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GOVERNMENT OF SPAIN
MINISTRY OF ECOLOGICAL TRANSITION AND THE DEMOGRAPHIC CHALLENGE
Energy Saving and Diversification Institute (IDAE)

SECOND ASSESSMENT OF THE POTENTIAL FOR EFFICIENT HEATING AND COOLING

PART I: OVERVIEW OF HEATING AND COOLING PART III: ANALYSIS OF THE ECONOMIC POTENTIAL FOR EFFICIENCY IN HEATING AND COOLING

In accordance with Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU of the European Parliament and of the Council on the contents of comprehensive assessments of the potential for efficient heating and cooling

TABLE OF CONTENTS

INDEX OF FIGURES:

INDEX OF TABLES:

INTRODUCTION

Following the amendment of Annex VIII to Directive 2012/27/EU by Commission Delegated Regulation 2019/826, the required contents of **national comprehensive assessments of the potential for efficiency in heating and cooling** are:

- Part I – Points 1-4: Overview of heating and cooling
- Part II – Points 5-6: Objectives, strategies and policy measures
- Part III – Points 7-8: Analysis of the economic potential for efficiency in heating and cooling
- Part IV – Point 9: Potential new strategies and policy measures

This document covers Parts I and III, and addresses all the points that the Commission Delegated Regulation requires those parts to contain, without, however, following the original format. Similarly, Annexes I and II together cover Parts II and IV under the Commission Delegated Regulation. They contain separately the calculation of the contribution required under point 5 (Part II), and the details of policy measures, both those in existence and those planned for the future, as required by points 6 (Part II) and 9 (Part IV).

0. EXECUTIVE SUMMARY

0.1. INTRODUCTION

This document presents the results of the comprehensive assessment of the potential for efficient heating and cooling, in accordance with Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU, and with Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. The Commission Recommendation of 25 September 2019 on the content of the comprehensive assessment of the potential for efficient heating and cooling under Article 14 of Directive 2012/27/EU was taken into account when performing the assessment.

We will begin by describing the calculation methodology used to characterise Spain’s demand for heating and cooling in 2018 and the results of this process. This demand involves the following types of thermal energy depending on the sector consuming that energy:

- domestic hot water (DHW), heating and air conditioning in the housing and service sectors;
- heating water and gases, producing steam and cooling for production processes in the industrial sector.

We will then calculate the technical and economic potential of certain ‘efficient’ technologies, distinguishing between ‘on-site’ systems, where the energy is generated in the demand location, and ‘district-type’ systems, where the energy is generated remotely.

Finally, we will assess the impact that developing the potential of ‘efficient’ technologies would have in terms of CO_2 emission reductions, primary energy savings and the use of renewables.

0.2. SPANISH HEATING AND COOLING DEMAND CHARACTERISATION

‘Demand characterisation’ is the process of quantifying the heating and cooling requirements in each activity sector or area and identifying the fuel type and technology currently being used to meet those requirements. This characterisation was performed using a database and calculation tool developed using data from the Land Register that allowed the Spanish demand for heating and cooling in various activity sectors to be modelled, identifying each property’s thermal demand value and the technology being used.

The results of this process – national heating and cooling demand by sector for 2018 – are shown in the table below:

Table 1: Spain's estimated heating and cooling demand in 2018

Heating demand, useful energy	Housing sector	87 586 GWh
	Service sector	53 026 GWh
	Industrial sector	154 346 GWh
Cooling demand, useful energy	Housing sector	3 819 GWh
	Service sector	22 224 GWh
	Industrial sector	18 584 GWh
Overall demand, useful energy	Housing sector	91 404 GWh
	Service sector	75 250 GWh
	Industrial sector	172 930 GWh
TOTAL		**339 584 GWh**

Source: authors' own

We also analysed how this demand is covered by the different technologies, using the data available in a number of studies and sources of information (the *Statistical Analysis of Natural Gas Consumption In Main Residences with Stand-alone Heating Systems* ('SPAHOUSEC'), the *Spanish Building Sector Long-Term Energy Renovation Strategy* ('ERESEE'), the register of power stations covered by the 'ordinary' remuneration scheme (as opposed to the 'specific' scheme for plants generating power using cogeneration technology, renewable energy or waste), and the Eurostat final energy consumption balances). The table on the next page shows the results of this analysis.

Table 2: Heating and cooling demand coverage by sector, technology and source type

SECTOR	THERMAL ENERGY USE	SOURCE	TECHNOLOGY	DEMAND COVERAGE (GWh)		
Housing	Heating, DHW	Fossil fuels	Coal boiler	10.15	87 586	91 404
			Petroleum-product-fired boiler	27 900.93		
			Gas boiler	29 288.90		
		Electricity	Heat pump	2 212.68		
			Electric boiler and radiator	9 077.38		
		Cogeneration	Cogeneration	1.17		
		Renewables	Heat pump (renewable-powered only)	1 601.66		
			Biomass boiler	15 109.07		
			Solar thermal panel	2 383.85		
	Cooling	Electricity	Heat pump	3 818.63	3 819	
		Cogeneration	Cogeneration	0.04		
Services	Heating, DHW	Fossil fuels	Petroleum-product-fired boiler	7 673.89	53 026	75 250
			Gas boiler	25 845.63		
		Electricity	Heat pump	10 173.60		
			Electric boiler and radiator	2 827.90		
		Cogeneration	Cogeneration	211.44		
		Renewables	Heat pump (renewable-powered only)	4 483.58		
			Biomass boiler	1 163.27		
			Solar thermal panel	646.26		
	Cooling	Electricity	Heat pump	22 167.05	22 224	
		Cogeneration	Cogeneration	57.43		
Industry	Hot water, steam, low- + high-temp. gases	Fossil fuels	Coal boiler	25 185.66	154 346	172 930
			Petroleum-product-fired boiler	13 112.01		
			Gas boiler	82 227.32		
			Cogeneration	25 924.43		
		Renewables	Biomass boiler	7 813.63		
			Solar thermal panel	82.46		
	Cooling	Electricity	Compression machinery	15 281.50	18 584	
		Cogeneration	Cogeneration	3 302.25		
TOTAL						**339 584**

Source: authors' own

The above table does not specify demand coverage by district heating systems because the information available is limited to the statistics compiled in accordance with Article 24(6) of Directive 27/2012/EU, which are based on a survey by the Association of District Heating and Cooling Businesses (ADHAC) and are not broken down by technology. The 2018 district heating and cooling statistics are shown in the table below.

Table 3: Spanish district heating and cooling capacity and generation in 2018

Sector	Number of installations	Capacity		Demand	
		Heating (MW)	Cooling (MW)	Heating (MWh)	Cooling (MWh)
Housing and services	40	194	29	215 890	20 015
Industry	11	293	208	319 726	174 196
Total	**51**	**487**	**237**	**535 687**	**194 212**

Source: ADHAC 2018 network statistics

0.3. FINAL ENERGY CONSUMPTION

In the same way, we estimated final energy consumption, which is identified as the quantity of fuel and electricity used to meet the heating and cooling demand, as shown in the table below.

Table 4: Estimated final energy consumption to meet Spanish demand for heating and cooling in 2018

Final energy consumption – heating	Housing sector	107 180 GWh
	Service sector	49 790 GWh
	Industrial sector	183 931 GWh
Final energy consumption – cooling	Housing sector	1 645 GWh
	Service sector	9 616 GWh
	Industrial sector	10 004 GWh
Overall final energy consumption	Housing sector	108 825 GWh
	Service sector	59 406 GWh
	Industrial sector	193 935 GWh
TOTAL		**362 166 GWh**

Source: authors' own

0.4. HEATING AND COOLING DEMAND PROJECTIONS TO 2050

The 2018 demand characterisation was used as a reference case from which to project the change in demand up to 2050 and propose efficient, carbon-reducing alternatives to the technologies currently used for heating and cooling. The baseline scenario and demand forecasts presented in Spain's Integrated National Energy and Climate Plan (NECP), drawn up by the Ministry of Ecological Transition and the Demographic Challenge, were used to model the expected evolution of heating and cooling demand. The table below shows the results of this process.

Table 5: Estimated demand projection (in GWh per year)

		2020	2025	2030	2035	2040	2045	2050
Heating demand, useful energy	Housing sector	88 529	90 264	91 198	90 995	90 907	90 809	90 562
	Service sector	55 072	56 834	57 585	58 162	58 614	59 219	60 336
	Industrial sector	160 840	168 737	174 836	180 435	185 703	191 876	200 649
Cooling demand, useful energy	Housing sector	4 181	4 769	5 357	5 905	6 498	6 512	6 515
	Service sector	23 081	23 764	24 020	24 201	24 327	24 514	24 909
	Industrial sector	18 584	18 584	18 584	18 584	18 584	18 584	18 584
Overall demand	Housing sector	92 710	95 033	96 555	96 900	97 405	97 321	97 077
	Service sector	78 153	80 598	81 605	82 363	82 941	83 733	85 245
	Industrial sector	179 424	187 321	193 420	199 019	204 287	210 460	219 233
TOTAL		**350 287**	**362 952**	**371 580**	**378 282**	**384 633**	**391 514**	**401 555**

Source: authors' own based on the NECP baseline scenario

0.5. TECHNICAL AND ECONOMIC POTENTIAL OF EFFICIENT RENEWABLE TECHNOLOGIES

To assess the technical and economic potential of efficient renewable technologies that could replace the technologies currently in use in the reference case, we divided the overall thermal demand figure into a number of '**thermal systems**'. The criteria used for this division varied depending whether the efficient technology used in a given thermal system energy is generated close to the demand location ('on-site' systems) or remotely ('district-type' systems):

- For 'on-site' systems demand was grouped by economic sector and sub-sector and locations with the same environmental conditions;
- For 'district-type' systems demand was grouped by geographical proximity into high-demand-density areas.

