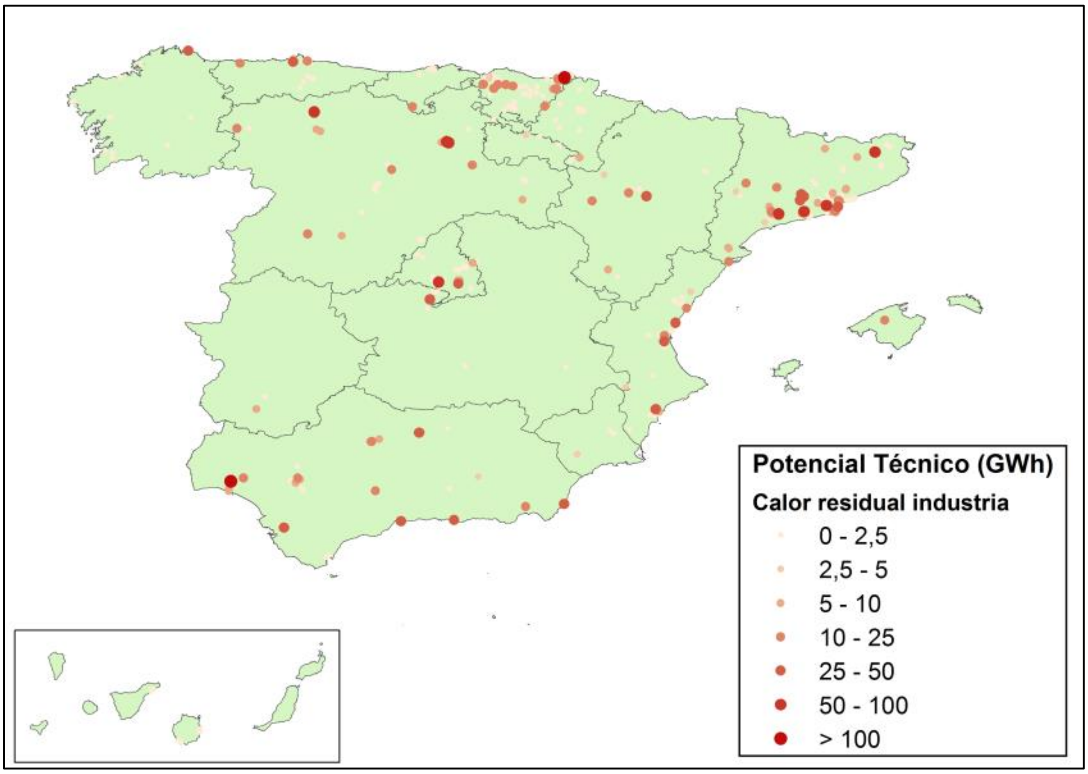
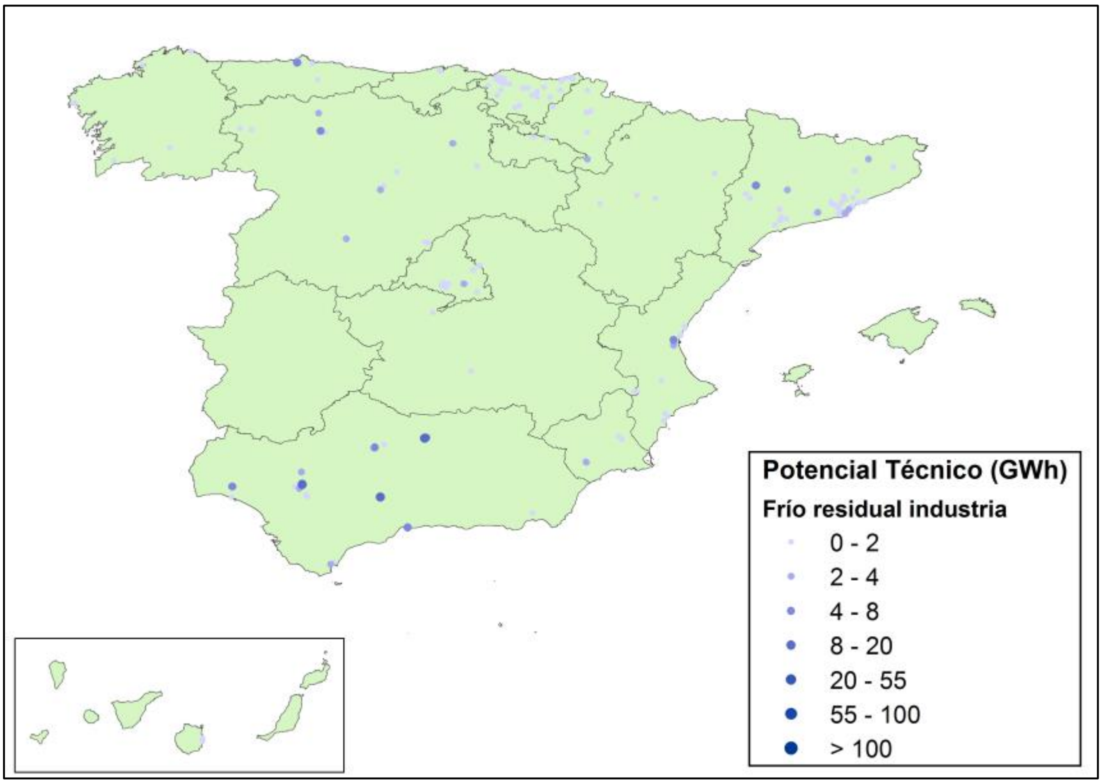


Figure 45: Geographic distribution of the technical potential for cooling using residual heat from industry



6.2. Technical potential of residual heat from power plants

The use of residual heat from power plants has been identified in **157 systems** which, based on the criteria of section 5.2, could contribute a total of **3.2 TWh** in heating and **0.3 TWh** in cooling.

The following table disaggregates the heating and cooling potential provided through the use of residual heat from power plants in the residential, tertiary and industrial sectors.

Table 43: Technical potential of residual heat from power plants

Sector	Use	Residual heat from Power Plants Use of direct heat Cooling absorption machine Technical potential (MWh)
Sector residential	*Heating*	138,944
	Hot water	166,004
	Cooling	2,055
Sector tertiary	*Heating*	1,424,302
	Hot water	175,158
	Cooling	201,605
Industrial sector	*Heating*	1,325,563
	Cooling	140,053
TOTAL	***Heating***	**2,888,809**
	Hot water	**341,163**
	Cooling	**343,713**

The geographic distribution of the systems that could potentially use residual heat from power plants is shown in Figure 46 and Figure 47.

Figure 46: Geographic distribution of the potential for heat recovery at power plants.

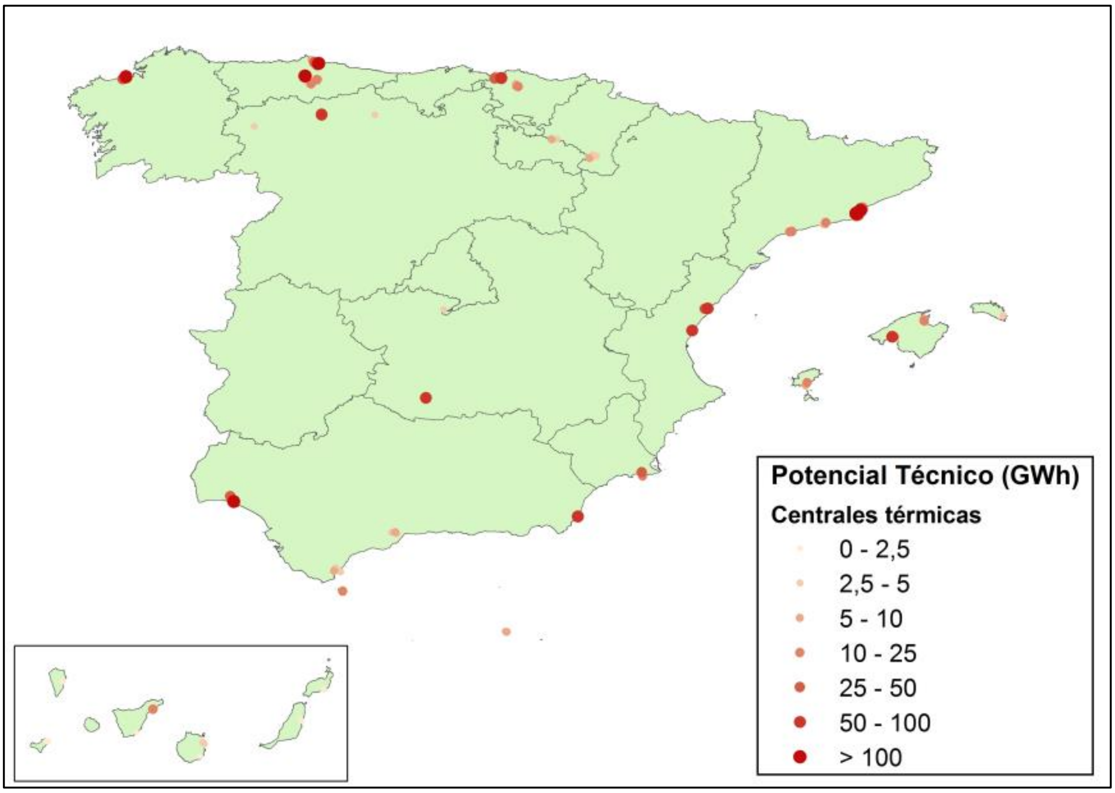
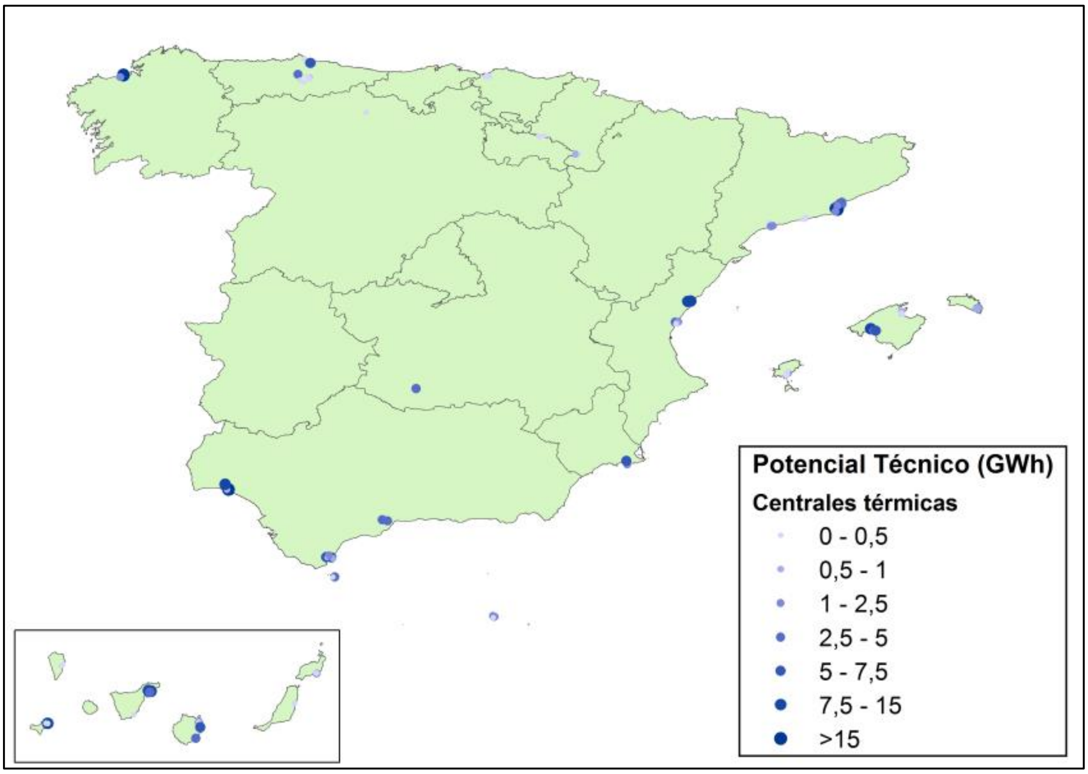


Figure 47: Geographic distribution of the potential for generating cold at power plants.



6.3. Technical potential of residual heat from waste recovery plants

In the case of using heat from waste recovery plants, a total of **57** systems have been identified which would enable the supply of around **1.7 TWh** of heating and **0.3 TWh** of cooling.

The following table disaggregates the heating and cooling potential provided through the use of residual heat from waste recovery plants in the residential, tertiary and industrial sectors.

Table 44: Technical potential of residual heat from waste recovery plants

Sector	Use	Residual Heat from Waste Recovery Plants. Use of direct heat Cooling absorption machine Technical potential (MWh)
Residential sector	*Heating*	14,395
	Hot water	14,412
	Cooling	1,142
Tertiary sector	*Heating*	318,994
	Hot water	34,848
	Cooling	143,259
Industrial sector	*Heating*	1,287,618
	Cooling	119,546
TOTAL	***Heating***	**1,621,007**
	Hot water	**49,259**
	Cooling	**263,948**

The geographic distribution of the systems that could potentially use residual heat from waste recovery plants is shown in Figure 48 and **Figure** 49.

Figure 48: Geographic distribution of the potential for heat recovery at waste recovery plants.