The renewable-energy-based and/or high-efficiency thermal technologies assessed in this study were:

- 'On-site' technologies:
  - Conventional (i.e. not concentrated) solar thermal
  - Concentrated solar thermal
  - Air-source heat pump
  - Ground-source heat pump
  - Biomass boiler
  - High-efficiency cogeneration
- 'District-type' technologies:
  - District heating using industrial waste heat
  - District heating using heat from waste incineration
  - District heating using waste heat from thermal power plants
  - District heating using biogas

- District heating using biomass
- District heating using direct-use geothermal energy
- District heating using cogeneration
- District heating using a ground-source heat pump
- District heating using conventional solar thermal power
- District heating using concentrated solar thermal power

A commonly used ‘on-site’ technology based on non-renewable source – the natural gas boiler – was also analysed alongside the above technologies. An assessment of the technical and economic potential of renewable-energy-based technologies needs to be benchmarked against at least one non-renewable technology, such as the natural gas boiler. Otherwise, any conclusions drawn would fail to take account of the different options that consumers have at their disposal to meet their energy requirements – the natural gas boiler would always be a point of reference for consumers in this respect.

The potential of each of the technologies has been assessed on the basis of heating to low and medium temperatures (up to 250 °C) and cooling. The demand for heating to high temperatures (above 250 °C) present in the industrial sector has not been taken into account because we are unable to identify generic technology meeting this need. This assessment is therefore based on the technologies listed above, using simplified models.

For each efficient renewable technology that could replace the technologies present in the reference case, we quantified the installable capacity and the energy that the technology could supply to each thermal system in order to establish its technical potential.

Then, considering aspects such as the cost of investment, operation, fuel and externalities, we performed the cost-benefit analysis, comparing the technologies currently in use in the reference case with each efficient renewable technology analysed in order to establish the economic potential of that technology. The economic selection criterion used was the net present value (NPV) calculated by discounting cash flows at a discount rate of 5%, considering only positive NPVs.

We performed this analysis from two different perspectives: that of the investor and that of society. The investor NPV provides information on whether replacing an existing technology with a new one would lead to savings for the party that invested in that new technology, while the society NPV considers the costs and benefits of replacing the technology, including socio-economic and environmental factors (reducing fuel imports, creating jobs, environmental impact), providing information on whether replacing a given technology would be beneficial for the country’s economy as a whole.

The table below shows the technical and economic potential of the different technologies analysed:

Table 6: Analysis results of the technical and economic potential (aggregated values for heating and cooling)

	Technical potential		Economic potential – investor		Economic potential – society	
Technology	Capacity (GW)	Generation (GWh)	Capacity (GW)	Generation (GWh)	Capacity (GW)	Generation (GWh)
Conventional solar thermal	29.245	28 137	23.781	23 788	28.431	27 601
Concentrated solar thermal	19.204	18 985	2.785	3 103	19.201	18 984
Air-source heat pump	114.777	166 781	12.079	32 097	91.573	139 306
Ground-source heat pump	56.047	71 783	4.126	12 626	33.717	51 563
Biomass boiler	63.286	119 128	45.139	88 258	57.697	99 409
High-efficiency cogeneration	12.438	76 270	1.747	12 143	2.434	15 041
Natural gas boiler	126.201	210 655	21.635	82 323	17.182	66 123
District – industrial waste heat	0.105	591	0.045	288	0.100	562
District – waste heat from incinerators	0.634	3 541	0.283	1 907	0.546	3 161
District – waste heat from thermal power plants	0.426	2 438	0.168	1 233	0.333	2 056
District – biogas	0.139	623	0.055	278	0.117	538
District – biomass	7.385	31 826	2.633	14 941	7.184	31 186
District – direct-use geothermal	0.972	5 839	0.954	5 738	0.972	5 839
District – cogeneration	1.187	8 421	0.000	0	0.437	3 424
District – ground-source heat pump	9.729	43 703	0.952	4 923	6.392	30 361
District – conventional solar thermal	5.233	4 330	1.577	1 463	5.062	4 174
District – concentrated solar thermal	5.155	4 827	1.997	1 893	4.964	4 645

Source: authors' own

0.6. COST-EFFICIENT POTENTIAL

We also assessed what is known as the 'cost-efficient' potential, ranking the technological solutions from highest to lowest in terms of the ratio of NPV for society to the useful energy generated (the NPV-to-MWh ratio), and applying the solutions to the energy demand of **each system studied**, starting with the technology with the highest ratio and continuing down the list until the system's entire demand is met.

The cost-efficient potential maximises the NPV of the economic balances from society's perspective, considering that energy demand is met by the solutions with the best NPV-to-MWh ratios. This ranking of technologies was as follows:

Table 7: Thermal generation technologies ranked by their cost-effective potential for society

Technology	Technology type	Generation (GWh)
Air-source heat pump	On-site	85 784
Biomass boiler	On-site	47 255
Natural gas boiler	On-site	20 344
Conventional solar thermal	On-site	18 375
District heating using biomass	District	13 781
Ground-source heat pump	On-site	5 378
Concentrated solar thermal	On-site	5 191
District heating using direct-use geothermal	District	4 985
High-efficiency cogeneration	On-site	3 008
District heating using waste heat from incineration	District	1 734
District heating using waste heat from industry	District	448
District heating using concentrated solar thermal power	District	354
District heating using waste heat from thermal power plants	District	307
District heating using a ground-source heat pump	District	233
District heating using biogas	District	173
District heating using conventional solar thermal power	District	24
TOTAL		**207 374**

Source: authors' own

In addition to this demand coverage of 207 374 GWh, the 'district-type' technologies and high-efficiency cogeneration solutions considered in the cost-efficient analysis could cover a further 4 521 GWh with back-up support from natural gas, bringing the overall demand coverage figure to 211 896 GWh.

0.7. CO_2 EMISSION REDUCTIONS, PRIMARY ENERGY SAVINGS AND THE IMPACT ON THE SHARE OF RENEWABLES IN THE NATIONAL ENERGY MIX

We began by estimating the reduction in CO_2 emissions, primary energy savings and the impact on the share of demand covered by renewable energy that would be achieved by implementing the entire cost-efficient potential with the technological solutions identified (the 'cost-efficient' scenario). The results are shown in the table below.

Table 8: CO_2 emissions, primary energy consumption and use of renewables in the reference case and the cost-efficient scenario

Scenario	CO_2 emissions		Primary energy consumption		Use of renewables	
	Thousand tCO_2 per year	tCO_2 per MWh (1)	GWh p.a.	E_P/E_U (2) (Energy use per unit generated)	GWh p.a.	Coverage
Reference case	47 696	0.187	298 664	1.17	30 766	12%
Cost-efficient scenario	21 192	0.083	236 666	0.93	143 511	56%
Variation	-26 504	-0.104	-61 998	-0.24	112 745	44%
	-55.57%		-20.76%		366.46%	

(1) *Ratio of CO_2 emissions per unit of useful energy generated.*
(2) *Ratio of primary energy used per unit of useful energy generated.*

Source: authors' own

Fully developing the cost-efficient potential with the above technologies would therefore achieve:

- Savings of around 55% in CO_2 emissions, equivalent to avoiding emissions of some 26 million tonnes of CO_2 each year;
- A reduction of around 20% in primary energy consumption, equivalent to around 62 000 GWh each year;
- Significant growth in the use of renewable energy, which would increase to 143 511 GWh, almost quadrupling the reference case figure of 30 766 GWh.

1. INTRODUCTION, CONTEXT AND OBJECTIVES

1.1. PURPOSE OF THIS REPORT

This report presents the comprehensive assessment of the potential for efficient heating and cooling, in accordance with Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU, and with Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. The Commission Recommendation of 25 September 2019 on the content of the comprehensive assessment of the potential for efficient heating and cooling under Article 14 of Directive 2012/27/EU was also taken into account in the drafting of this report. The points required by Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 that are covered by this report are:

1. Overview of heating and cooling (Part I of the Commission Delegated Regulation)
    a. An estimation of heating and cooling demand and the final energy consumed in meeting this demand, by sector;
    b. An identification of current heating and cooling supply by technology;
    c. An identification of installations that generate waste heat or cold;
    d. A map of the entire national territory, indicating the areas with heating and cooling demand and the areas offering waste heat and cold;
    e. A forecast of trends in the demand for heating and cooling for the next 30 years, up to 2050, in GWh per year.
2. Analysis of the technical and economic potential for efficiency in heating and cooling (Part II of the Commission Delegated Regulation)
    a. Analysis of the available technical potential of the technologies studied for more efficient heating and cooling;
    b. The identification of the reference case and the baseline projection to 2050 as a basis for comparing efficient solutions;
    c. Analysis of the economic potential of the alternative scenarios considered;
    d. A cost-benefit analysis.