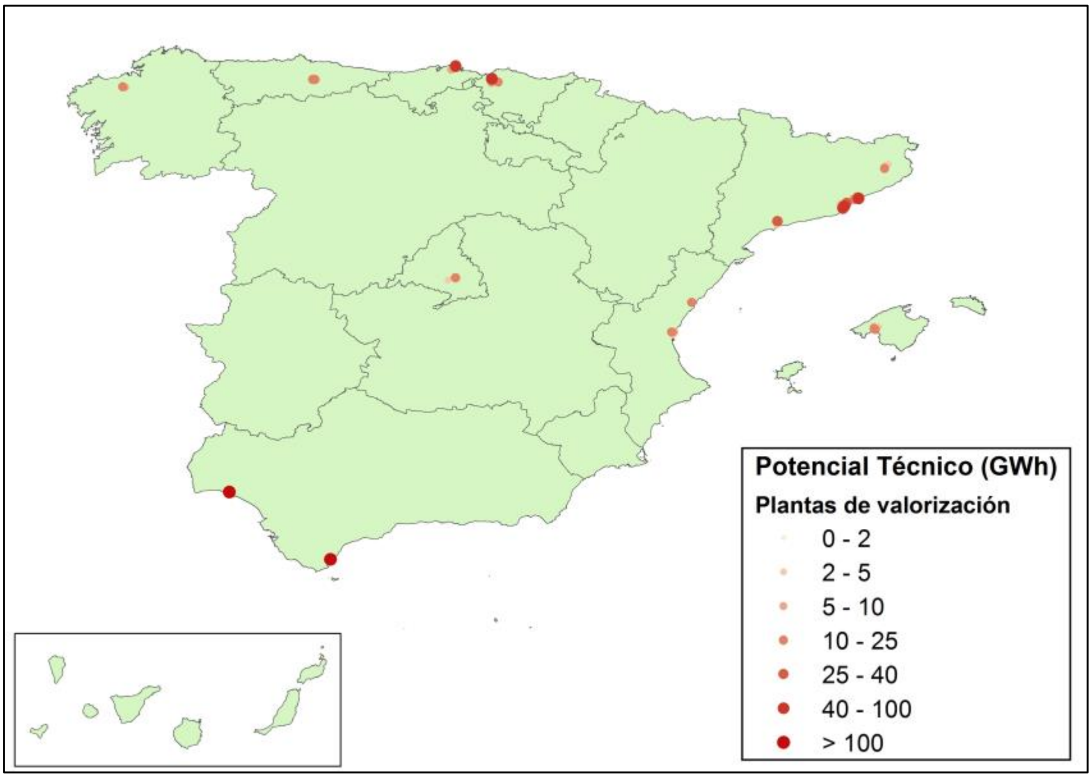
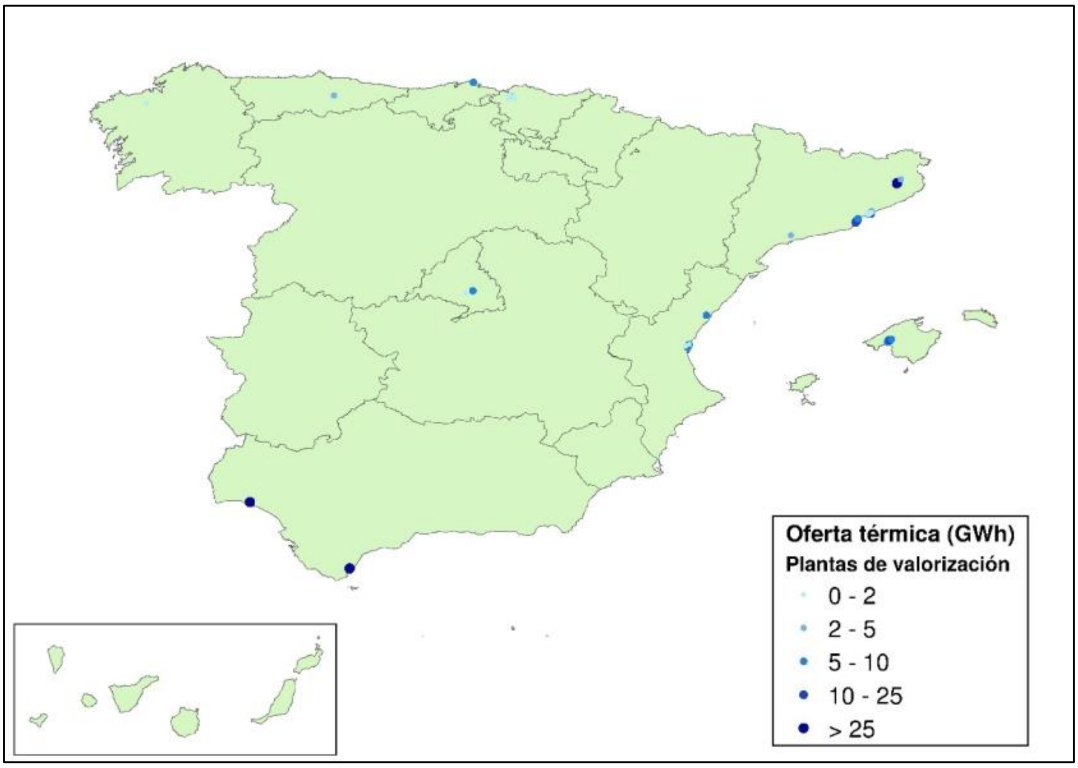


Figure 49: Geographical distribution of the technical potential for generating cold from waste recovery plants



6.4. Technical potential of Geothermics

The study of the geothermal potential has identified **146** systems that could satisfy part of their demand using this resource. The energy that this resource could provide to these systems is **1.1 TWh** of heating and **0.3 TWh** of cooling.

The following table disaggregates the heating and cooling potential provided through geothermal use in the residential, tertiary and industrial sectors.

Table 45: Technical potential of Geothermics

Sector	Use	Geothermal Use of direct heat Cooling absorption machine Technical potential (MWh)
Residential sector	*Heating*	24,609
	Hot water	31,631
	Cooling	2,172
Tertiary sector	*Heating*	343,293
	Hot water	48,749
	Cooling	237,720
Industrial sector	*Heating*	649,592
	Cooling	92,061
TOTAL	***Heating***	**1,017,494**
	Hot water	**80,381**
	Cooling	**331,954**

The geographic distribution of the systems that could potentially use Geothermics is shown in Figure 50 and Figure 51.

Figure 50: Geographic distribution of the technical potential of using heat from Geothermics.

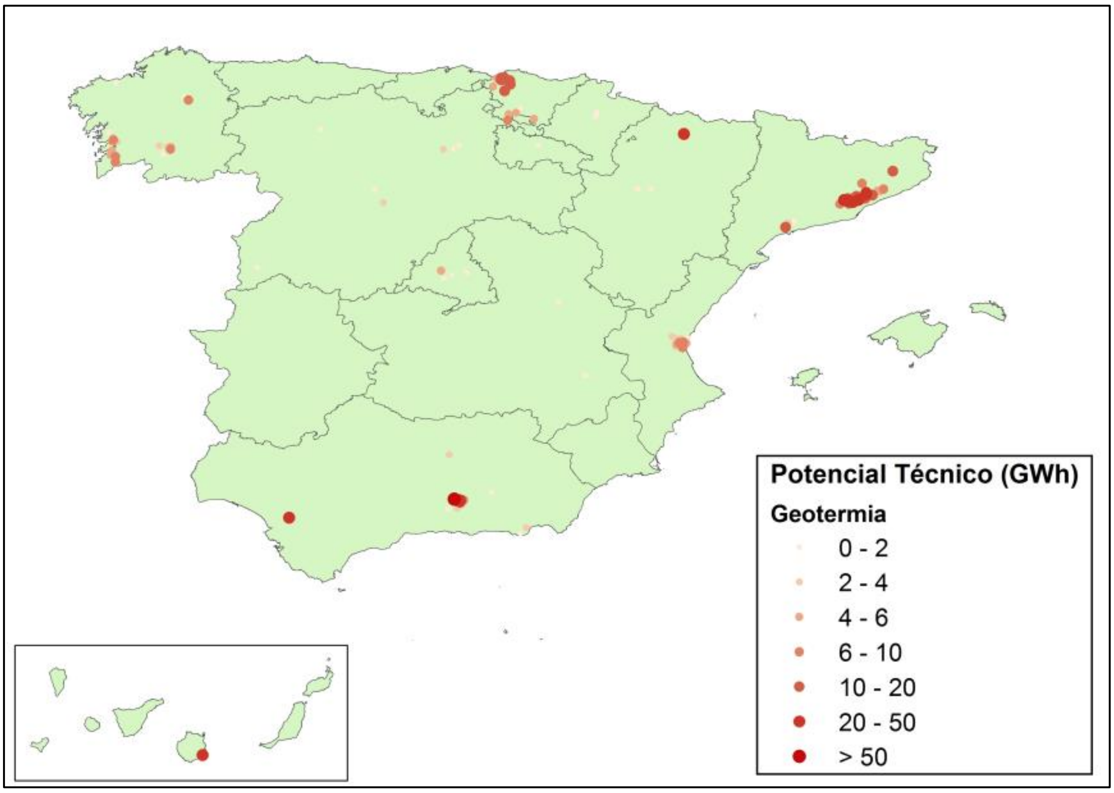
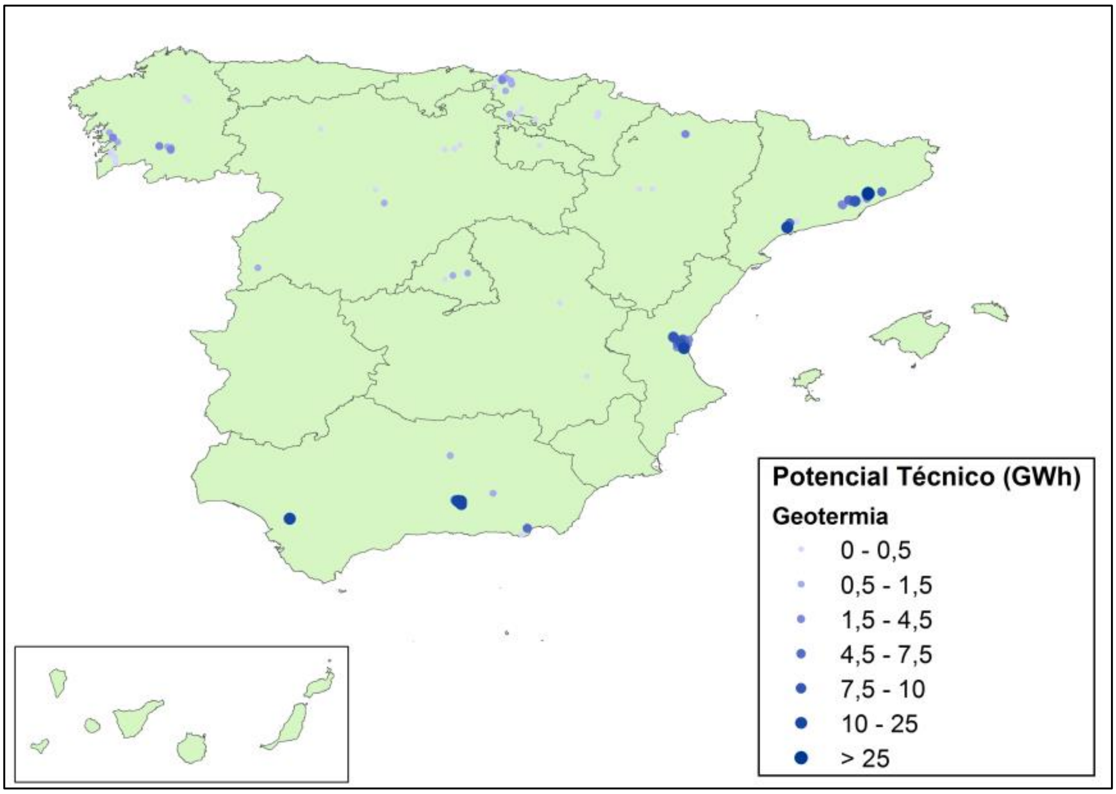


Figure 51: Geographic distribution of the technical potential of generating cold from Geothermics



6.5. Technical potential of solar energy for production of hot water for sanitation purposes

In the case of solar energy, there are **1,357** systems that could potentially provide energy to satisfy the demand for hot water for sanitation purposes, based on the baseline criteria established. The heat demand that could be satisfied within the systems is **6.0 TWh**.

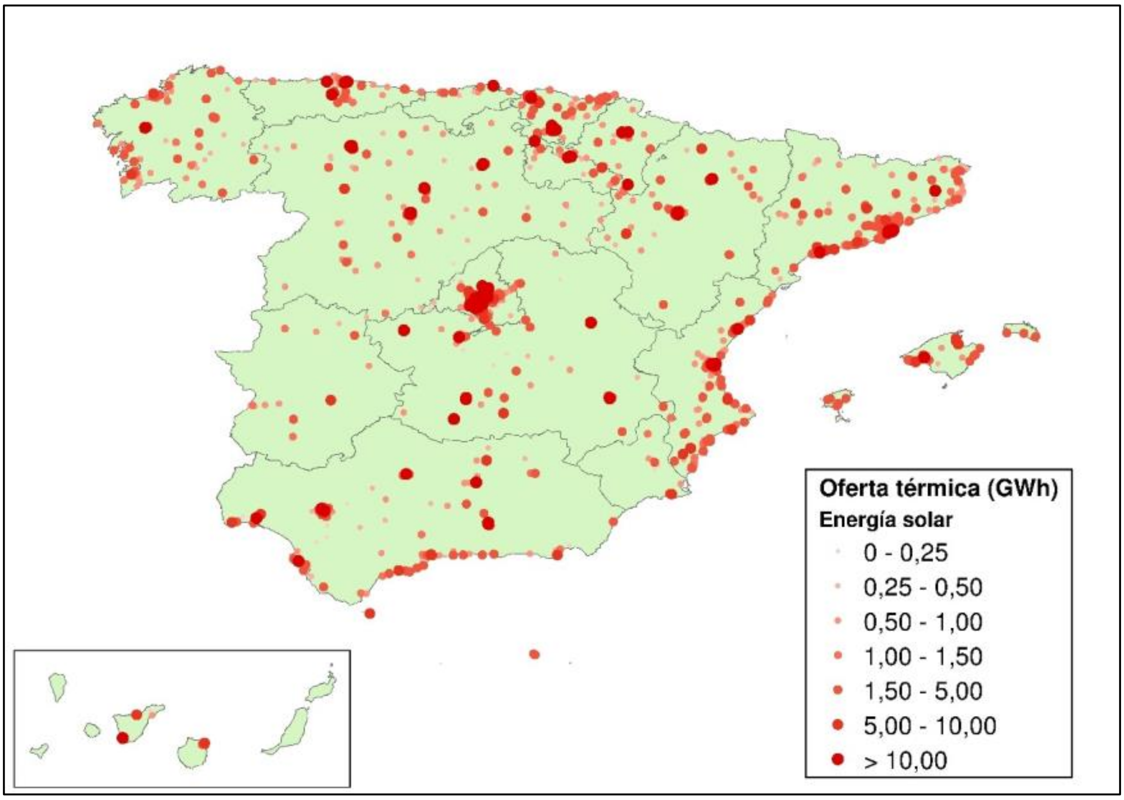
The following table disaggregates the heating potential provided through solar energy in the residential, tertiary and industrial sectors.