The first point of Part II of the outline laid down in the Regulation is covered by Annex I. Annex II provides details of both existing policies and measures and any new ones that could be implemented (the second paragraph of Part II and Part IV according to the Regulation).

1.2. STUDY METHODOLOGY

In order to characterise demand, we created a model that uses Land Register data to simulate the demand for thermal energy (heating and cooling) and a heating or cooling technology for each Land Register record. This simulation is done using the information available in the Land Register itself as well as additional data from other sources and studies specific to each economic sector.

This model was set up in two stages: in the first stage we compiled all the information into a database and generated the actual calculation model, and in the second stage we cross-checked and corrected the model to bring it into line with the final energy consumption balances.

We then examined the technical feasibility of a group of technologies based on the demand simulation model.

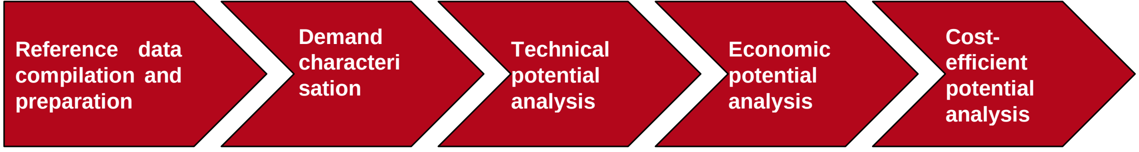
The renewable-energy-based and/or high-efficiency thermal technologies assessed in this study were:

- on-site conventional and concentrated solar
- on-site air-source and ground-source heat pump
- on-site biomass boiler
- on-site cogeneration and micro-CHP
- district heating using industrial waste heat
- district heating using waste heat from thermal power plants and/or waste incineration
- district heating using biogas
- district heating using biomass
- district heating using direct-use geothermal energy
- district heating using cogeneration and/or micro-CHP
- district heating using a ground-source heat pump
- district heating using conventional and concentrated solar thermal power

We also included a non-renewable technology, the natural gas boiler, in the study to see how it competes economically with less efficient technologies in the industrial sector.

We then conducted a cost-benefit analysis for each of the technologies analysed, comparing the proposed solutions to the values already calculated for the reference case in the characterisation of demand projected up to 2050 using the baseline scenario from the National Energy and Climate Plan (NECP). This cost-benefit analysis was carried out from both the investor's and society's perspective.

Finally we identified the optimum cost-effective potential for society, selecting the technology with the highest economic return for society for each MWh delivered at each of the identified demand points. The results were then aggregated. This made it possible to identify the potential of the technologies that are optimal for society with the aim of establishing possible policies to help them to penetrate.

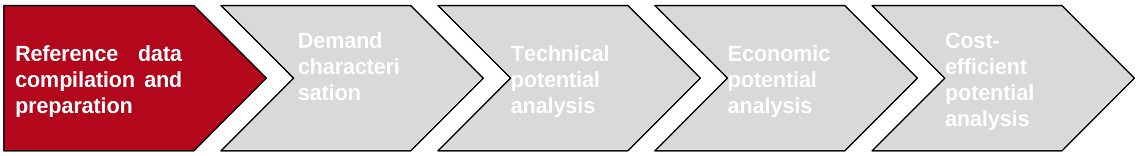


Reference data compilation and preparation	Demand characterisation	Technical potential analysis	Economic potential analysis	Cost-efficient potential analysis
Compilation, based on the Land Register and other sources of information, of data on energy-demanding parcels; introduction to and technical information on types of consumption and technologies used	Calculation of the demand for heating and cooling and the available waste heat and cold supply and alternative fuels based on the fuel mix in the national energy balance and consumption ratios for each sector, considering the specificities of each system (use, climate zone, technology, etc.)	Sizing the technological alternatives for the energy-demanding systems that are efficient and environmentally friendly; calculating the new fuel consumption figures and estimating the equipment needed	Cost-benefit analysis of the investments associated with a change in technology and consumption by technical alternatives	Cost efficient analysis, including aggregation of the optimal solution for each system analysed

Figure 1: Method established for the comprehensive assessment of the potential for efficient heating and cooling

Source: authors' own

2. REFERENCE DATA COMPILATION AND PREPARATION



2.1. INTRODUCTION

This chapter describes the reference case data that were gathered, correlated and entered into an SQL[1]-based database managed using MySQL, which is open-source software offering efficient solutions in the subsequent application of calculation tools.

Here is an overview of the method used and the steps taken, from generating the database using Land Register data to extracting the results for heating and cooling demand:

1. Aggregated data – We consulted several sources of aggregated data on fuel consumption and the technologies used in each economic sector, which formed the basis for classifying the land uses listed in the register into demand types, establishing demand ratios (kWh per m²) and assigning the different technologies used to meet this demand. These sources of information were:
    - **a.** the Final Energy Balances and other official documents for fuel consumption statistics by sector (housing, services and industry);
    - **b.** versions I and II of the *Statistical Analysis of Natural Gas Consumption In Main Residences with Stand-alone Heating Systems* (‘SPAHOUSEC’) for details of the technology mix in the housing sector;
    - **c.** statistics published by the National Statistics Institute (‘INE’) for details of population and main residences by municipality;
    - **d.** the Integrated National Energy and Climate Plan (NECP) for information on trends in demand in the housing, services and industrial sectors;
    - **e.** the 2020 *Spanish Building Sector Long-Term Energy Renovation Strategy* (‘ERESEE’) for details of consumption and demand in the housing and service sector;
    - **f.** other studies for information on thermal demand in specific sub-sectors.

2. External audits – The aggregated information for the service and industrial sectors was supplemented with data from audits involving the authors of this study.
3. The Land Register, for the location, activity, area and other relevant details on each registered parcel analysed.

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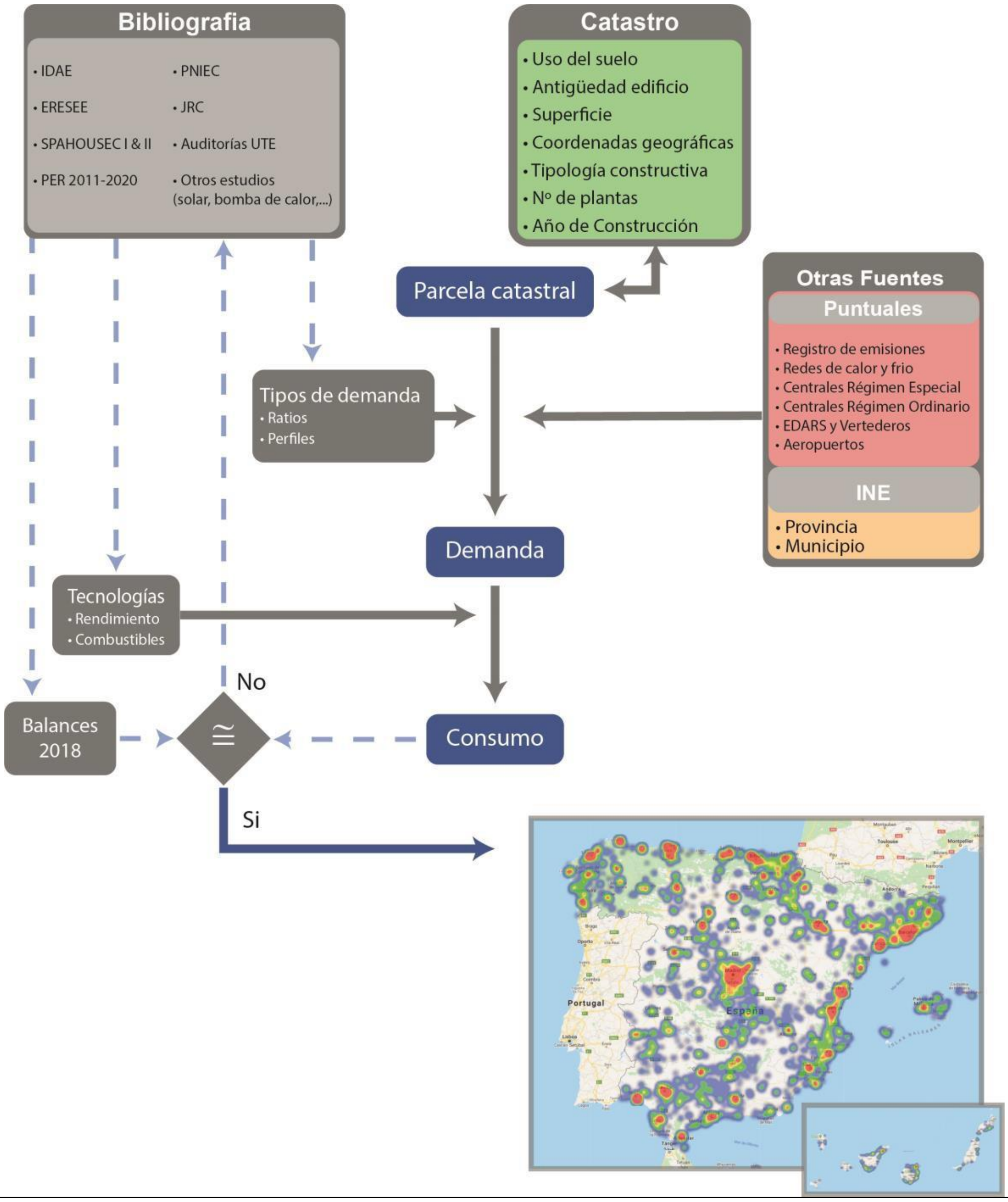
[1] SQL (Structured Query Language) is a domain-specific language used in programming, designed for managing and retrieving information from relational database management systems.