Table 46: Technical potential of hot water for sanitation purposes from thermal solar energy.

Sector	Use	Solar energy Solar collectors Technical potential (MWh)
Residential sector	*Heating*	-
	Hot water	3,118,787
	Cooling	-
Tertiary sector	*Heating*	-
	Hot water	2,911,104
	Cooling	-
TOTAL	***Hot water***	**6,029,892**

The geographic distribution of the systems that could potentially use solar energy is shown in Figure 52.

Figure 52: Geographic distribution of solar energy for production of hot water for sanitation purposes



6.6. Technical potential of Biogas

In the case of energy from biogas, there are **266** systems that could potentially provide energy to satisfy demand, based on the baseline criteria established. The heat demand that could be satisfied within the systems is **2.6 TWh** as heating and **0.7 TWh** as cooling.

The following table disaggregates the heating and cooling potential provided through biogas in the residential, tertiary and industrial sectors.

Table 47: Technical potential of biogas

Sector	Use	Biogas Heat Cooling absorption machine Technical potential (MWh)
Residential sector	*Heating*	115,924
	Hot water	80,256
	Cooling	5,261
Tertiary sector	*Heating*	1,305,273
	Hot water	148,861
	Cooling	569,416
Industrial sector	*Heating*	921,047
	Cooling	119,963
TOTAL	***Heating***	**2,342,244**
	Hot water	**229,117**
	Cooling	**694,639**

The geographic distribution of the systems that could potentially use biogas is shown in Figure 53 and Figure 54.

Figure 53: Geographic distribution of the potential for heat from biogas

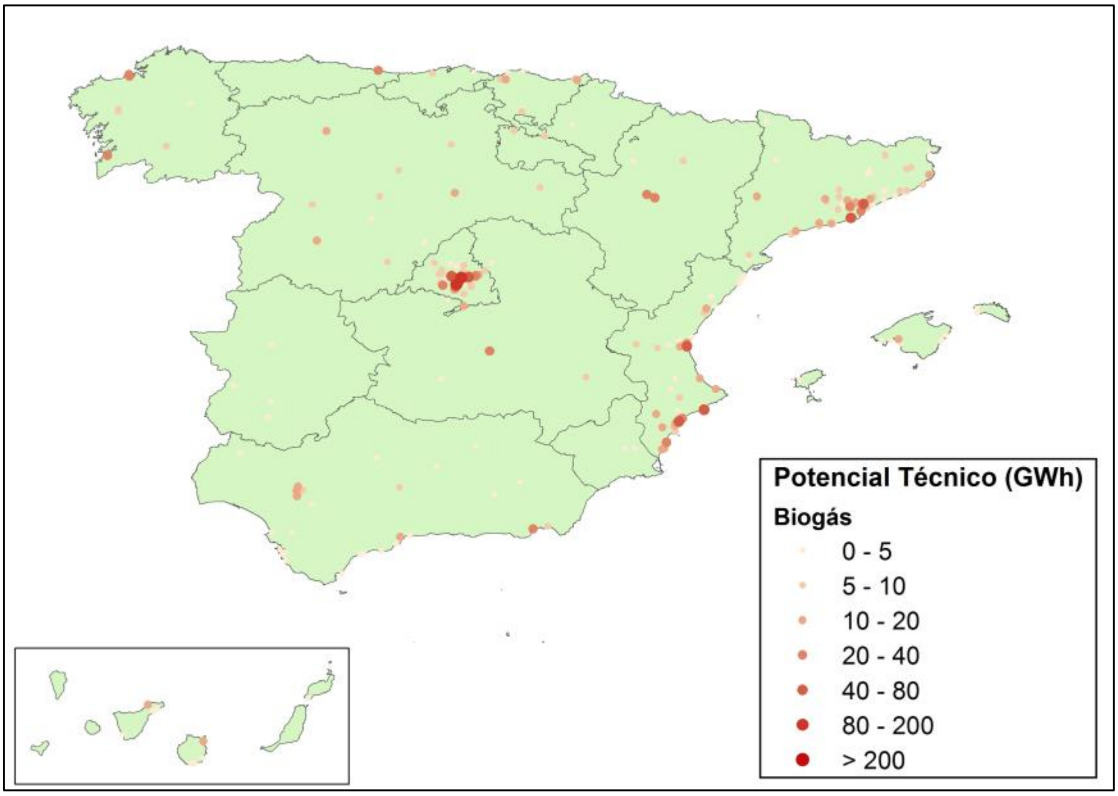
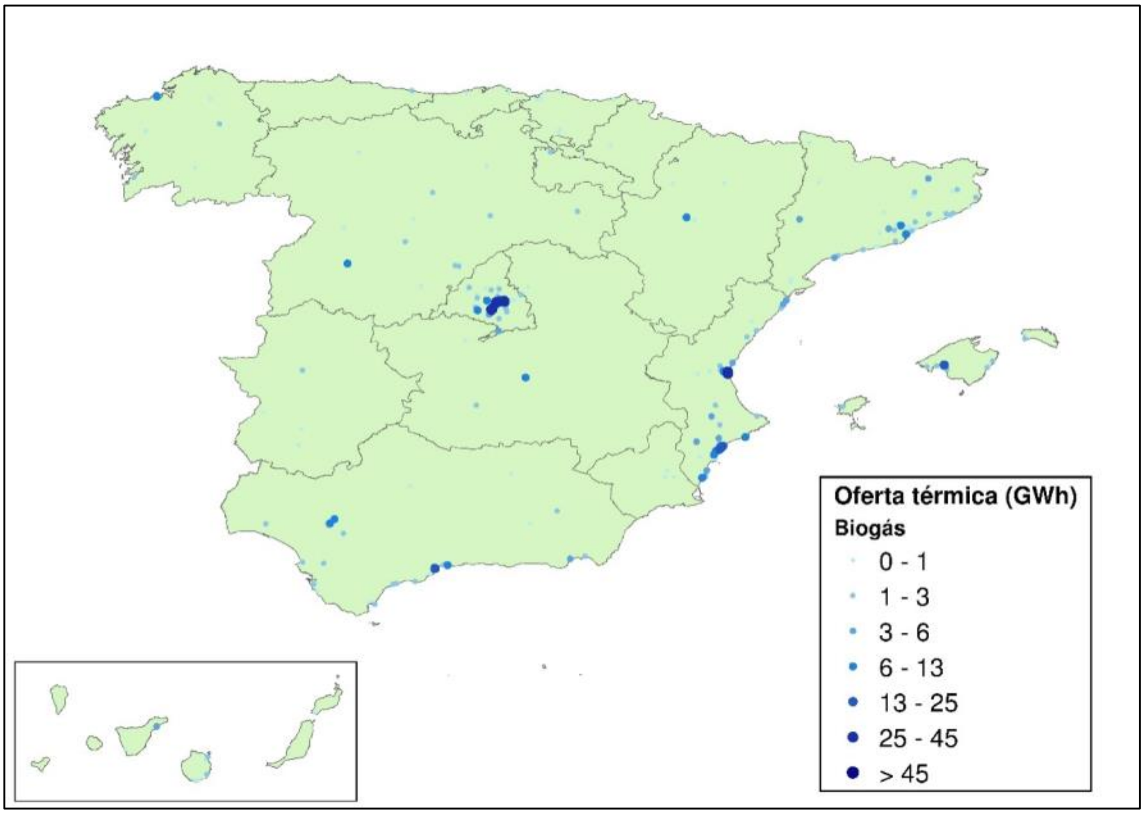


Figure 54: Geographic distribution of the potential of biogas for cooling.



6.7. Technical potential of biomass

In the case of biomass, there are **1,845** systems that could potentially provide energy, based on the baseline criteria established. According to calculations, the demand that could be satisfied is **31.9 TWh** of heat and **6.2 TWh** of cold.

The following table disaggregates the heating and cooling potential provided through biomass in the residential, tertiary and industrial sectors.

Sector	Use	Biomass
		Use of direct heat
		Technical potential (MWh)
Residential sector	*Heating*	1,581,037
	Hot water	988,240
	Cooling	57,715
Tertiary sector	*Heating*	11,171,175
	Hot water	960,325
	Cooling	4,065,736
Industrial sector	*Heating*	17,160,984
	Cooling	2,075,913
TOTAL	***Heating***	**29,913,197**
	Hot water	**1,948,565**
	Cooling	**6,199,365**

The geographic distribution of the systems that could potentially use biogas is shown in Figure 55 and Figure 56.

Figure 55: Geographic distribution of the potential for heat from biomass

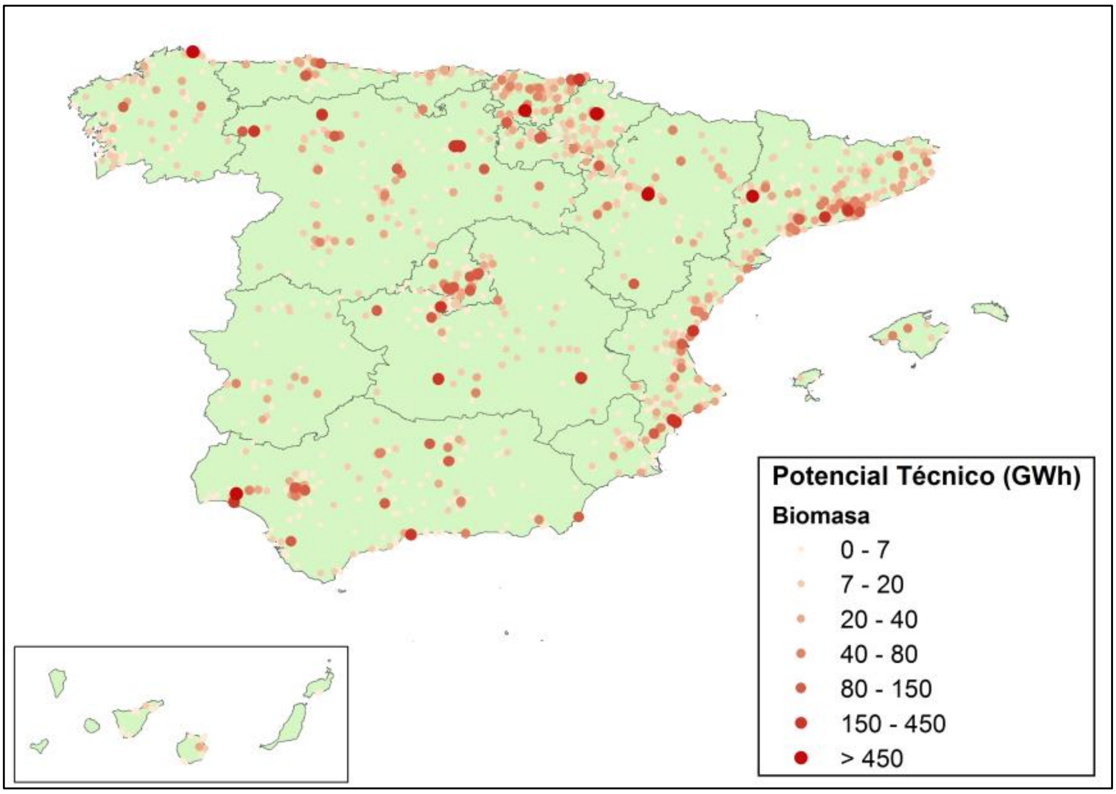
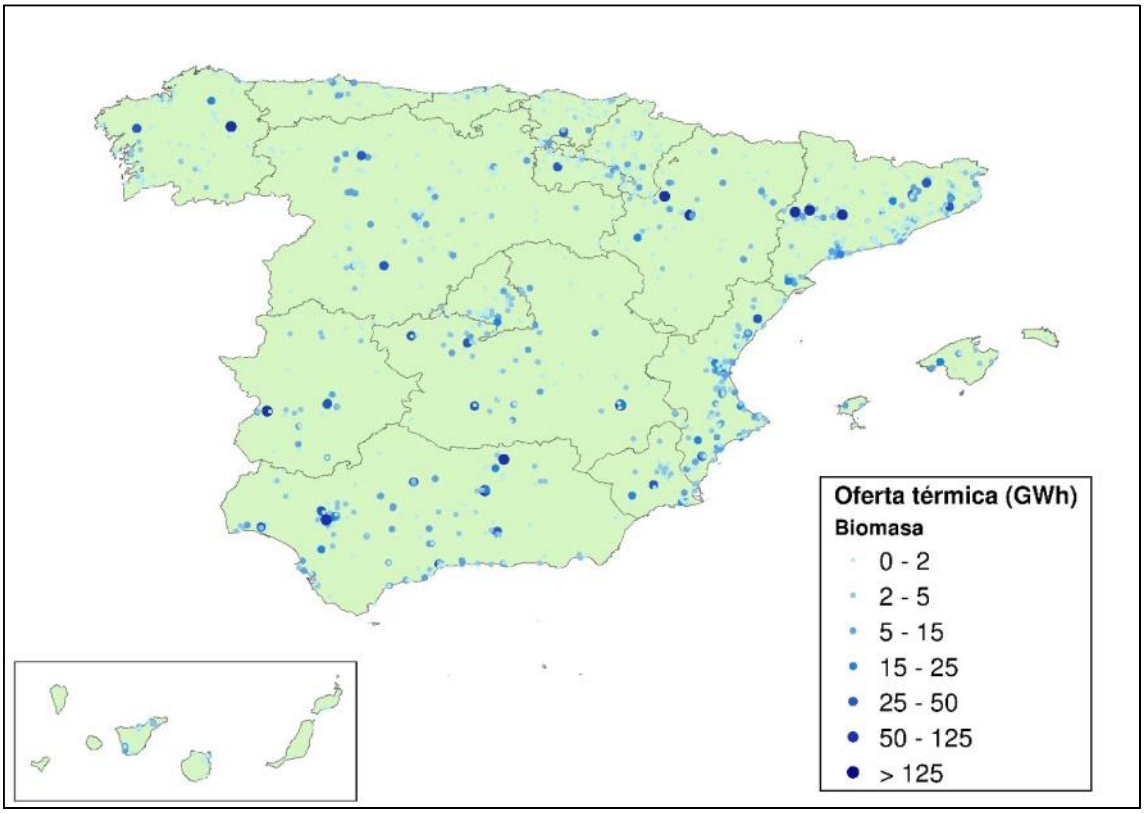


Figure 56: Geographic distribution of the potential for cooling from biomass



6.8. Technical potential of Cogeneration

In the case of cogeneration, micro-cogeneration and tri-generation, the technical potential depends on the quantity of energy to be supplied, the method of consumption and its distribution over the year.

According to the criteria set out in section 5.2.4, a total of 858 systems have been identified with high efficiency cogeneration electricity potential of **8,911 MWe** and a thermal supply of **30.1 TWh** of heat and **2.9 TWh** of cooling.

Table 48 and Table 49 respectively identify the disaggregation of the potential for using high-efficiency cogeneration both for sectors of activity as well as by technology.

Table 48: Technical potential of cogeneration.

Sector	Use	Natural gas Heat CHP Cooling CHP Technical potential (MWh)
Residential sector	*Heating*	2,319,687
	Hot water	1,365,233
	Cooling	32,302
Tertiary sector	*Heating*	15,681,419
	Hot water	1,234,956
	Cooling	2,317,438
Industrial sector	*Heating*	9,544,438
	Cooling	592,346
Total	*Heating*	27,545,544
	Hot water	2,600,189
	Cooling	2,942,087

Table 49: Technical potential of high-efficiency cogeneration in accordance with the technology.

Province	Units	Electrical power (MWe)	Heat CHP (GWh)	Cooling CHP (GWh)	PES	Average PES	Average OE	Average EEE
ECSD	**22**	**1,542**	**7,378**	**318**	**7,200**	**15.9%**	**78.8%**	**70.4%**
Steam	22	1,542	7,378	318	7,200	15.9%	78.8%	70.4%
SCGM	**591**	**2,511**	**4,477**	**1,147**	**2,885**	**15.3%**	**77.4%**	**69.1%**
Hot water	591	2,511	4,477	1,147	2,885	15.3%	77.4%	69.1%
SCGM<1MW	**137**	**64**	**221**	**97**	**151**	**14.9%**	**79.0%**	**70.6%**
Hot water	137	64	221	97	151	14.9%	79.0%	70.6%
SCmGT	**17**	**12**	**108**	**24**	**24**	**11.4%**	**79.0%**	**70.4%**
Hot water	17	12	108	24	24	11.4%	79.0%	70.4%
SCGT	**91**	**4,782**	**17,962**	**5,327**	**7,864**	**16.2%**	**84.3%**	**76.2%**
Hot water	69	4,596	15,795	4,608	7,176	17.5%	84.5%	77.4%
Hot gases	7	69	869	118	284	11.7%	84.9%	74.5%
Steam	15	117	1,298	601	404	11.9%	82.8%	71.6%
TOTAL	**858**	**8,911**	**30,146**	**6,912**	**18,124**	**15.2%**	**78.5%**	**70.1%**

The geographic distribution of the systems that could potentially use cogeneration is shown in Figure 57 and Figure 58.

Figure 57: Geographic distribution of the technical potential of heat from cogeneration

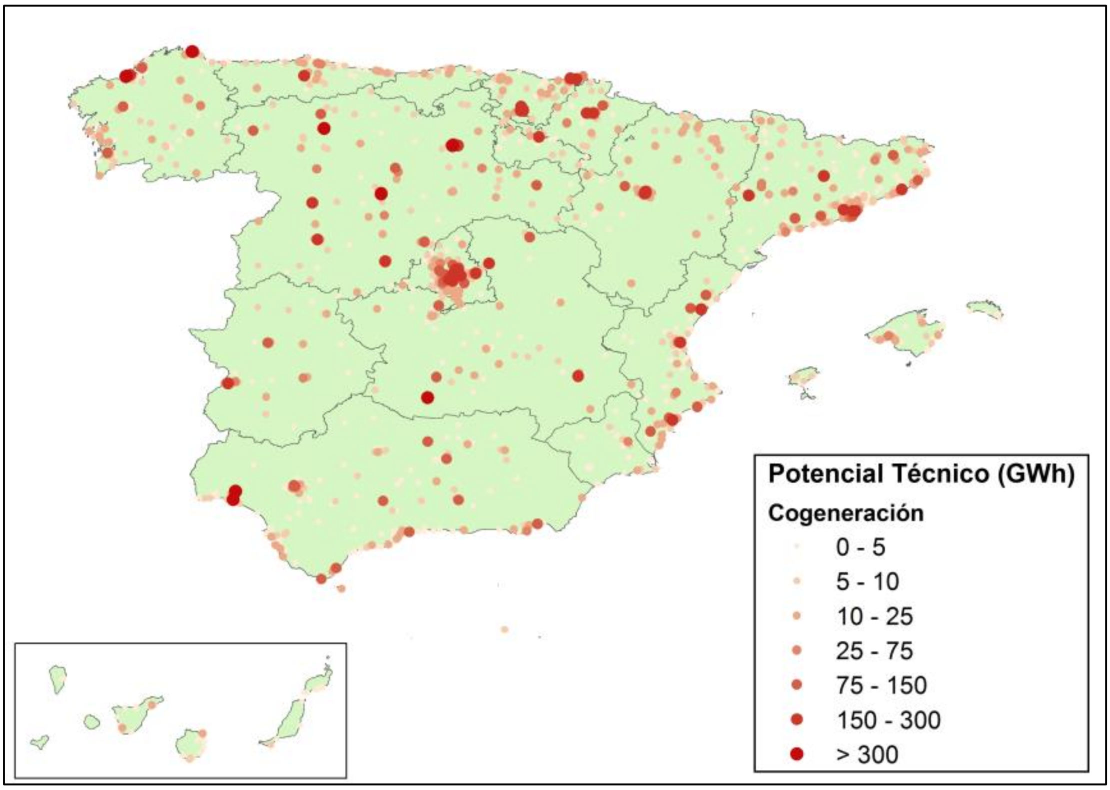
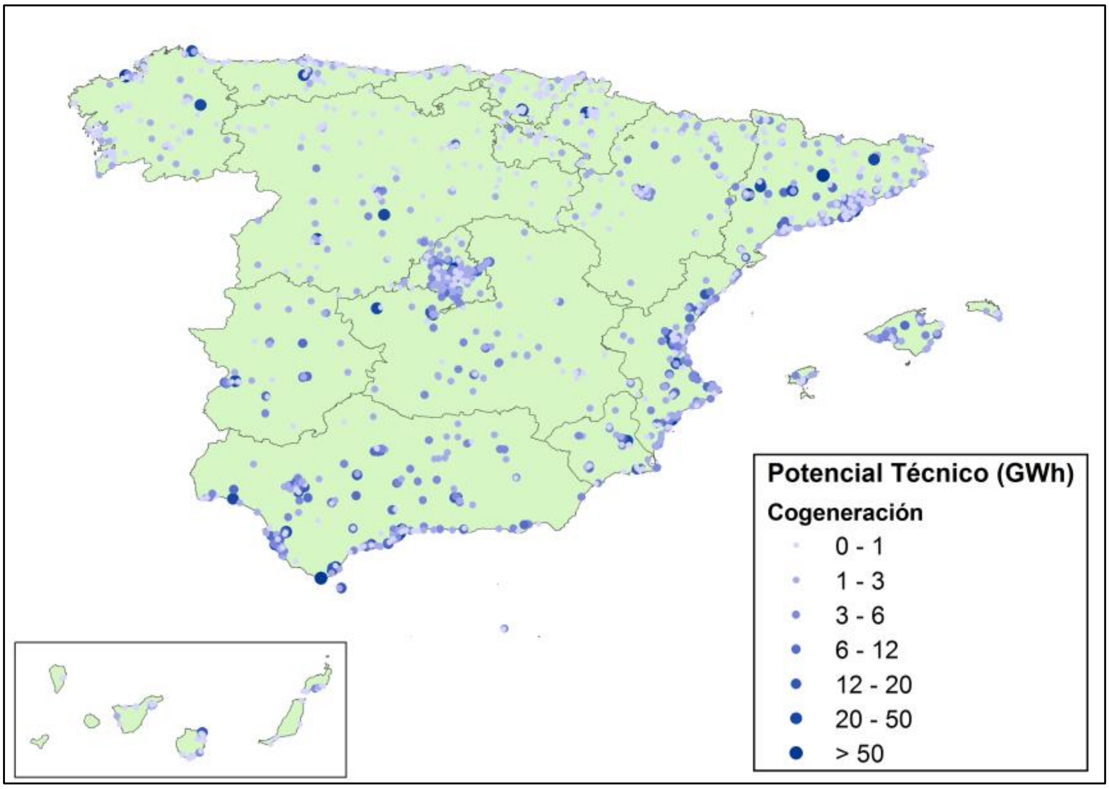


Figure 58: Geographic distribution of the technical potential of cooling from cogeneration

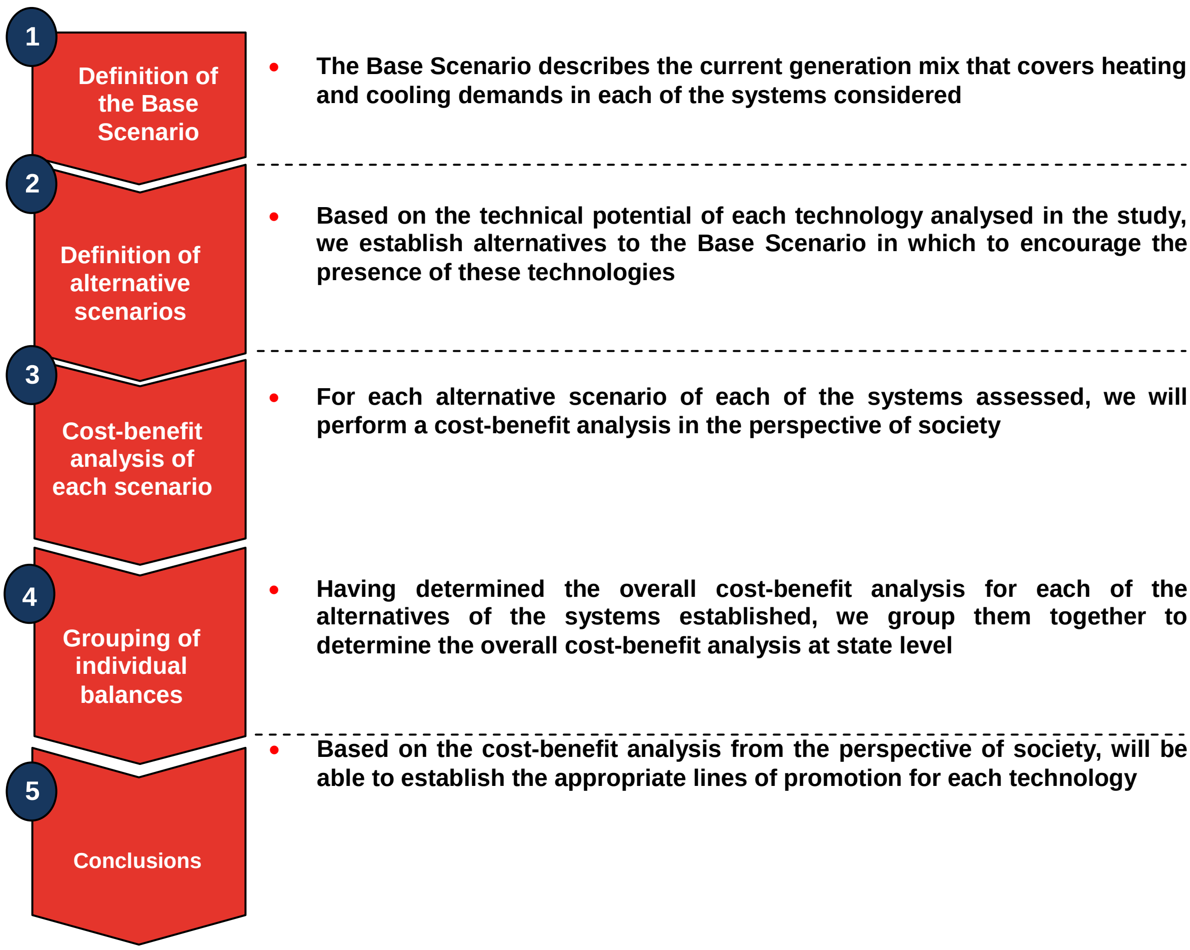


7. COST-BENEFIT ANALYSIS AT COUNTRY LEVEL

The overall cost-benefit analysis is an analytical tool that allows us to assess the investment decisions through valuation of the changes in costs and benefits (between the Base Scenario and the Alternative Scenario) attributable to these.

Below we show the methodology developed to perform the cost-benefit analysis at society level:

Figure 59: Methodological diagram of the cost-benefit analysis from the perspective of society



7.1. Definition of the Base Scenario

The Base Scenario is the starting point on which we will construct the overall cost-benefit analysis and it needs to describe the existing thermal generation mix in the current timeline, in other words the technologies that currently exist to cover heating and cooling demand in each of the three segments of consumption considered (residential, tertiary and industrial). It will serve as a reference point to assess the incremental value of the different solutions to be analysed. Furthermore, the Base Scenario must establish the expected evolution of this mix and of thermal demand up until 2050.

Below we describe the methodology used to characterise the technologies that make up the current technological mix in Spain, for each of the sectors analysed.

7.1.1. Residential Sector

The Current technological mix of the residential sector has been established on the basis of the SECH-SPAHOUSEC project "*Analysis of the energy consumption of the residential sector in Spain*"**.** To this end, based on the disaggregation of the final energy consumption by energy sources and by climatic zone of all dwellings in Spain shown in this report, it has been possible to determine the main technologies used to supply heating, cooling and hot water for sanitation in the residential sector for each of the three climatic zones of Spain (North Atlantic, Continental and Mediterranean).