4. **4.** Other sources of specific information – We consulted other sources, including data on specific installations that go beyond the details used to characterise the registered land parcels, and more specifically:
    - **a.** the national Pollutant Release and Transfer Register;
    - **b.** the register of power stations covered by the 'specific' remuneration scheme (for plants generating power using cogeneration technology, renewable energy or waste), and the 'ordinary' remuneration scheme (for all other power stations);
    - **c.** the District Heating and Cooling Survey;
    - **d.** the register of waste water treatment plants and landfill sites;
    - **e.** the airport and passenger traffic register.
5. **5.** Database and model creation – We compiled all this information into tables, drew up additional tables and established the correlation between the different tables to aid the modelling of thermal demand and fuel consumption.
6. **6.** Demand characterisation calculation based on the ratios and the area obtained from the Land Register – Once the demand ratios per area unit had been established for each type of demand considered, they were cross-checked against the area extracted from the Land Register in order to obtain the heating and cooling demand for the whole of Spain. The final result was compared to the different sources of information in order to validate the model.

Thanks to the relational database created in this process, a geo-referenced characterisation of thermal demand and the associated consumption could be drawn up for the whole of Spain. The results of this could then be displayed on a map to help plan efficient and/or renewable technological solutions.

The process described above is depicted in Figure 2.



KEY					
Bibliografía	Documentation	*Coordenadas geográficas*	Geographical coordinates	*Centrales Régimen Ordinario*	Power plants operating under the 'ordinary' scheme
IDAE	Energy Saving and Diversification Institute	*Tipología constructiva*	Building type	*EDARS y Vertederos*	Waste water treatment plants and landfill sites
ERESEE	ERESEE	*Nº de plantas*	No of storeys	*Aeropuertos*	Airports
SPAHOUSEC I & II	SPAHOUSEC I and II	*Año de Construcción*	Year of construction	*INE*	National Statistics Institute
PER 2011-2020	Renewable Energy Plan 2011-2020	*Parcela catastral*	Registered parcel	*Provincia*	Province
PNIEC	NECP	*Tipos de demanda*	Demand types	*Municipio*	Municipality
JRC	Joint Research Centre	*Ratio*	Ratio	*Tecnologías*	Technologies
Auditorías UTE	Joint venture (*Uniones Temporales de Empresa*) audits	*Perfiles*	Profiles	*Rendimiento*	Efficiency
Otros estudios (solar, bomba de calor…)	Other studies (solar, heat pumps, etc.)	*Demanda*	Demand	*Combustibles*	Fuels
Catastro	Land register	*Otras fuentes*	Other sources	*Balances 2018*	2018 balances

Uso del suelo	Land use	*Puntuales*	Specific	*No*	No
Antigüedad edificio	Building age	*Registro de emisiones*	Pollutant Release & Transfer Register (PRTR)	*Sí*	Yes
Superficie	Area	*Centrales Régimen Especial*	Power plants operating under the 'specific' scheme	*Consumo*	Consumption

Figure 2: Database creation and thermal demand calculation flowchart

Source: authors' own

2.2. AGGREGATED DATA

The main sources of aggregated data used in this study are detailed below. These official documents provided the context and reference used as a basis for structuring this report, and allowed us to gain an overview of the demand for heating and cooling in Spain in 2018.

2.2.1. 2018 FINAL ENERGY BALANCES

The Energy Saving and Diversification Institute (IDAE) publishes final energy balances[2] each year, reporting the main ways in which energy sources are consumed, broken down by economic sector. This includes consumption data for the industrial sectors and for the housing and service sectors.

In order to distribute service sector consumption between the different sub-sectors, we used a report entitled *Service sector breakdown*[3], which details fuel consumption by sub-sector, including offices and healthcare, commercial, catering and educational establishments.

The IDAE report *Energy use and consumption in the housing sector*[4] details consumption of the main energy sources broken down by main use, and the consumption associated with heating, domestic hot water, cooling, cooking and lighting.

2.2.2. SPAHOUSEC I AND II

In its SPAHOUSEC[5] and SPAHOUSEC II[6] studies, IDAE used information gathered in telephone surveys and provided by energy retailers to identify consumption and the technology installed in Spain's housing stock.

2.2.3. National Statistics Institute

The National Statistics Institute regularly publishes the statistics it produces on its website[7]. These publications include the *2011 Population and Housing Survey*, which details the number of main dwellings located in each municipality.

2.2.4. NECP

The *2021-2030 Integrated National Energy and Climate Plan* (NECP)[8] sets out targets for reducing greenhouse gas emissions, increasing the penetration of renewable energy and improving energy efficiency. It is based on a modelling process using the Times-Synergia software, enabling a technical and economic analysis of how certain demands and technologies will evolve on the basis of policies and government support schemes.

2.2.5. ERESEE

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[2] http://sieeweb.idae.es/consumofinal/

[3] https://www.idae.es/informacion-y-publicaciones/estudios-informes-y-estadisticas

[4] *https://informesweb.idae.es/consumo-usos-residencial/index.php*

[5] https://www.idae.es/uploads/documentos/documentos_Informe_SPAHOUSEC_ACC_f68291a3.pdf

[6] https://www.idae.es/publicaciones/spahousec-ii-analisis-estadistico-del-consumo-de-gas-natural-en-las-viviendas

[7] *https://www.ine.es/dyngs/INEbase/listaoperaciones.htm*

[8] *https://www.miteco.gob.es/es/prensa/pniec.aspx*

The Spanish Building Sector Long-Term Energy Renovation Strategy (ERESEE)[9], published in 2020 by the Ministry of Transport, Mobility and the Urban Agenda, analyses heating and cooling in Spain in more detail than the other documents already mentioned. It provides an in-depth assessment of thermal demand for both the housing and service sectors and outlines a number of policies focusing on renovating buildings to reduce the energy consumption associated with heating and air conditioning.

2.2.6. OTHER STUDIES

We also consulted other sources of information in addition to the documents and studies listed above, notably including:

- the IDAE's *Assessment of the Potential of Solar Thermal Power in Industry*[10], which details the energy consumption of various industrial sectors and sub-sectors (and breaks it down by process and thermal level);
- the IDAE's *Summary of the Study of the Heat Pump Stock in Spain*[11], containing details of the useful heat delivered using heat pump technology, broken down by economic sector (housing, services and industry), and supplemented by its *Heat Pump Statistics* report[12], providing information on heating provided by heat pumps fuelled by renewable sources;
- the IDAE's 2016 report, *Comprehensive assessment of the potential for using high-efficiency cogeneration and efficient district heating and cooling systems*[13].

2.2.7. EXTERNAL AUDITS

The information was supplemented with a database of over 5 000 energy audits of buildings in the service sector, as well as numerous studies on energy efficiency in the industrial sector, in which the authors of this study were involved.

2.3. THE LAND REGISTER

The Land Register is the most detailed geo-referenced source of information used to compile the database for this study.

We used alphanumeric files extracted from the national Land Register and the devolved registers of the Basque Country and Navarre.

The main information obtained for each registered land parcel was:

- parcel area (m²)
    - geographical coordinates (latitude, longitude)
    - province

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[9] https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/es_ltrs_2020.pdf

[10] https://www.idae.es/publicaciones/evaluacion-del-potencial-de-energia-solar-termica-en-el-sector-industrial

[11] https://www.idae.es/uploads/documentos/documentos_Bombas-de-calor_FINAL_04ee7f42.pdf

[12] http://estadisticas-bombasdecalor.idae.es/

[13] https://www.idae.es/tecnologias/eficiencia-energetica/transformacion-de-la-energia/evaluacion-potencial-uso-cogeneracion-alta-eficiencia-y- sistemas-urbanos

- municipality
- usage code and building type
- No of storeys
- year of construction

2.4. OTHER SOURCES OF SPECIFIC INFORMATION

In addition to the information obtained from the Land Register, we were able to obtain key thermal demand or consumption data for individual buildings or installations from other sources. We included this additional information in the database created using the Land Register, correlated to the corresponding registered parcel. The sources of this specific additional information and the reasons for consulting them were as follows:

- the **National Pollutant Release and Transfer Register** for information on large industrial consumers;
- the **District Heating and Cooling Survey** for details of existing district heating and cooling installations;
- the **'specific' remuneration scheme and 'ordinary' remuneration scheme registers** for information on power stations and potential suppliers of waste heat;
- details of **waste water treatment plants and landfill sites**;
- information on the location of **airports** and passenger numbers.

The specific information sources consulted and the data obtained from each of them are described below.

2.4.1. THE NATIONAL POLLUTANT RELEASE AND TRANSFER REGISTER

This Register[14] provides information on pollutant releases into the air, water and soil by large industrial plants, power plants, waste water treatment plants, etc.

We obtained the following information on installations listed in this register:

- Pollutant Release and Transfer Register:
    - CO_2 emissions (tonnes per year)
    - Plant name
    - Province
    - Municipality
    - National Economic Activity Classification (CNAE) code
    - Geographical coordinates (latitude, longitude)

2.4.2. THE DISTRICT HEATING AND COOLING SURVEY

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[14] www.prtr-es.es

The Association of District Heating and Cooling Businesses (ADHAC) draws up an annual survey[15] which serves as a basis for compiling statistics on district heating and cooling installations. We used the following information:

- Plant name
- Province
- Municipality
- Network type (heating/cooling)
- Fuel (biomass, solar, natural gas, cogeneration, waste...)
- Heating capacity (kW)
- Cooling capacity (kW)

2.4.3. THE 'SPECIFIC' AND 'ORDINARY' REMUNERATION SCHEME REGISTERS

The register of power stations covered by the 'specific' remuneration regime[16], published by the Ministry of Ecological Transition and the Demographic Challenge, contains details of cogeneration, biomass, wind, solar photovoltaic and solar thermal power plants.

- 'Specific' remuneration scheme:

    - Plant name
    - Municipality
    - Province
    - Capacity
    - Group (as specified in the legislation – a.1.1, a.1.2, b.1.1 etc.)
    - Type
    - Registration code

Records on power plants covered by the 'ordinary' scheme are also publicly available[17]. They contain the following information:

- 'Ordinary' remuneration scheme:

    - Plant name
    - Capacity

We supplemented the above research with the *Spanish Electricity System Report*[18] published by Red Eléctrica

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[15] *www.adhac.es*

[16] *http://energia.gob.es/electricidad/energias-renovables/Paginas/registro-administrativo.aspx*

[17] https://sede.serviciosmin.gob.es/es-ES/datosabiertos/catalogo/registro-productores-electrica

[18] https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/informe-del-sistema-electrico-espanol-2018

(REE), which provides aggregated figures on installed capacity and generation for each technology.

2.4.4. WASTE WATER TREATMENT PLANTS AND LANDFILL SITES

The Ministry of Ecological Transition and the Demographic Challenge publishes information on waste water treatment plants, including the map of such plants and urban agglomerations in accordance with the requirements of Council Directive 91/271/EEC[19]. The information available in the 2017 versions of the factsheets on each waste water treatment plant has been included in the corresponding table. Full details of the data fields can be found in the service description document[20].

- Waste water treatment plants:
  - UWW code
  - Name
  - Coordinates
  - Input load
  - Design capacity

We also consulted the map of existing landfill sites, the most recent version of which dates from 2018. Unfortunately the metadata they contain does not include data on the waste load managed by each site. We therefore had to cross-check the geographical coordinates of the sites against the information contained in the 2017 version of the *Annual waste generation and management report: waste managed by municipal authorities*[21].

- Landfill sites:
  - Environmental ID (‘NIMA’) code
  - Name
  - Coordinates
  - Municipality
  - Province
  - Waste

2.4.5. AIRPORTS

Spain’s airport authority (AENA) publishes an annual summary of passenger traffic, operations and cargo through Spanish airports[22].

We assigned the airports’ coordinates (longitude and latitude) manually.

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[19] https://www.miteco.gob.es/es/cartografia-y-sig/ide/descargas/agua/situacion-q2017.aspx

[20] https://sig.mapama.gob.es/Docs/PDFServiciosProd2/EDAR_Q2017.pdf

[21] https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/memoria-anual

[22] https://wwwssl.aena.es/csee/Satellite?pagename=Estadisticas/Home

- Airports:
  - Airport name
  - Number of passengers per year
  - Coordinates

2.5. DATABASE CREATION AND DEMAND MODELLING

Once we had gathered all of this information, we structured it into a database that enables the modelling of the thermal demand associated with each parcel listed in the Land Register.

The Land Register allows us to identify the land uses and building types present on each parcel and classify them using a set of 'demand types', which form the basis for modelling the parcel's thermal demand. Each demand type has a required thermal level (heating, air conditioning, hot water, high-temperature industrial processes, etc.) and demand intensities/rates.

At the same time, the technology (or set of technologies) used to meet thermal needs was assigned to each Land Register record, allowing fuel consumption to be modelled.

The coordinates associated with each registered parcel allowed us to identify geo-referenced figures for estimated demand and consumption. With this information, thermal demand intensity across Spain could be mapped out and displayed using an online tool: the 'heat map'[23], which gives the possibility of filtering the view to show demand in a specific economic sector, display specific installations, generate reports on a specific region with demand broken down by criteria including economic sector, waste heat and fuel supply, and the availability of renewable resources.

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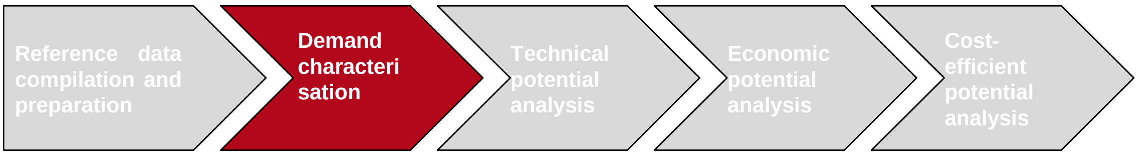
[23] https://mapadecalor.idae.es/

3. DEMAND CHARACTERISATION



To characterise thermal demand we must first gather the data needed to estimate the demand of each energy-consuming centre depending on the sector to which it belongs.

3.1. IDENTIFYING DEMAND TYPES AND DEMANDED THERMAL LEVELS

Spanish energy demand comes from a huge number of consumers, which can be categorised based on the land use and building type defined in the Land Register. We assigned a demand type to each Land Register record, so that energy requirements could then be modelled using demand ratios per m² and an hourly energy demand intensity curve.

These demand types are summarised in Table 9 and are identified by the economic sector and subsector, as well as a more specific code differentiating between different types of demand within the same sub-sector.

- In the **housing sector** this code reflects the province, type of municipality (rural or urban) and the period in which the property was built.
- In the **service sector** it reflects the climate zone and aspects of the establishment type (such as whether or not there is housing in the same building).
- In the **industrial sector** it reflects the activity of each industrial plant based on the corresponding National Classification of Economic Activities ('CNAE') code.

Table 9: Demand types considered in the demand characterisation process

Sector	Sub-sector	Sector code	Sub-sector code	Details code
Housing [*Residencial*]	Single-family home [*Unifamiliar*]	R	U	Province – Rural/Urban – Property age bracket
	Flat in small block [*Colectiva*]	R	C	Province – Rural/Urban – Property age bracket
	Flat in large block [*Bloque*]	R	B	Province – Rural/Urban – Property age bracket
Services [*Terciario*]	Public authorities [*Administración*]	T	A	Climate zone as per Technical Building Code ('CTE') 17: prison, police station, military building, etc. 16: offices, courts, local councils, etc.
	Retail [*Comercial*]	T	C	Climate zone as per Technical Building Code ('CTE') 5: retail 6: market or supermarket
	Sports [*Deportivos*]	T	D	Climate zone as per CTE 7: indoor facilities, swimming pools 8: ancillary facilities
	Culture and religion [*Cultural y religioso*]	T	E	14: with housing 15: without housing
	Offices [*Oficinas*]	T	O	Climate zone as per CTE
	Restaurants and catering [*Restauración*]	T	R	Climate zone as per CTE 10: with housing 11: without housing
	Health and welfare [*Sanidad y beneficencia*]	T	S	Climate zone as per CTE 12: with housing 13: without housing
	Entertainment [*Espectáculos*]	T	X	Climate zone as per CTE
	Airports, service stations [*Aeropuertos, estaciones de servicio*]	T	Z	39: stations / service stations 40: airports
Industry [*Industrial*]	Mining and quarrying (non-energy-producing) [*Extractivas (no energéticas)*]	I	EXT	CNAE codes 500-999
	Food, beverages and tobacco [*Alimentación, bebidas y tabaco*]	I	AL	CNAE codes 1000-1299
	Textile, leather and footwear [*Textil, cuero y calzado*]	I	TXT	CNAE codes 1300-1399
	Pulp, paper and printing [*Pasta, papel e impresión*]	I	PAP	CNAE codes 1700-1899
	Petrochemical [*Petroquímica*]	I	PQU	CNAE codes 1900-1999
	Chemical [*Química*]	I	QUI	CNAE codes 2000-2299
	Non-metallic minerals [*Minerales no metálicos*]	I	BAR	CNAE codes 2300-2399
	Iron, steel and foundries [*Siderurgia y fundición*]	I	SID	CNAE codes 2400-2499 (except 244X)
	Non-ferrous metals [*Metalurgia no	I	NFE	CNAE codes 2440-2499

	férrea]			
	Fabricated metals [*Transformados metálicos*]	I	TRA	CNAE codes 2500-2699
	Transport equipment [*Equipo de transporte*]	I	EQU	CNAE codes 2800-2999
	Wood, cork and furniture [*Madera, corcho y muebles*]	I	MAD	CNAE codes 1600-1699
	Other / undefined [*Otras / Indefinidas*]	I	IND	CNAE codes > 3000 or unknown

Source: authors' own

We will now analyse the characterisation of demand for each sector studied.

3.2. HOUSING SECTOR

In Table 9 the housing sector is divided into the following sub-sectors: flats in small blocks, flats in large blocks and single-family homes. The thermal uses considered for this sector are space heating (HT), domestic hot water (DHW) and air conditioning (AC).