Given that this report does not provide data on supply through district heating and micro-generation systems, the percentage of demand satisfied by these technologies has been obtained from figures provided by the Association of Heating and Cooling Grid Companies (ADHAC) and from the Cogeneration Statistics Report.

7.1.2. Tertiary Sector

Given that there are no studies available that characterise this sector in a similar way to that of the residential sector, in order to determine the technologies that make up the energy mix we have used information obtained from the energy audits undertaken at installations where activities corresponding to the different land uses of the tertiary sector in each climatic zone take place.

7.1.3. Industrial sector

Neither is there any official characterisation for the industrial sector with regard to the technologies that supply the thermal demand. Consequently, this sector has been characterised by taking into consideration the final energy consumption by energy resource and industrial subsector, shown in the Final Energy Balances of 2013, as well as in the 2013 Cogeneration Statistics Report

7.2. Definition of Alternative Scenarios

In this step we have constructed the alternative scenarios to the Base Scenario, simulating that the technical solutions analysed within the framework of this study that combine different energy resources: residual heat from different sources and renewable energies, with technologies for the generation of heating and cooling, which include cogeneration and micro-cogeneration and which distribute the thermal energy produced through centralised systems, district heating and cooling systems in the residential, tertiary and industrial sectors.

As with the Base Scenario, the alternatives need to be assessed on the current timeline and up to 2050.

For each of the systems established nationwide, we assess the following technical solutions.

- Use of residual heat from:

  - ✓ Industries
  - ✓ Power plants
  - ✓ Waste recovery plants

  For the three kinds of residual heat we analyse the direct use of heat through exchangers and the production of cooling through absorption.

- Use of renewable energies and fuels

  - ✓ Biogas from WWTP
  - ✓ Residual biomass
  - ✓ Solar energy
  - ✓ Geothermics

  For biogas and biomass we analyse heat production using boilers, and the production of heating and cooling with boiler and absorption machine.

  In the case of solar energy, the technical solution involves the production of hot water for sanitation using solar collectors.

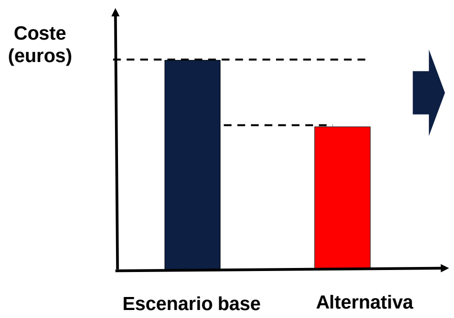
With Geothermics we analyse the production of heat using exchangers and the production of cooling using an absorption machine.

- Use of cogeneration to produce heating and cooling with different types of cycle and technologies (gas turbine, alternative motor, steam turbine).

7.3. Cost-benefit analysis of each scenario

The overall cost-benefit analysis is an analytical tool that allows us to assess the investment decisions through valuation of the changes in costs and benefits between the base scenario and the alternative scenario in each one of the systems to be analysed, based on the following diagram.

Figure 60: An example of assessment in cost-benefit analysis



$$Coste_t = [Coste_t]_{Alternativa} - [Coste_t]_{Escenario\ Base}$$

Source: Cost-benefit analysis and interpretation of results. JRC

The costs and benefits that remain constant in both scenarios must not be included because they will be cancelled when the differences between them are assessed.

Firstly, for each of the technical solutions analysed there is a cost-benefit analysis of each project from the perspective of a potential investor.

Then, to conduct the overall economic analysis from the perspective of society as a whole, we set out from the analysis of the cash flows of each specific project from the investor's perspective, eliminating any direct taxes.

Then the appropriate modifications are carried out over these analyses and for each scenario, in order to include the perspective of society as a whole:

- Inclusion of the most relevant impacts that the implementation of the technological solution considered would cause to society as a whole:
  - Environmental Impact
  - Impact on the country's energy dependence
  - Macro-economic impact

Having considered all relevant costs and revenue, the economic evaluation criterion used has been the NPV (Net Present Value) of the investment with a discount rate of 5%.

Each technical solution that has a positive NPV compared with the baseline at the system level analysed will be considered as potentially economic and the energy demand in MWh that this solution would satisfy in each system will be considered as the economic potential.

The sum of the economic potential of a specific solution in each of the systems analysed will represent the economic potential of this solution at national level.

7.4. Economic parameters

When analysing the overall cost-benefit, the following parameters need to be considered:

- **The social discount rate:** this reflects, from a social point of view, how future benefits and costs need to be assessed with regard to the current ones. We have considered a rate of 5%.

- **The project lifetime (years**): The assessment of the overall cost-benefit analysis will be carried out between 2015 and 2050.

7.4.1. Inputs of the overall cost-benefit analysis tool

The inputs required when assessing the overall cost-benefit analysis will be the data of technical potential of each of the technological solutions analysed. The baseline data will be the following:

STATE OF PLAY
Sector
Annual heat demand of the system (MWh)
Annual hot water for sanitation demand of the system (MWh)
Annual cooling demand of the system (MWh)
Climatic zone of the system

FOR EACH TECHNICAL SOLUTION
Heat supplied in the system during one year (MWh)
Cooling supplied in the system during one year (MWh)
Anticipated annual fuel consumption (MWh)
Sale of electricity to the system during one year (MWh)
Sale of heat to the system during one year (MWh)
Sale of cooling to the system during one year (MWh)
CAPEX of the technical solution (€)
OPEX of the technical solution (€)

Based on the inputs determined in the previous table, we will determine the cost-benefit analysis at society level for each of the technical solutions assessed for existing systems nationwide.

To find out the economic potential of implementing these technologies we need to know the economic parameters associated with them, such as the investment required, the fuel costs, operation and maintenance, and the revenue that could be obtained through the sale of heat.

The estimated investments and the operation and maintenance costs have been worked out using regressions based on historic prices and/or bibliography for the following equipment and installations:

- Natural gas boilers:
- Compression machines:
- Absorption machines:
- Heat-exchange units:
- Heat recovery boilers:
- Biomass boilers:
- Biogas boilers:
- Geothermal installations:
- Thermal solar installations:
- Cogeneration plants:
- District grids:

7.4.2. Determination of the investment

Both for the benchmark situation and for each of the solutions proposed, we determine the capital that needs to be invested both for the main systems or equipment as well as to carry out possible thermal connections of heating and/or cooling supply or for the use of residual heats or fuels. The investment of each of the alternatives will be determined by a value in EUR/MW.

7.4.3. Determination of costs

Below we determine each of the costs that have to be taken into consideration.

7.4.3.1. Capital costs

These are the costs of the resources used in making a specific investment.

7.4.3.2. Operation and maintenance costs

This includes the costs required to guarantee proper performance of an installation as regards operation and maintenance of its equipment and facilities.

7.4.3.3. Purchase of fuels and electricity

These are the costs stemming from the purchase of fuels to generate thermal energy and/or electric energy, depending on the case analysed. This is based on knowledge of the following:

- Purchase price of fuel or electricity (EUR/MWh)
- Anticipated consumption of fuel or electricity (MWh/y)

7.4.3.4. Environmental impact

Energy production causes a major environmental impact arising mainly from the issue of contaminating particles, but also through the occupation of lands and the consumption of resources. These impacts generate a loss of well-being in society, which must be taken into consideration when analysing the overall cost-benefit.

To determine the economic assessment of damages, we have used the *"Subsidies and cost of EU energy"* (Alberici et al., 2014) study, which establishes, for different technologies, the environmental damage factor associated with the emission of an energy unit produced by that technology (EUR/MWh). These environmental damage factors will be used to assess the environmental costs that the introduction of each of the alternatives has on society with regard to the Base Scenario.

The incremental environmental cost (EC) of the solution will be assessed based on the increase of energy production by technology (ΔE) of the Solution with regard to the Base Scenario, by the environmental damage factor (EDF) of the technology selected, in accordance with the following expression:

$$\left[\Delta CA_{y,t}\right]_{Alt} = \left[\Delta E_{y,t}\right]_{Alt} * \ FDA_{y,t}$$

Where:

- $\left[\Delta CA_{y,t}\right]_{Alt}$ is the environmental cost associated with the increase of energy produced by the technology and, in year t, in the technological solution (MWh).
- $\left[\Delta E_{y,t}\right]_{Alt}$ is the difference between the energy produced by the technology and, in year t, in the technological solution and the Base Scenario (MWh).
- $FDA_{y,t}$ is the environmental damage factor by energy unit, produced by the technology and [ ] (EUR/MWh).

The environmental cost of each scenario in a specific year will be the sum of the environmental damages produced through the production of all technologies used in that technological solution, that year, as shown below:

$$\left[\Delta CA_{Total,t}\right]_{Alt} = \left[\sum_{y=1}^{n} \Delta CA_{y,t}\right]_{Alt}$$

Table 50: Example of environmental damage factors

Technologies	EDF (EUR/MWhth)
CHP– heat – biomass	4.3
CHP – heat – natural gas	11.7
CHP – heat – coal	24.1
Domestic natural gas boiler	17.9
Domestic biomass boiler	11.2
Domestic heat pump	12.5
Domestic thermal solar	9.6

Source: Subsidies and costs of EU energy

Although the EDF may be modified over the years, the study by Alberici *et al.* (2014) offers no evolutions for these parameters. To maintain a continuist and conservative scenario we have decided to keep these parameters constant over time.

7.4.3.5. Costs arising from the energy dependency impact

As described by *Arnold et al (2007)*, in the context of the *ExternE - External Costs of Energy* project compiled by the European Union and the American Energy Agency, to assess the external factors arising from energy dependence we need to estimate the impact on the economy caused by an increase in the price of imported fuels.

To establish the energy dependence impact on the country's economy, we first need to determine the elasticity of the economy based on increases in the price of fuels in accordance with the following formula:

$$e_t = \frac{\Delta PIB/PIB}{\Delta P/P}$$

Where:

- e_t is the elasticity of GDP in year t
- $\frac{\Delta PIB}{PIB}$ is the percentage of GDP change between years t and t-1 (%)
- $\frac{\Delta P}{P}$ is the percentage of change to fuel prices between years t and t-1 (%)

Thus, the impact on the economy in year t, by MJ of fuel consumed is measured as follows:

$$\Delta PIB_{per\ unit} = \frac{e_t \cdot PIB_t}{Ft}$$

Where:

- $\Delta PIB_{por\ unidad}$ is the impact on GDP by fuel unit consumed (EUR/MJ)
- $e$is the elasticity of GDP
- PIB is the GDP of the economy in year t (EUR)
- F is overall fuel consumption in year t (MJ)

Based on the difference of the fuel consumed in one year in the benchmark technological solution versus the Base Scenario, as well as price evolution, it will be possible to assess the GDP variation as a cost associated with the energy dependence of each technological solution in accordance with the following formula:

$$[\Delta PIB_t]_{Alt} = \Delta PIB_{Per\ unit,t} \cdot \left[\left(\frac{\Delta P}{P}\right)_t\right]_{Alt.} \cdot ([F_t]_{Alt} - [F_t]_{EB})$$

However, to include this in the overall cost-benefit analysis it is appropriate to convert the GDP into a welfare measurement. Thus, bearing in mind the Fixed Capital Consumption (FCC) we will transform the GDP into a Net Domestic Product (NDP) based on the ratio established by Weitzman.

$$[\Delta PIN_t]_{Alt} = \Delta PIB_t * (1 - \frac{CCF_t}{PIB_t})$$

The end result will be attributed as an energy dependence cost in the overall cost-benefit analysis of the technological solution.

To extrapolate this to 2050, we have considered the following evolutions:

- **GDP**: the forecast data to 2020 by the 2014 NEEAP have been taken as reference. From 2020 onwards we have assumed a continuous trend with regard to the previous year.
- **Fuel price**: as set out in Order IET/1045/2014, annual growth of 1% in the fuel prices has been taken into consideration.
- **Fixed Capital Consumption (FCC)**: we have assumed a continuist trend of 1% with regard to data for the last five years.

7.4.4. Determination of the benefits

The benefits from introducing a specific project could be either due to a reduction of costs or to an increase of revenue with regard to the benchmark situation. Below we set out the different benefits to be considered:

7.4.4.1. Revenue through the sale of electricity

This will occur where the forecast installation is a cogeneration plant. The electricity produced could be sold to the public grid or used for self-consumption at the site in order to reduce the need to import grid electricity. Revenue from the sale of electricity will be determined in accordance with:

- Electricity generated (MWh)
- Prices of electricity sales (EUR/MWh)

7.4.4.2. Macroeconomic impact

The methodology used to determine the macroeconomic impact is the so-called supply route, which allows us to assess how the GDP would vary based on direct and indirect impacts arising from a change of demand in certain economic sectors.

The assessment of each of these effects will be determined as follows:

* **Direct contribution to GDP ("contribution of technologies")**: this is the effect caused by an increase in end demand, generated through an increase of production by the sector. In other words, it is the calculation of the proportion that corresponds to the activities carried out by all companies that engage most of their efforts on the production of goods or services related to the technology of the sector analysed.

  The determination of the direct contribution to GDP stemming from a change of technology will be determined as the sum of the following partial contributions to GDP:

  - Contribution to GDP of the installations: this parameter is solely influenced by those new installations that are built to satisfy demand. It will be determined using the following formula:

    $\Delta GDP_{INSTALLATIONS}$ =ΔMW installed in the year * CAPEX * Manpower costs of CAPEX * % of margin from manufacture and sale of equipment.

  - Contribution to GDP of Operation and Maintenance: this parameter is affected by those installations already built, which require recurrent maintenance. It is determined as follows:

    $\Delta GDP_{O\&M}$ = Total MW installed * OPEX * Manpower costs of OPEX * % margin of operation of the installation.

  - Contribution of exports and imports to the GDP: this parameter is affected by net exports and, as such, by the manufacture and sale of equipment.