The energy demand of the housing sector is very sensitive to the climate zone where a home is located, because heating and air conditioning are strong drivers of a home's overall consumption. Demand for domestic hot water is, on the other hand, less location-dependent and mainly driven by number of occupants.

3.2.1. HOME TYPE

We used the following classification established in the ERESEE report:

- **Building type:** the ERESEE reports divides Spanish housing into single-family homes, flats in small blocks and flats in large blocks. The difference between the two types of blocks of flats is the number of floors: buildings of up to three storeys are 'small blocks', and those with more than three storeys are 'large blocks'.
- **Municipality size:** 'Rural' homes are located in municipalities with fewer than 20 000 inhabitants and 'urban' homes are located in municipalities with more than 20 000 inhabitants.
- **Year of construction:** Buildings are divided into the following brackets according to the year they were built:
    - up to 1900
    - 1901-1940
    - 1941-1960
    - 1961-1980
    - 1981-2007
    - 2008-2020
- **Province:** Annex A.2 of the ERESEE report provides consumption rates classified by province.

By cross-referencing these different classifications (except classification by province) we identified 36 categories of building to be used to characterise the housing sector. The province in which each home studied is located was also taken into consideration to allow us to model the effect of geographical location on the demand characterisation.

It is important to stress that although the ERESEE report provides recent, disaggregated data, it only contains specific consumption figures for heating. This meant we had to use sources other than the ERESEE report to estimate consumption on air conditioning and domestic hot water for each of the categories of homes into which we had segmented the housing sector. To do so, we began with the rates of consumption per unit of area (kWh per m²) reported in the SPAHOUSEC I study, and reduced those figures using statistics on main residences from the National Statistics Institute and the domestic appliance rates per climate zone from the SPAHOUSEC study.

3.2.2. CLIMATE ZONES

As we have already mentioned, the ERESEE report specifically provides data on heating consumption. As this data is broken down by province, the figures can then be grouped into climate zones, Autonomous Communities, etc., depending on the level of analysis required.

For the characterisation of demand for domestic hot water and cooling, however, the SPAHOUSEC and SPAHOUSEC II studies do not provide a breakdown by province, instead presenting the values for each climate zone (Continental, Mediterranean and Atlantic/North). Figure 3 shows which provinces belong to which climate zones.

KEY	
Islas Canarias	Canary Islands
Atlántico Norte	Atlantic/North
Continental	Continental
Mediterráneo	Mediterranean

Figure 3: Geographical distribution of the climate zones used in the SPAHOUSEC study

Source: SPAHOUSEC study 2011

In the interests of simplification and consistency in the representation of data, details of heating, domestic hot water and cooling are presented into the SPAHOUSEC climate zones throughout this study.

3.2.3. TECHNOLOGY

In this study we have used the same distribution of heating demand coverage technologies as the ERESEE report. The heating technologies used in the properties listed in the Land Register could be inferred using the distribution established from that information.

For demand for domestic hot water (DHW) and air conditioning (AC), we performed a probability distribution based on the proportion of homes with each technology according to thermal use as detailed in the SPAHOUSEC study.

We have assigned each home a set of technologies (one technology for each thermal use), applying a conditional probability approach whereby the same fuel type is likely to be used for domestic hot water, heating and air conditioning. We also bore in mind that not all main residence have heating and cooling systems installed, whereas they do all have domestic hot water systems. The table below shows the technologies considered for the housing sector and the assumed efficiency rates.

Table 10: Technologies considered in the housing sector and assumed efficiency rates

Name used in this report	Code	Thermal level	Corresponding technology as per ERESEE	Efficiency
Natural gas boiler	NGB	DHW, HT	Boiler	0.85
Diesel/heating oil boiler	OILB	DHW, HT	Boiler	0.85
LPG boiler	LPGB	DHW, HT	Boiler	0.85
Biomass boiler	BMB	DHW, HT	Boiler	0.56
Heat pump – non-renewable	HP	HT, AC	Heat pump – non-renewable	2.2
Heat pump for cooling	HP C	AC	Heat pump – non-renewable, cooling	2.2
Heat pump – renewable	HP2	HT, AC	Heat pump – renewable	3.0
Heat pump for cooling	HP2 C	AC	Heat pump for cooling	2.4
Electric boiler	EB	DHW, HT	Boiler	1
Solar panels	SOL	DHW	Flat-plate collectors	1

Source: the author's own calculations based on NECP data

We used the *Heat Pump Statistics* published by IDAE to differentiate between heat pumps powered by renewable and non-renewable energy sources.

We included conventional solar thermal technology, assuming that this technology meets 60% of domestic hot water demand in the homes fitted with solar panels, taking into account both the SPAHOUSEC study and the 2018 Energy Balances.

3.2.4. DEMAND RATES

Tables 11 and 12 detail energy demand for heating purposes for each type of home. This information is taken directly from the database used in the ERESEE report. To facilitate understanding and comparison with demand rates for domestic hot water and cooling, the heating demand rates are presented as average figures for each SPAHOUSEC climate zone.

Table 11: Average heating demand rates by climate zone, home type and building age in the rural housing sector

RURAL	Demand by climate zone – including energy poverty (kWh per m^2 per year)								
Climate zone	**Continental**			**Mediterranean**			**Atlantic/North**		
Building age	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**
<1900	148.24	97.82	63.48	87.75	43.20	29.01	87.73	49.93	33.94
1901-1940	146.93	97.05	62.29	81.07	41.06	29.46	87.60	50.99	31.28
1941-1960	137.85	84.27	63.99	72.28	36.37	24.49	80.37	49.86	32.27
1961-1980	139.49	60.47	52.07	75.38	25.48	21.31	78.95	33.99	27.20
1981-2007	88.51	43.15	32.51	44.90	17.14	11.24	47.69	23.32	16.30
2008-2012	59.79	30.33	23.40	27.38	10.49	6.63	30.72	14.97	10.34
No of homes	**1 257 965**	**425 395**	**294 739**	**1 715 304**	**616 549**	**421 880**	**414 030**	**116 855**	**331 589**
Total homes in climate zone	**1 978 099**			**2 753 733**			**862 474**		
Total homes	**5 594 306**								

Source: authors' own based on the ERESEE report

Table 12: Average heating demand rates by climate zone, home type and building age in the urban housing sector

URBAN	Demand by climate zone – including energy poverty (kWh per m^2 per year)								
Climate zone	**Continental**			**Mediterranean**			**Atlantic/North**		
Building age	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**	**Single-fam.**	**Flat, small bl.**	**Flat, large bl.**
<1900	98.22	97.90	66.07	91.06	38.76	30.84	74.97	45.43	32.69
1901-1940	107.48	95.56	64.67	88.93	37.94	30.23	80.77	46.45	33.35
1941-1960	121.60	90.71	60.55	75.84	34.86	24.72	74.97	45.09	31.14
1961-1980	106.48	62.26	51.99	70.52	22.54	20.58	67.64	28.90	26.45
1981-2007	66.09	46.11	32.63	37.90	14.14	10.02	38.90	19.32	15.38
2008-2012	42.85	30.71	21.76	21.40	8.60	5.72	23.54	11.82	9.73
No of homes	**387 484**	**323 298**	**2 846 376**	**1 506 751**	**859 838**	**3 799 299**	**186 297**	**87 798**	**1 006 680**
Total homes in climate zone	**3 557 158**			**6 165 888**			**1 280 775**		
Total homes	**11 003 821**								

Source: authors' own based on the ERESEE report

To calculate the demand for domestic hot water and cooling, we began with the energy consumption figures by type of home and climate zone detailed in the SPAHOUSEC study. Homes are classified based on use as: main residences (occupied most of the year), second residences (second or holiday homes) and empty homes. To limit the consumption data to reflect only main residences, we adjusted the consumption figures by type of home and climate zone using the home occupancy rates specified in the 2011 population census conducted by the National Statistics Institute. Based on adjusted consumption figures and the average floor area of each home in the corresponding climate zones[24] we were able to calculate energy consumption rates by type of home, use and climate zone.

Once we had established the energy consumption for DHW and cooling purposes for each type of home and

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[24] Obtained from the SPAHOUSEC study and the National Statistics Institute

climate zone, we turned these into demand rates by applying the efficiency rate associated with each of the technologies used to meet demand.

The rates resulting from this calculation process are shown in Tables 13 and 14.

Table 13: Demand rates for domestic hot water by climate zone and type of home

DHW demand by climate zone and type of home (kWh per m² p.a.)			
Type of home \ climate zone	**Continental**	**Mediterranean**	**Atlantic/North**
Single-family homes	10	10	12
Flats – small and large blocks	15	14	15

Source: authors' own

Table 14: Demand rates for air conditioning by climate zone

Cooling demand by climate zone and type of home (kWh per m² p.a.)			
Type of home \ climate zone	**Continental**	**Mediterranean**	**Atlantic/North**
Single-family homes, flats – small and large blocks	3.84	5.44	0.0064

Source: authors' own

When calculating the demand for cooling based on these rates, we considered that only a percentage of homes would have air conditioning systems. We took the figure specified in the SPAHOUSEC study as the percentage of homes with air conditioning equipment and applied it to the number of homes with heating systems installed.

3.2.5. RESULTS OF THE CHARACTERISATION OF DEMAND IN THE HOUSING SECTOR

The table below summarising the results produced by from the model developed to characterise demand for heating and cooling in the housing sector:

Table 15: Summary of demand characterisation of the housing sector

Sector				Housing			
Type				Single-family homes	Flat – small block	Flat – large block	Total
Demand by technology [MWh]	DHW	Electricity	Electric water heater	1 791 374	634 459	3 713 823	6 139 656
		Fossil fuels	Gas boiler	1 062 965	965 272	6 163 065	8 191 302
			Diesel/heating oil boiler	1 427 834	129 407	924 810	2 482 051
			LPG boiler	2 529 452	529 644	3 005 898	6 064 994
			Coal boiler	3 429	662	6 063	10 155
		Renewables	Biomass boiler	47 996	2 249	26 341	76 586
			Solar thermal	1 648 245	108 425	627 183	2 383 853
		Cogeneration	Cogeneration	43	41	84	168
	HT	Electricity	Electric radiator	968 248	390 058	1 579 420	2 937 727
			Heat pump	773 328	280 342	1 159 011	2 212 681
		Fossil fuels	Gas boiler	7 776 833	2 388 788	10 931 977	21 097 597
			Diesel/heating oil boiler	8 473 113	1 004 136	5 603 820	15 081 069
			LPG boiler	2 280 272	367 074	1 625 470	4 272 816
		Renewables	Biomass boiler	15 032 482	0	0	15 032 482
			Heat pump (renewable share only)	557 849	200 967	842 846	1 601 661
		Cogeneration	Cogeneration	416	386	205	1 007
	AC	Electricity	Heat pump	1 636 663	345 368	1 836 603	3 818 635
		Cogeneration	Cogeneration	13	8	20	41
Demand [MWh]	DHW			8 511 338	2 370 158	14 467 267	25 348 763
	HT			35 861 578	4 630 770	21 744 693	62 237 041
	AC			1 636 676	345 376	1 836 623	3 818 676
	Total			46 009 592	7 346 304	38 048 584	**91 404 480**

Source: authors' own

As Table 15 shows, single-family homes have a significantly higher thermal demand than the other categories, accounting for approximately 50% of the overall thermal demand in the housing sector.

Technologies based on non-renewable fuels account for 79% of the total, with the most frequently used appliance being the natural gas boiler.

In terms of use, heating represents 68% of total demand and domestic hot water accounts for 28%.

3.2.6. FINAL ENERGY CONSUMPTION

The table below summarises energy consumption for each type of home by fuel type and energy source.

Table 16: Details of consumption in the housing sector by type of home (GWh)

Consumption (GWh)		Single-family homes	Flat – small block	Flat – large block	Total
Fuel	Electricity	3 968	1 355	6 842	12 165
	Natural gas	10 400	3 946	20 112	34 458
	Diesel/heating oil	11 648	1 334	7 681	20 663
	LPG	5 659	1 055	5 449	12 162
	Coal	4	1	7	12
	Biomass	26 930	4	47	26 981
	Solar thermal	1 648	108	627	2 384
	Total	60 256	7 803	40 765	108 824

Source: authors' own

3.3. SERVICE SECTOR

The service sector was divided into the following sub-sectors for the analysis of thermal demand:

- O: Offices
- C: Retail
- A: Public authorities
- S: Healthcare
- E: Education
- D: Sport
- X: Entertainment
- R: Restaurants and catering
- Z: Airports / service stations

External energy audits in which the authors of this study participated were main source of information used to characterise demand in the service sector.

3.3.1. DEMAND TYPES IN THE SERVICE SECTOR

Using the classification shown in Table 9, we segmented the sub-sectors into the demand types shown below for the purpose of calculating demand rates for each type.

Table 17: Service sector activity classification

Sub-sector	Description
O	Offices
C	General retail
C	Market or supermarket
D	Indoor sports facilities, swimming pools
D	Ancillary sports facilities
X	Entertainment
R	Leisure and hospitality with housing
R	Leisure and hospitality without housing
S	Health and welfare with housing
S	Health and welfare without housing
E	Culture and religion with housing
E	Culture and religion without housing
A	Public authorities
A	Prisons
Z	Service stations
Z	Airports

Source: authors' own

The thermal uses considered for this sector are space heating (HT), domestic hot water (DHW) and air conditioning (AC).

3.3.2. DEMAND RATES BY CLIMATE ZONE

We grouped the demand data gathered from external audits by the climate zones established in the Technical Building Code (CTE).

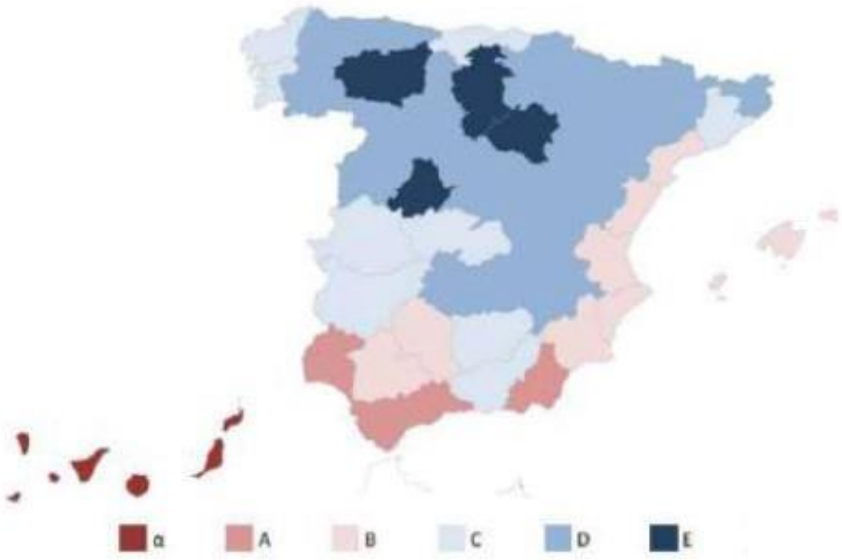

Figure 4: Geographical distribution of the climate zones as per the CTE

Source: ERESEE report

As there was little or no data for of the some climate zones (due to a lack of audits carried out in a certain zone), we needed to extrapolate the data from another climate zone with available data in order to obtain the final result. For this extrapolation, we designed an internal tool that estimates a heating or cooling demand value based on a comparison of the degree days in the different climate zones.

1. The basis for this is a demand rate that is already known from audits (one example being the demand per unit of area for the 'Offices' land use in climate zone D3).
2. In order to extrapolate the demand rate for the 'Offices' land use to another climate zone for which insufficient information is available, the tool uses the difference in degree days between the two zones. An estimated heating and cooling demand rate can be obtained by extrapolating the value from one climate zone (the one on which we have information) to the other (the one we want to know about).

This is how we arrived at the final demand rates in kWh per m² for the 16 demand types – the energy-consuming centres identified in the service sector – in each climate zone.

3.3.3. TECHNOLOGY

The different technologies were distributed among service sector buildings as follows:

1. According to the 2014 IDAE report *Heat Pumps in Spain*, heat pumps generate 18 TWh of heat in the service sector each year, accounting for approximately 42% of that sector's estimated demand for heating. On this basis, we established that there is a likelihood of 42% that the energy demand for heating and air conditioning in establishments smaller than 4 000 m² is met by heat pumps. We used the *Heat Pump Statistics* published by IDAE to establish the share of renewable and non-renewable energy sources in heat pumps.
2. All other buildings are assumed to use technologies other than heat pumps. The distribution of the

different technologies is based on the availability of natural gas in the municipality. Natural gas use is assumed in premises located in municipalities with a natural gas supply. For municipalities where there is no natural gas supply, we assigned diesel/heating oil or LPG in the same proportions reported in the *Service sector consumption breakdown* (2018).

3. We included biomass and solar thermal in the same proportions reported in the 2018 Final Energy Balances, with the assumption that biomass systems cover 100% of domestic hot water and space heating demand and that solar thermal covers only 60% of domestic hot water demand.
4. For parcels where cogeneration had been identified, we assumed that this technology covers 100% of domestic hot water and heating demand and 75% of cooling demand, using the same fuel as the main technology allocated to each demand.
5. We assumed that premises larger than 4 000 m² have systems with more capacity and higher efficiency, whereas premises smaller than this are assumed to have the same efficiency rates as the housing sector.

No allocation was made for other technologies representing only a very small share in the 2018 Energy Balances (direct-use geothermal for example).

The technologies considered to be present in the service sector and the corresponding efficiency rates are shown in Table 18.

Table 18: Efficiency rates for energy sources used for heating in the service sector

System	Thermal uses	Efficiency
Oil/LPG boiler < 50 kW	DHW, HT	0.85
Oil/LPG boiler > 50 kW	DHW, HT	0.90
Gas boiler < 50 kW	DHW, HT	0.85
Gas boiler > 50 kW	DHW, HT	0.90
Biomass boiler	DHW, HT	0.7
Electric boiler	DHW	1
Air-source heat pump – non-renewable	HT, AC	2.2
Air-source heat pump – renewable (heating) and non-renewable (cooling)	HT, AC	3.0 / 2.4
Conventional solar thermal	DHW	1

Source: authors' own based on NECP data

3.3.4. RESULTS OF THE CHARACTERISATION OF DEMAND IN THE SERVICE SECTOR

The table below summarises the results produced by the model developed to characterise demand for heating and cooling in the service sector.