  The sources from which we have obtained the values required to determine the partial contribution to the GDP are as follows:

  - Average CAPEX and OPEX of each of the technologies assessed in accordance with the "*Energy Technology Reference Indicator projections for 2010-2050"* by the *Joint Research Centre,* broken down into the following levels:
    - Component
    - Installation
    - Manpower costs
  - Margins of the main activities of the value chain of each of the technologies, obtained from interviews:
    - Manufacture and sale of equipment
    - Installation and commissioning
    - Operation of the installation

- Import and export figures for each of the National Business Activity Codes (CNAE) to which each of the technologies assessed refers, obtained from the Ministry of Foreign Trade of Spain.

- **Indirect effect ("impact on other sectors")**: this is the effect caused by the change of direct consumption on the remaining sectors that supply inputs to the specific sector. In other words, this effect encompasses the activities both of the sectors closely related to the technologies being studied as well as the remaining economic sectors which experience the drag-along effect as a consequence of the activity of the sector analysed.

This drag-along effect is deduced from the technical coefficients of production, determined from the Symmetrical Matrix of branches of activity compiled by the Spanish National Institute of Statistics (INE). This is a squared matrix, measured in Euros, which addresses all sectors of the Spanish economy (73), represented in:

- Columns: the information of resources that the sector uses from others, to achieve its final production. In other words, the outputs or sales of the sector from the row to the sector of the columns.
- Rows: the information on goods and services produced by one sector and consumed by another. In other words, the inputs or purchases from the column sector to the sectors of the rows.

Operating this matrix, until we get a Technical Coefficient matrix, we obtain the indirect effect arising from the implementation of one technology.

The results of the sum of the direct and indirect effects on GDP will be transformed into NDP (Net Domestic Product) as shown in point 7.4.3.5, and the resulting value will be attributed in the overall cost-benefit analysis as revenue measured year-on-year.

7.4.4.3. Impact on the reliability of the system operation

A further benefit stemming from the expansion of cogeneration is its contribution to the reliability of the electricity grid. This reliability measures the capacity of the electricity system to supply the electrical needs of consumers. Cogeneration, as a source of electricity generation, can help avoid power cuts.

The methodology used by the *Joint Research Centre* establishes two approximations to determine this impact:

- To estimate the costs avoided as a consequence of increased reliability of the system through other technical solutions.
- To estimate the costs avoided as a consequence of power cuts.

However, this methodology also specifies that the introduction of any of these two approximations requires an in-depth analysis, and that solely Member States that have tools for the modelling of reliability of the system could include it in their cost-benefit analysis. Consequently, in this case it is not been possible to assess this in a quantitative way.

7.5. Economic Potential

Based on the methodology of the cost-benefit analysis described previously, we have calculated the economic potential of each technical solution within each system. We therefore consider each solution at system level where the cost-benefit analysis has a positive NPV

Having conducted the analysis for all systems, we pooled the economic potential of each technical solution at national level. The findings obtained are shown in detail in point 8.

7.6. Efficient cost potential

Based on the economic potential we have optimised the best technical solutions for each system from a global standpoint. This optimisation has been carried out based on the NPV/MWh ratio for each solution, prioritising those technologies that have greater ratios in each system.

Having conducted the analysis for all systems, we pooled the cost-efficient potential of each technical solution at national level. The findings obtained are shown in detail in point 9.

8. PRESENTATION OF ECONOMIC POTENTIAL RESULTS

Based on the methodology explained in the previous point we have calculated the economic potential of each technological solution for each of the systems analysed. Below we show the aggregate results for each resource studied with regard to the economic potential of the technique and what would be obtained from a possible investor's standpoint.

For each technical solution, we also include the investment associated with the implementation of all projects which, in accordance with foregoing point 7, have a positive cost-benefit for the Country, as well as the investment from the viewpoint of a developer. These investments have been separately calculated for each technical solution studied, but for the same systems that are the object of study.

For each system we have studied the possibility of satisfying the highest possible percentage of its demand through each of the technical solutions addressed, calculating the investment of each of these alternatives.

The comparison of the global economic potentials (at country level) and of the investor reveal the weight that the external factors considered could have for each technical solution analysed.

We should point out, given what has been explained above, that the sum of potentials or investments makes no physical sense given that they are alternative solutions for the same consumer systems.

As pointed out previously, we should also highlight the fact that the findings obtained from the economic potential study are highly sensitive to the assumptions considered in their calculation, given both the amplitude of the 2015-2050 time horizon considered as well as the high number of economic and energy variables that intervene in each of the alternatives put forward. The evolution of the baseline itself adds uncertainty to the final results. In this regard, the economic potential should not be understood as a static figure but rather has to evolve, and not only because of the dynamics of the change in the variables that determine it, but also through the introduction of suitable policies for its implementation.

The findings of the economic potential, despite their sensitivity with regard to the variables considered, should be considered as an initial approximation to the disaggregate knowledge of the economic potential of efficient heating and cooling in the different sectors nationwide, and therefore susceptible to improvement based on subsequent studies focused on specific areas of national territory.

8.1. Technical and economic potential of residual heat from industry

Of the **402 systems** identified with technical potential, **357** have economic potential for the Country, which represents **4.0 TWh** of heating and **0.1 TWh** of cooling. The implementation of this solution would represent **1.0%** of all heating demand and **0.2%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€178 million.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of residual heat from industry.

Table 51: Technical and economic potential of residual heat from industry

Sector	Use	Residual Heat From Industry Use of direct heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	18,955	16,369	16,340
	Hot water	18,362	14,878	14,864
	Cooling	834	486	486
Tertiary sector	*Heating*	185,635	149,570	148,883
	Hot water	24,265	17,837	17,746
	Cooling	90,178	32,685	32,414
Industrial sector	*Heating*	3,806,294	3,785,146	3,806,294
	Cooling	79,510	59,541	54,033
Total	*Heating*	**4,010,885**	**3,951,085**	**3,971,517**
	Hot water	**42,627**	**32,714**	**32,609**
	Cooling	**170,522**	**92,712**	**86,933**

Investment associated with execution of the economic potential (€M)	**178**	**174**

8.2. Technical and economic potential of residual heat from power plants

Of the **157 systems** identified with technical potential, **105** have economic potential for the Country, which represents **3.0 TWh** of heating and **0.2 TWh** of cooling. The implementation of this solution would represent **0.7%** of all national heating demand and **0.3%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€2.406 billion.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of residual heat from power plants.

Table 52: Technical and economic potential of residual heat from power plants

Sector	Use	Residual heat from Power Plants Use of direct heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	138,944	126,024	74,775
	Hot water	166,004	150,397	69,305
	Cooling	2,055	1,521	127
Tertiary sector	*Heating*	1,424,302	1,303,734	587,331
	Hot water	175,158	139,714	64,946
	Cooling	201,605	74,356	20,987
Industrial sector	*Heating*	1,325,563	1,258,036	1,256,735
	Cooling	140,053	76,635	76,195
TOTAL	***Heating***	**2,888,809**	**2,687,795**	**1,918,840**
	Hot water	**341,163**	**290,110**	**134,251**
	Cooling	**343,713**	**152,512**	**97,309**

Investment associated with execution of the economic potential (€M)	**2,406**	**835**

8.3. Technical and economic potential of residual heat from waste recovery plants

Of the **57 systems** identified with technical potential, **34** have economic potential for the Country, which represents **1.5 TWh** of heating and **0.2 TWh** of cooling. The implementation of this solution would represent **0.4%** of all national heating demand and **0.3%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€279 million.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of residual heat from waste recovery plants.

Table 53: Technical and economic potential of residual heat from waste recovery plants

Sector	Use	Residual Heat from Waste Recovery Plants		
		Use of direct heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	14,395	10,089	7,706
	Hot water	14,412	7,685	4,218
	Cooling	1,142	529	179
Tertiary sector	*Heating*	318,994	178,216	113,136
	Hot water	34,848	22,914	14,494
	Cooling	143,259	41,732	21,818
Industrial sector	*Heating*	1,287,618	1,276,475	1,276,473
	Cooling	119,546	107,976	107,976
TOTAL	***Heating***	**1,621,007**	**1,464,780**	**1,397,315**
	Hot water	**49,259**	**30,599**	**18,712**
	Cooling	**263,948**	**150,237**	**129,973**

Investment associated with execution of the economic potential (€M)	**279**	**183**

8.4. Technical and economic potential of Geothermics

Of the **146 systems** identified with technical potential, **144** have economic potential for the Country, which represents **1.1 TWh** of heating and **0.3 TWh** of cooling. The implementation of this solution would represent **0.3%** of all national heating demand and **0.6%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€280 million.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of Geothermics.

Table 54: Technical and economic potential of Geothermics

Sector	Use	Geothermal Use of direct heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	24,609	24,609	24,609
	Hot water	31,631	31,631	31,631
	Cooling	2,172	2,172	2,172
Tertiary sector	*Heating*	343,293	332,374	330,274
	Hot water	48,749	48,113	48,028
	Cooling	237,720	228,491	225,754
Industrial sector	*Heating*	649,592	649,592	649,592
	Cooling	92,061	92,061	92,061
Total	***Heating***	**1,017,494**	**1,006,575**	**1,004,476**
	Hot water	**80,381**	**79,744**	**79,659**
	Cooling	**331,954**	**322,725**	**319,988**

Investment associated with execution of the economic potential (€M)		
Investment associated with execution of the economic potential (€M)	**280**	**277**

8.5. Technical and economic potential of solar energy for production of hot water for sanitation purposes

Of the **1.357 systems** identified with technical potential, **1.355** have economic potential for the Country, which represents **6.0 TWh** of heating. The implementation of this solution would represent **14.7%** of all demand for hot water for sanitation or **1.5%** of all national heating demand with regard to the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€12.161 billion.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of solar energy for the production of hot water for sanitation purposes.

Table 55: Technical and economic potential of solar energy for production of hot water for sanitation purposes[7]

Sector	Use	Solar energy		
		Hot water for sanitation purposes with solar collectors		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	-	-	-
	Hot water	3,118,787	3,103,487	271,221
	Cooling	-	-	-
Tertiary Sector	*Heating*	-	-	-
	Hot water	2,911,104	2,910,638	1,032,222
	Cooling	-	-	-
Total	***Heating***			
	Hot water	**6,029,892**	**6,014,125**	**1,303,443**
	Cooling			

Investment associated with execution of the economic potential (€M)	**12,161**	**2,340**

[7] *We have considered a scaling effect in the investments due to the larger size of the centralised installations with regard to the individual ones. However, we should point out that the economic potential from the investor's viewpoint is very sensitive to the size of the investment, and a 10% increase to this investment could result in null potential.*

8.6. Technical and economic potential of Biogas

Of the **266 systems** identified with technical potential, **263** have economic potential for the Country, which represents **2.6 TWh** of heating and **0.7 TWh** of cooling. The implementation of this solution would represent **0.6%** of all national heating demand and **1.3%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€1.417 billion.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of biogas.

Table 56: Technical and economic potential of biogas

Sector	Use	Biogas Heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	115,924	115,622	105,128
	Hot water	80,256	79,778	70,113
	Cooling	5,261	5,223	4,148
Tertiary sector	*Heating*	1,305,273	1,302,025	1,085,249
	Hot water	148,861	148,728	133,584
	Cooling	569,416	567,751	498,285
Industrial sector	*Heating*	921,047	921,047	908,410
	Cooling	119,963	119,963	119,129
Total	***Heating***	**2,342,244**	**2,338,694**	**2,098,787**
	Hot water	**229,117**	**228,506**	**203,698**
	Cooling	**694,639**	**692,937**	**621,562**

Investment associated with execution of the economic potential (€M)	**1,417**	**1,096**

8.7. Technical and economic potential of Biomass

Of the **1.845 systems** identified with technical potential, **1.714** have economic potential for the Country, which represents **30.0 TWh** of heating and **5.1 TWh** of cooling. The implementation of this solution would represent **7.3%** of all national heating demand and **9.8%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€13.502 billion.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of biomass.

Table 57: Technical and economic potential of biomass

Sector	Use	Biomass Heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
residential sector	*Heating*	1,581,037	1,487,669	696,841
	Hot water	988,240	860,513	393,242
	Cooling	57,715	43,345	18,201
tertiary sector	*Heating*	11,171,175	9,621,113	4,814,544
	Hot water	960,325	851,517	471,907
	Cooling	4,065,736	3,004,266	2,053,352
Industrial sector	*Heating*	17,160,984	17,160,806	16,942,176
	Cooling	2,075,913	2,053,407	2,019,839
Total	***Heating***	**29,913,197**	**28,269,588**	**22,453,561**
	Hot water	**1,948,565**	**1,712,029**	**865,149**
	Cooling	**6,199,365**	**5,101,018**	**4,091,393**

Investment associated with execution of the economic potential (€M)	**13,502**	**6,217**

8.8. Technical and economic potential of Cogeneration

Of the **858 systems** identified with technical potential, **592** have economic potential for the Country, which represents high-efficiency cogeneration electricity power of **3,677 MWe** and generation of **11.2 TWh** of heating and **0.8 TWh** of cooling. The implementation of this solution would represent **2.7%** of all national heating demand and **1.6%** of cooling demand, both with regard to the national total in the base year. Consequently, the investment associated with the performance of all economically feasible projects would account for a total of **€4.315 billion.**

The following table shows the results of the technical and economic potential from the country standpoint and from the viewpoint of a possible investor, associated with use of cogeneration.

Table 58: Technical and economic potential of cogeneration

Sector	Use	Natural Gas Cogeneration heat Cooling absorption machine		
		Technical potential (MWh)	Country Economic Potential (MWh)	Investor Economic Potential (MWh)
Residential sector	*Heating*	2,319,687	688,397	106,550
	Hot water	1,365,233	433,821	101,755
	Cooling	32,302	8,058	6
tertiary sector	*Heating*	15,681,419	6,568,728	849,619
	Hot water	1,234,956	641,940	88,674
	Cooling	2,317,438	827,430	66,820
Industrial sector	*Heating*	9,544,438	2,826,748	0
	Cooling	592,346	0	0
Total	***Heating***	**27,545,544**	**10,083,872**	**956,169**
	Hot water	**2,600,189**	**1,075,762**	**190,429**
	Cooling	**2,942,087**	**835,488**	**66,827**

Investment associated with execution of the potential (€M)	**4,315**	**357**

9. PRESENTATION OF EFFICIENT COST POTENTIAL RESULTS

Based on the methodology explained in point seven, we have calculated the efficient cost potential at both national level as well as for each sector of demand. This analysis considers that each system analysed satisfies its energy demand, prioritising those technological solutions that have the highest NPV/MWh ratios, starting with the one with the biggest ratio, followed by the next one and so on successively until the system demand is completed. Evidently, if the technical potential of the best solution is sufficient to satisfy the system demand, this solution will be the only one that appears in this system as a cost efficient solution.

The cost efficient potential therefore maximises the NPV at country level on considering that energy demand is satisfied with those solutions that have the best NPV/MWh ratios.

Table 59 below shows the results obtained from the study of the systems selected, added together at national level for each technical solution, as well as the investments corresponding to the projects required to be able to use this potential. Furthermore, point 9.1 indicates the percentage of national demand referring to the base year that can be satisfied by the technologies studied.

Sections 9.2, 9.3, 9.4 show the potential data obtained for each technological solution within each sector studied (residential, tertiary, industrial), as well as the percentage of sectoral demand of the systems analysed that can be satisfied by each technology.

9.1. Cost efficient potential at national level

Below we provide the data obtained of the cost efficient potential of each technical solution analysed and for all consumer sectors, as well as their contribution with regard to demand of the systems analysed and the associated investment.

Table 59: National cost efficient potential

Use	Demand of systems analysed (GWh)	National demand base year (GWh)
Heating + Hot Water for Sanitation	135,728	408,019
Cooling	24,609	51,818

Solution	Use	Cost Efficient Potential (GWh)	Contribution of Systems Analysed	Investment (€M)
Residual heat from industry	*Heating + Hot*	3,966	2.9%	175
	Cooling	91	0.4%	
Residual heat from Power Plants	*Heating + Hot*	2,977	2.2%	2,405
	Cooling	152	0.6%	
Residual heat from Waste Recovery Plants	*Heating + Hot*	1,490	1.1%	276
	Cooling	150	0.6%	
Geothermal	*Heating + Hot*	1,064	0.8%	271
	Cooling	320	1.3%	
Solar	*Heating + Hot*	5,739	4.2%	11,608
	Cooling	-	-	
Biogas	*Heating + Hot*	2,562	1.9%	1,413
	Cooling	693	2.8%	
Biomass	*Heating + Hot*	29,780	21.9%	13,288
	Cooling	5,087	20.7%	
Cogeneration	*Heating + Hot*	8,005	5.9%	2,805
	Cooling	508	2.1%	

The implementation of all the cost efficient potential would generate **56 TWh** of heating and **7 TWh** of cooling, which would account for **13.6 %** of heating demand and **13.5 %** of cooling demand, both with regard to the national total in the base year, with an overall associated investment of **€32.242 billion.**

9.2. Cost efficient potential in the residential sector

Below we provide the data obtained of the cost efficient potential of each technical solution analysed for the residential sector, as well as their contribution with regard to demand of the systems analysed.

Table 60: Cost efficient potential of each technical solution in the residential sector

Use	Demand of systems analysed (GWh)	National demand base year (GWh)
Heating + Hot Water for Sanitation	9,433	102,567
Cooling	189	2,231

Solution	Use	Cost Efficient Potential (GWh)	Contribution of Systems Analysed
Residual heat from industry	*Heating + Hot Water for Sanitation*	31	0.3%
	Cooling	0	0.3%
Residual heat from Power Plants	*Heating + Hot Water for Sanitation*	276	2.9%
	Cooling	2	0.8%
Residual heat from Waste Recovery Plants	*Heating + Hot Water for Sanitation*	18	0.2%
	Cooling	1	0.3%
Geothermal	*Heating + Hot Water for Sanitation*	56	0.6%
	Cooling	2	1.2%
Solar	*Heating + Hot Water for Sanitation*	2,996	31.8%
	Cooling	-	-
Biogas	*Heating + Hot Water for Sanitation*	195	2.1%
	Cooling	5	2.8%
Biomass	*Heating + Hot Water for Sanitation*	2,347	24.9
	Cooling	43	22.9%
Cogeneration	*Heating + Hot Water for Sanitation*	904	9.6%
	Cooling	6	3.4

The implementation of the cost efficient potential in the residential sector would generate **6.8 TWh** of heating and **0.1 TWh** of cooling, which would account for **6.7 %** of total heating demand and **2.7 %** of cooling demand, both with regard to the national total of the residential sector in the base year.

9.3. Cost efficient potential in the tertiary sector

Below we provide the data obtained of the cost efficient potential of each technical solution analysed for the tertiary sector, as well as their contribution with regard to demand of the systems analysed.

Table 61: Cost efficient potential of each technical solution in the tertiary sector

Use	Demand of systems analysed (GWh)	National demand base year (GWh)
Heating + Hot Water for Sanitation	46,555	93,194
Cooling	14,561	28,409

Solution	Use	Cost Efficient Potential (GWh)	Contribution of Systems Analysed
Residual heat from industry	*Heating + Hot*	165	0.4%
	Cooling	32	0.2%
Residual heat from Power Plants	*Heating + Hot*	1,443	3.1%
	Cooling	74	0.5%
Residual heat from Waste Recovery Plants	*Heating + Hot*	196	0.4%
	Cooling	42	0.3%
Geothermal	*Heating + Hot*	360	0.8%
	Cooling	226	1.6%
Solar	*Heating + Hot*	2,743	5.9%
	Cooling	-	-
Biogas	*Heating + Hot*	1,447	3.1%
	Cooling	567	3.9%
Biomass	*Heating + Hot*	10,337	22.2%
	Cooling	2,991	20.5%
Cogeneration	*Heating + Hot*	4,275	9.2%
	Cooling	502	3.4

The implementation of the cost efficient potential in the tertiary sector would generate **21.0 TWh** of heating and **4.4 TWh** of cooling, which would account for **22.5 %** of total heating demand and **15.6 %** of cooling demand, both with regard to the national total of the tertiary sector in the base year.

9.4. Cost efficient potential in the industrial sector

Below we provide the data obtained of the cost efficient potential of each technical solution analysed for the industrial sector, as well as their contribution with regard to demand of the systems analysed.

Table 62: Cost efficient potential of each technical solution in the industrial sector

Use	Demand of systems analysed (GWh)	National demand base year (GWh)
Heating + Hot Water for Sanitation	79,740	212,259
Cooling	9,860	21,179

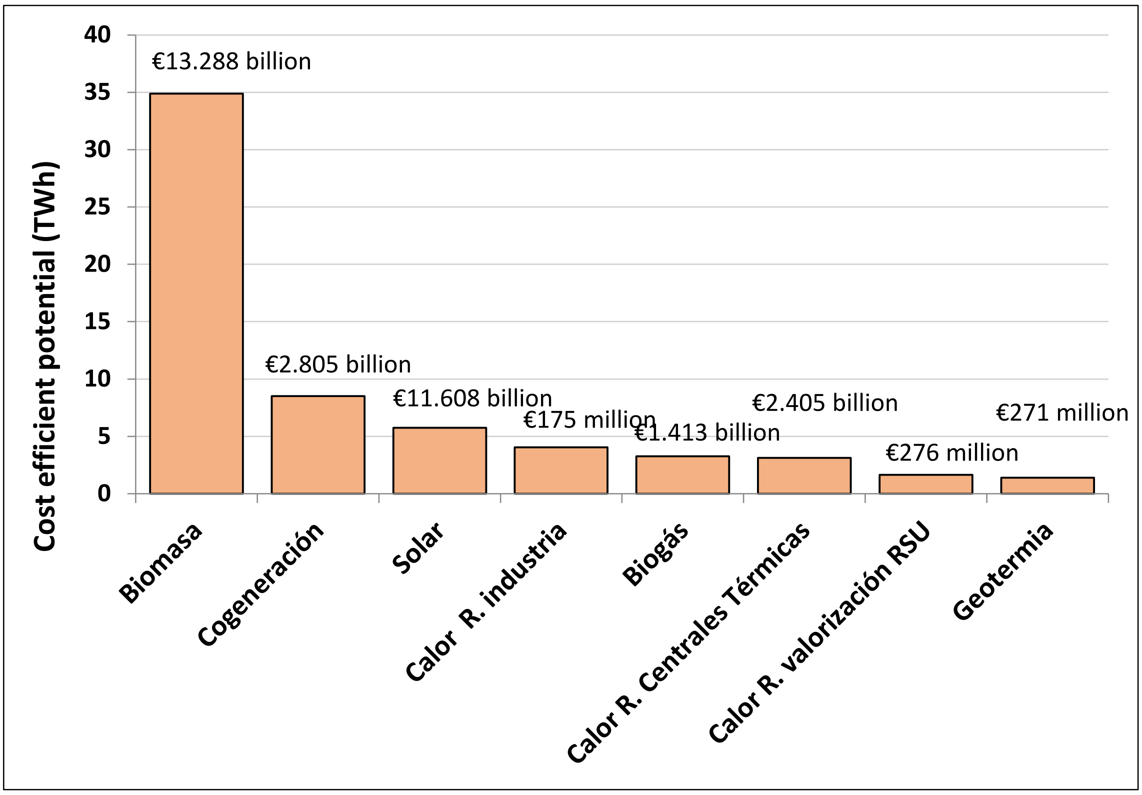
Solution	Use	Cost Efficient Potential (GWh)	Contribution of Systems Analysed
Residual heat from industry	*Heating + Hot*	3,770	4.7%
	Cooling	59	0.6%
Residual heat from Power Plants	*Heating + Hot*	1,258	1.6%
	Cooling	77	0.8%
Residual heat from Waste Recovery Plants	*Heating + Hot*	1,276	1.6%
	Cooling	108	1.1%
Geothermal	*Heating + Hot*	649	0.8%
	Cooling	92	0.9%
Biogas	*Heating + Hot*	920	1.2%
	Cooling	120	1.2%
Biomass	*Heating + Hot*	17,096	21.4%
	Cooling	2,053	20.8%
Cogeneration	*Heating + Hot*	2,827	3.5%
	Cooling	0	0.0%

The implementation of the cost efficient potential in the industrial sector would generate **27.8 TWh** of heating and **2.5 TWh** of cooling, which would account for **13.1 %** of total heating demand and **11.8 %** of cooling demand, both with regard to the national total of the industrial sector in the base year.

9.5. Conclusions

If we organise the figures of Table 59 in accordance with the energy each of the solutions analysed could potentially supply, we obtain the following chart which clearly shows the importance that certain energy resources could have in covering national energy demand from a thermal point of view.

Figure 61: Cost efficient potential and investment of the technical solutions analysed



The figure above shows that biomass is the resource which, with the proposed technical solutions, could satisfy the highest percentage of demand, with the possibility of supplying 34,868 GWh with an associated investment of €13.288 billion.

This would be followed by cogeneration, which could provide 8,514 GWh and require an investment of €2.805 billion.

Solar energy reveals thermal potential of 5,739 GWh, which would place it third. The associated investment for the use of this potential is €11,608 billion.

The next resource with the highest potential for use is residual heat from industry, which could provide 4,057 GWh with an associated investment of €175 million.

The technologies associated with the use of biogas and residual heat from power plants reveal potentials that are very similar, of 3,255 and 3,130 GWh and with associated investments of €1.413 and €2.405 billion, respectively.

The use of residual heat from waste recovery plants reveals a potential of 1,641 GWh and an associated investment of €276 million.

Lastly, Geothermics has a potential of 1,385 GWh with an associated investment of €271 million.

Elsewhere, we should also point out that the findings obtained from the potential study are highly sensitive to the assumptions considered in their calculation, given both the amplitude of the 2015-2050 time horizon considered as well as the high number of economic and energy variables that intervene in each of the alternatives put forward. The evolution of the baseline itself adds uncertainty to the final results. In this regard, the potential should not be understood as a static datum but rather has to evolve, and not only because of the dynamics of the change in the variables that determine it, but also through the introduction of suitable policies for its implementation.

Notwithstanding the foregoing, it is important to point out that the methodology adopted will be of great help in future energy planning processes as it will facilitate the taking of decisions in optimising the economic resources used.

ANNEXE

ANNEX I Sources of information and collection of data used

Below we set out the main sources of information, both official and private, that we have used in the development of this report.

1. The Land Registry

The Land Registry is a subordinate administrative record of the MINHAP (Ministry of Finance and Public Administrations) regulated by the Redrafted Text of the Land Registry Act[8], which records the urban, rural and special properties.

2. National Institute of Statistics [Instituto Nacional de Estadísticas – INE]

The National Institute of Statistics is an autonomous organisation of an administrative nature which is affiliated to the MINECO (Ministry of Economy and Competitiveness). It is governed by Law 12/1989, of 9 May, on the Public Statistical Function (LFEP), which regulates the statistical activity for state purposes (which falls exclusively to the State). This organisation is responsible for major statistical operations (demographic and economic censuses, national accounts, demographic and social statistics, economic and social indicators, coordination and maintenance of business directories, compilation of the Electoral Roll ...).

From the INE we have taken information that completes the data given by the Land Registry. This is the case, for example, with regard to the number of main, secondary and empty dwellings in Spain. The Land Registry does not include details on the occupation of properties and so if we applied the same thermal demand ratio to all properties, we would be overestimating the demand of the sector. The INE figures allow application of a corrective related to occupation by climatic zone.

3. Institute for Diversification and Saving of Energy (IDAE)

The IDAE Is an organisation affiliated to the Ministry of Industry, Energy and Tourism through the State Secretariat for Energy, to which it is answerable from an organisational standpoint and from which we have obtained the following information.

- SECH-SPAHOUSEC project. Analysis of energy consumption of the residential sector in Spain. Final report. (2011).

- Assessment of the potential for solar photovoltaic energy stemming from compliance with the Technical Building Code. Final report. (2011).
- Journal of Cogeneration Statistics (2013).
- Final Energy Balances (2013).
- Detail of consumption in the residential/household sector (2013).
- Detail of consumption in the services sector (2013).
- Monitoring of Sectoral Energy.

4. PRTR-Spain (Pollutant Release and Transfer Register)

The PRTR is a register made available to the public and which contains information on emissions into the atmosphere, water and land of polluting substances, as well as figures on the transfer of waste from the main industries and other singular and isolated sources, pursuant to the provisions set out in international legislation (Kiev Protocol and the Aarhus Convention), European legislation (E-PRTR) and national legislation (Royal Decree 508/2007 and subsequent modifications).

Information can be consulted at industrial complex level or aggregate information broken down by sector of activities, and polluting substances, type of waste and geographical sphere. Among other figures, for each installation on the register there is: the name of the industry, industrial activity code, location, industrial sector, year and polluting emissions.

5. CITL (Community Independent Transaction Log)

This contains information on the emissions trading system of each EU Member State (EU ETS). The log records all polluting emission transactions carried out by specific industries in each country and aggregate information is available by country, sector and year. Among other figures, for each installation on the register the following are given: the name of the industry, industrial activity code, industrial sector, location, year and emissions.

6. MINETUR (Ministry of Industry, Energy and Tourism)

The electricity production installations are on record with the administrative register of electricity production installations of the Ministry of Industry, Energy and Tourism, which sets out the conditions of each installation and, more specifically, their respective power. We have taken information from the Register of Installations under the Specific Regime and the Register of Electricity Production Installations.

- <u>Register of Specific Remuneration Regime Installations</u>. This includes information on installations that produce electricity from renewable energy sources, highly-efficient cogeneration and waste. It includes the name of the installation, location, electrical power, date of commissioning and type of installation.

- Register of Electricity Production Installations. This includes information on installations that produce electricity but not from renewable energy sources, highly-efficient cogeneration and waste. It includes the name of the installation, location, electrical power, date of commissioning and type of installation.

7. IPCC (Intergovernmental Panel on Climate Change)

The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 for the purpose of providing comprehensive assessments on the status of scientific, technical and social economic knowledge on climate change, its causes, possible repercussions and response strategies.

We have consulted *Vol.3 Industrial Processes and use of products* of the publication "*IPCC Guidelines 2006 for National inventories of greenhouse gases*" from which we have extracted information on industrial processes of different sectors in which there are emissions of CO_2 that are not due to combustion processes.

8. Reference efficiency parameters

To determine the thermal demand both at cogeneration installations as well as conventional installations, we have considered the energy efficiency reference parameters published in the following documents:

- Royal Decree No 413/2014 of 6 June 2014.This regulates the production of electricity from renewable energy sources, cogeneration and waste. From this royal decree we obtain information on the energy efficiency conditions required of cogeneration installations (Annex XIV).
- Commission Implementing Decision of 19 December 2011 (2011/877/EU). It contains harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council and repealing Commission Decision 2007/74/EC

9. Sources consulted for the services sector

To characterise the thermal demand of the Services Sector, the sources consulted came from ministries such as the Ministry of Public Works and Transport or the Ministry of Health, as well as some private sources such as AENA. Below we detail the sources consulted:

- National Catalogue of Spanish Hospitals-2013 (MSSSI). This contains information on Hospital Centres nationwide, and includes details such as the name, address, number of beds and centre type.

- Energy Inventory of Buildings of the General State Administration (MINETUR). It contains a list with all the Buildings of the State Administration and provides information on their type, location, floor area, energy consumption and energy rating.

- Technical Building Code (CTE) – HE Basic Document. This establishes the procedures that enable compliance with the basic energy-saving requirement in buildings. We have taken information on the average temperature values of cold water broken down by province, climatic zones, etc.

- Reference Climates - Ministry of Public Works and Transport. This includes a description of the parameters that characterise the reference climates of the BD HE. It defines the calculation exterior solicitations for a standard year through a series of parameters (temperature, humidity, solar radiation, etc.), representative of each climatic zone.

- Passenger traffic, operations and cargo at Spanish Airports (AENA). It contains a register of all Spanish airports and the number of operations carried out during 2013.

ANNEX II. Uses of the land registry

Table 63. Land uses

CODE	USE OF THE LAND REGISTRY	CLIMATIC ZONE
A	Storage	-
AAL	Store	-
AAP	Store (Car park)	-
AES	Store (Stopping)	-
BCR	Irrigation hut	-
BCT	Transformation hut	-
BIG	Farm installations	X
CCR	Meat Trading	X
CSP	Supermarket Trade	X
JAM	Mills	X
JAS	Sawmills	X
JBD	Wineries	X
JCH	Mushroom farms	X
YJD	100% private garden	-
YPO	100% porch	-
YSP	50% colonnade	-
YOU	Urban development works	-
YTD	100% uncovered terrace	-
YTZ	100% covered terrace	-
ZBE	Reservoirs, ponds	-
M	Unbuilt-up land	-
JGR	Farms	X
JIN	Greenhouses	X
I	Industry	X
IAG	Industry-Farming	X
IAL	Industry-Foodstuff	X
IAR	Industry-Agriculture	X
IBB	Industry-Beverage	X
IBR	Industry-Earthenware	X
ICN	Industry-Construction	X
ICT	Industry-Quarrying - (Mines)	X
IEL	Industry-Electricity	X
IIM	Industry-Chemicals	X

CODE	USE OF THE LAND REGISTRY	CLIMATIC ZONE
IMD	Industry-Wood	X
IMN	Industry-Manufactured	X
IMT	Industry-Metal	X
IMU	Industry-Machinery	X
IPL	Industry-Plastics	X
IPP	Industry-Paper	X
IPS	Industry-Fishing	X
IPT	Industry-Oil	X
ITB	Industry-Tobacco	X
ITX	Industry-Textile	X
IVD	Industry-Glass	X
111	Collective dwellings of an urban nature; open building	✓
112	Collective dwellings of an urban nature; closed block	✓
113	Collective dwellings of an urban nature; parking spaces, box rooms and business premises in structure	✓
121	Single-family dwellings of an urban nature: detached or semi-detached building	✓
122	Single-family dwellings of an urban nature: in-line or close block	✓
123	Single-family dwellings of an urban nature; parking spaces and porches on the ground floor	X
131	Rural building; exclusively used as dwelling	✓
132	Rural building; annexes	X
211	Manufacturing and storage premises; manufacturing on one floor	X
212	Manufacturing and storage premises; manufacturing on several floors	X
213	Manufacturing and storage premises; storage	X
221	Garages and car parks; garages	X
222	Garages and car parks; car parks	X
231	Transport services; service stations	✓
232	Transport services; stations	X
311	Exclusive building; multiple offices	✓
312	Exclusive building; unitary offices	✓
321	Mixed building; attached to dwellings	✓
322	Mixed building; attached to industry	✓
331	Banking and insurance; in an exclusive building	✓
332	Banking and insurance; in a mixed building	✓

CODE	USE OF THE LAND REGISTRY	CLIMATIC ZONE
411	Commerce in mixed building; shops and workshops	✓
412	Commerce in mixed building; shopping centres	✓
421	Commerce in an exclusive buildings; on a single floor	✓
422	Commerce in an exclusive buildings; on several floors	✓
431	Markets and supermarkets; markets	✓
432	Markets and supermarkets; hypermarkets and supermarkets	✓
511	Indoor areas; miscellaneous sports	✓
512	Indoor areas; swimming pools	✓
521	Outdoor areas; miscellaneous sports	X
522	Outdoor areas; swimming pools	X
531	Auxiliary areas; changing rooms, treatment plants, heating, etc.	✓
541	Sporting events; stadiums, ball rings	X
542	Sporting events; horseracing tracks, dog tracks, velodromes, etc.	X
611	Miscellaneous shows; covered areas	✓
612	Miscellaneous shows; uncovered areas	X
621	Music bars and discotheques; in an exclusive building.	✓
622	Music bars and discotheques; attached to other uses	✓
631	Cinemas and theatres; cinemas	✓
632	Cinemas and theatres; theatres	✓
711	With residence; hotels, hostels, motels	✓
712	With residence; apartment hotels, bungalows	✓
721	Without residence; restaurants	✓
722	Without residence; bars and cafeterias	✓
731	Exhibitions and meetings; clubs and social clubs	✓
732	Exhibitions and meetings; exhibitions and conferences	✓
811	Healthcare with beds; healthcare and clinics	✓
812	Healthcare with beds; hospitals	✓
821	Miscellaneous healthcare; outpatient and consultancy	✓
822	Miscellaneous healthcare; spas, bathhouses	✓
831	Welfare and assistance; with residence (asylums, residences, etc.)	✓

CODE	USE OF THE LAND REGISTRY	CLIMATIC ZONE
832	Welfare and assistance; without residence (canteens, clubs, nurseries, etc.)	✓
911	Cultural with residence; boarders	✓
912	Cultural with residence; senior schools	✓
921	Cultural without residence; faculties, colleges, schools	✓
922	Cultural without residence; libraries and museums	✓
931	Religious; convents and parish centres	✓
932	Religious; churches and chapels	✓
1011	Historic-artistic; monuments	X
1012	Historic-artistic; environmental or typical	X
1021	Of an official nature; administrative	✓
1022	Of an official nature; representative	✓
1031	Of a special nature; prisons, military and sundry	✓
1032	Of a special nature; interior development works	✓
1033	Of a special nature; campsites	X
1034	Of a special nature; golf courses	X
1035	Of a special nature; landscaping	X
1036	Of a special nature; silos and tanks for solids (m3)	X
1037	Of a special nature; liquid tanks (m3)	X
1038	Of a special nature; gas tanks (m3)	X

Where:

✓ Different thermal consumption between climatic zones.

X Same thermal consumption irrespective of climatic zone.

- Without thermal consumption.

ANNEX III. Correspondence of the thermal zone of the CTE (Technical Building Code) with the climatic zones considered in the SES (Sectoral Energy Monitoring)

Table 64. Correspondence of the thermal zone of the CTE[9] with the climatic zones considered in the SES

SES Climatic Zone	Province	CTE Climatic Zone
North Atlantic	Pontevedra	C1
	La Coruña	C1
	Lugo	D1
	Oviedo	D1
	Santander	C1
	Bilbao	C1
	San Sebastián	D1
Mediterranean	Málaga	A3
	Cádiz	A3
	Las Palmas	α3
	Tenerife	α3
	Almeria	A4
	Castellón	B3
	Murcia	B3
	Mallorca	B3
	Tarragona	B3
	Valencia	B3
	Seville	B4
	Alicante	B4
	Córdoba	B4
	Huelva	A4
	Barcelona	C2
	Girona	D2
	Granada	C3
	Jaén	C4

SES Climatic Zone	Province	CTE Climatic Zone
Continental	Soria	E1
	Ávila	E1
	Burgos	E1
	León	E1
	Madrid	D3
	Guadalajara	D3
	Ciudad Real	D3
	Albacete	D3
	Lleida	D3
	Zaragoza	D3
	Huesca	D2
	Logroño	D2
	Salamanca	D2
	Segovia	D2
	Teruel	D2
	Valladolid	D2
	Zamora	D2
	Palencia	D1
	Pamplona	D1
	Vitoria	D1
	Badajoz	C4
	Cáceres	C4
	Toledo	C4
	Orense	D2
	Cuenca	D2

[9] *For each Spanish province we have taken the climatic zone of the Province capital, in accordance with "Appendix B. Climatic Zones", of the CTE.*

ANNEX IV. Surface areas broken down by climatic zone and use of land in accordance with the Land Registry

Table 65. Specific surface area m^2

Use of land	North Atlantic	Continental	Mediterranean
1	-	72,161	1,092
4	293,370	1,096,771	808,741
5	1,494,941	3,105,579	5,543,425
12	2,193,924	6,842,593	8,078,924
13	10,873	144,724	121,011
14	-	104,157	720
15	60,194	946,211	402,697
16	192,197	1,428,462	692,531
17	341,409	1,416,424	2,066,240
18	1,308,035	1,399,974	4,613,985
19	31,539	105,600	56,986
20	168,368	1,192,004	544,641
21	675	33,497	57,367
22	16,060	204,293	404,872
23	83,163	344,845	350,441
24	163,758	436,668	1,404,927
25	41,669	71,484	18,717
26	72,858	146,453	64,127
27	395,723	158,720	1,239,995
28	92,205	142,394	84,830
29	18,618	1,157,406	369,353
30	735,356	702,313	2,123,336
31	74,138	814,473	265,001
32	488	62,252	3,680
33	41,115	251,119	288,970
34	16,006	-	-
35	70	7,585	326,557
36	-	-	10,085
37	1,280	68,056	56,245
38	77,583	213,290	152,688
39	-	5,019	493
40	2,193,924	6,841,077	8,064,164

Table 66. Diffused surface area m^2

Use of land	North Atlantic	Continental	Mediterranean
2	196,660,565	466,525,103	753,465,626
3	122,585,982	401,140,426	595,373,591
4	12,451,538	40,788,860	43,343,950
5	24,603,608	41,806,409	91,458,782
6	2,199,705	6,662,749	10,966,761
7	634,194	950,826	783,632
8	4,754,315	3,111,636	1,681,525
9	1,019,087	4,845,289	5,484,907
10	5,810,917	19,012,912	47,405,326
11	4,897,923	13,922,551	17,019,164
12	1,824,401	8,602,014	7,108,182
13	1,984,538	4,510,556	4,859,776
14	2,056,406	7,620,642	5,481,302
15	17,090,395	42,825,445	47,502,319
16	1,422,050	8,774,615	8,154,927
17	537,508	3,789,820	3,810,616
18	32,075,124	59,173,649	101,467,936
19	9,687,859	22,983,323	9,317,244
20	2,465,314	12,577,607	7,650,626
21	548,745	12,973,184	2,758,263
22	371,593	3,593,268	1,666,536
23	297,007	509,584	1,008,962
24	1,450,893	3,103,566	3,251,023
25	275,957	989,550	270,439
26	8,199,579	3,588,988	3,427,622
27	2,199,290	1,363,087	1,710,796
28	2,504,598	5,140,832	4,058,485
29	1,129,039	15,693,839	16,568,924
30	5,768,762	9,580,395	5,148,995
31	2,939,708	4,508,453	9,385,826
32	346,580	808,725	737,019
33	240,253	993,279	793,018
34	714,991	74,891	207,341
35	486,609	707,302	2,059,367
36	70,892	256,462	107,709
37	888,433	1,574,576	2,187,917
38	179,126	359,279	396,004
39	44,306	152,654	108,528