As Table 19 shows, the ‘Retail’ and ‘Offices’ sub-sectors lead the demand for thermal energy, between them accounting for 57% of overall thermal demand.

Notable among the technologies used are natural gas boilers and heat pumps, representing 34% and 49%, respectively, of overall demand.

In terms of use, heating represents 56% of total demand and cooling accounts for 30%.

Table 19: Summary of demand characterisation of the service sector

Sector				Services									
Type				Offices	Public authorities	Retail	Healthcare	Restaurants and catering	Education	Sports	Entertainment	Airports / service stations	Total
Demand by technology [MWh]	DHW	Electricity	Electric water heater	768 816	158 008	317 247	200 127	777 255	107 013	492 458	5 337	1 638	2 827 899
		Fossil fuels	Gas boiler	992 803	614 518	293 469	867 980	1 580 982	143 800	716 213	8 573	9 727	5 228 063
			Diesel/heating oil boiler	169 397	158 662	73 527	155 272	860 890	134 534	211 353	2 041	629	1 766 306
			LPG boiler	18 693	10 779	9 323	10 720	50 633	6 193	24 105	262	71	130 780
		Renewables	Biomass boiler	45 850	24 549	15 503	27 203	83 759	8 558	34 053	287	101	239 864
			Solar thermal	147 751	14 728	46 469	38 500	342 335	10 280	45 458	631	113	646 265
		Cogeneration	Cogeneration	8 479	1 057	452	30 027	11 863	342	2 461	0	64	54 746
	HT	Electricity	Heat pump	3 131 295	409 702	4 287 519	519 718	740 424	736 627	250 173	44 074	54 069	10 173 601
		Fossil fuels	Gas boiler	5 865 438	1 557 136	6 169 612	3 103 726	1 527 159	1 425 467	497 394	106 304	365 329	20 617 565
			Diesel/heating oil boiler	900 380	367 003	1 335 586	519 559	619 217	1 357 893	144 910	25 171	28 459	5 298 177
			LPG boiler	91 893	43 420	154 181	38 834	64 859	61 378	17 263	3 276	3 519	478 623
		Renewables	Biomass boiler	268 223	55 267	304 384	91 396	85 284	86 263	23 836	3 424	5 332	923 410
			Heat pump (renewable share only)	1 383 629	188 778	1 886 024	233 173	327 303	315 607	105 553	20 504	23 008	4 483 580
		Cogeneration	Cogeneration	53 458	4 286	7 906	76 515	4 331	4 605	2 748	8	2 841	156 697
	AC	Electricity Cogeneration	Heat pump	4 191 302	1 018 843	11 015 613	1 690 712	2 463 251	1 238 677	282 474	78 121	188 052	22 167 045
			Cogeneration	12 119	2 109	5 150	30 966	4 892	1 084	656	1	453	57 430
Demand [MWh]	DHW			2 151 789	982 302	755 991	1 329 829	3 707 718	410 720	1 526 101	17 130	12 344	10 893 924
	HT			11 696 138	2 629 702	14 143 454	4 584 986	3 369 073	3 983 325	1 039 527	203 301	482 148	42 131 653
	AC			4 203 421	1 020 952	11 020 763	1 721 678	2 468 143	1 239 761	283 130	78 121	188 505	22 224 475
	Total			18 051 347	4 632 956	25 920 208	7 636 493	9 544 935	5 633 807	2 848 757	298 552	682 998	**75 250 052**

Source: authors' own

3.3.5. FINAL ENERGY CONSUMPTION

As well as demand, we also identified final energy consumption values for the service sector by fuel used.

Table 20: Consumption figures calculated for the service sector

Consumption [GWh]		Offices	Public authorities	Retail	Healthcare	Restaurants and catering	Education	Sports	Entertainment	Airports / service	Total
Fuel	Electricity	4 393	831	7 562	1 216	2 259	1 055	755	65	111	**18 248**
	Natural gas	7 956	2 448	7 524	4 575	3 538	1 791	1 388	131	424	**29 776**
	Diesel/heating oil	1 264	618	1 658	816	1 749	1 761	419	32	34	**8 352**
	LPG	131	64	192	58	136	79	49	4	4	**718**
	Biomass	449	114	457	174	241	135	83	5	8	**1 667**
	Solar thermal	148	15	46	38	342	10	45	1	0	**646**
	Total	**14 341**	**4 090**	**17 439**	**6 878**	**8 266**	**4 833**	**2 740**	**238**	**582**	**59 406**

Source: authors' own

3.4. INDUSTRY SECTOR

This sector's energy demands are mainly linked to production processes. For this study we established the following classes of thermal demand: low temperature (hot water for processes – 80 °C), medium temperature (steam – 120 °C), medium-to-high temperature (low-temperature gases – 350 °C) and very high temperature (high-temperature gases – 1 000 °C).

As consumption for heating and air conditioning purposes in the industrial sector is considered to be largely unrepresentative, we have differentiated by industrial sector rather than by climate zone.

Another specific feature of this sector is that it features a large number of plants that are major individual consumers and therefore heavy emitters. Thus means that they are listed in the National Pollutant Release and Transfer Register and can therefore be analysed individually. These large individual plants have been treated as 'point consumers' and all other plants as 'dispersed consumers'.

We identified these 'point consumers' using the National Pollutant Release and Transfer Register, considering that the companies that report CO_2 emissions have large enough energy demands to be treated as 'point consumers'.

A brief outline of the methodology used to calculate thermal demand based on CO_2 emissions in the industrial sector is as follows:

1. We used the PRTR to identify the quantity of CO_2 emitted into the atmosphere by each of the companies concerned.
2. We corrected the emissions data to take into account only emissions from combustion processes covering thermal demands. This meant that we had to deduct emissions that are inherent to production processes (cement, glass, lime, etc.).
3. We calculated an emission factor for each 'point consumer' according to the fuel used. Where we were unable to identify the fuel used for a given plant, we used the emission factor for the sector to which that plant belongs as reported in the Final Energy Balances. Once we knew the emission factor and amount of CO_2 emitted, we were able to calculate the theoretical fuel consumption of each 'point consumer' directly.
4. We calculated each a thermal efficiency for each 'point consumer' according to the specific characteristics of that consumer (whether or not there is cogeneration, type of cogeneration, thermal level of the production process, etc.).
5. Having identified the fuel consumed and thermal efficiency, we obtained thermal demand directly.

Consumption by '**dispersed** consumers' was assumed to be the difference between the consumption calculated for the 'point consumers' and overall consumption as reported in the Final Energy Balances. In order to determine the rates of demand represented by 'dispersed consumers' in the industrial sector, we used an IDAE report entitled *Assessing the potential of solar thermal power in the industrial sector*, which provides rates of demand for different industrial sectors by thermal level (hot water, steam, high-temperature gases). For those industrial sectors where the availability of information was poorest, it was supplemented with the expertise of the authors of this report.

3.4.1. DEMAND CHARACTERISATION FOR 'POINT CONSUMERS' IN THE INDUSTRY SECTOR

In this section we explain the method used to characterise demand for cooling and heating demand in the industrial sector by elaborating on each of the points already mentioned above.

3.4.1.1. GATHERING AND PROCESSING CO_2 EMISSIONS DATA

The reason we used carbon dioxide emissions as our starting point for calculating the thermal demand is that they are usually the result of combustion processes in thermal systems, so if we know how much fuel was used based on the emissions statistics, we can calculate the thermal demand for a specific industrial plant.

However, the amount of CO_2 emitted into the atmosphere and recorded in the PRTR reflects all of a plant's emissions, i.e. both from combustion processes and from the production process itself, which is why we analysed the branches of industry that are likely to emit CO_2 as part of the chemical reactions involved in their production processes, so that those emissions could be subtracted from the final calculation. Without this correction, the CO_2 emissions would be allocated to combustion processes and the thermal demand of the branch would therefore be overstated.

We identified the non-metallic minerals branch as an industry that emits CO_2 as a result of reactions that occur in its production process.

Within this branch, the cement and lime production sub-sectors generate carbon dioxide emissions as a result of the limestone calcination process. Similarly, the manufacturing of ceramics (bricks, roof tiles, tiles, ceramics, etc.) and glass (both hollow and flat) also release CO_2 due to calcination in the former case and melting processes in the latter.

- As around 40% of the CO_2 emissions from the **cement** production process are the result of burning fossil fuels, we adjusted the CO_2 emissions shown in the PRTR accordingly.
- In the **lime manufacturing process**, calcium oxide or quicklime forms when limestone is heated in order to decompose the carbonates. Factoring in this chemical reaction, we established that 20.76% of CO_2 emissions are due to fuel combustion. We were able to use this value to adjust the CO_2 emissions obtained from the PRTR.
- The CO_2 emissions arising from **ceramics production processes** (bricks, roof tiles, refractory products, tiles, etc.) are due to the calcination of raw materials (particularly when clay, schists, limestone, dolomite, witherite/barium carbonate and limestone are used as fluxes).

  Processes in the ceramics industry cause CO_2 emissions due to the decomposition of calcium carbonate and, to a lesser extent, the decomposition of magnesium carbonate – a component of the raw material used to make bricks – at the firing stage.

  By analysing the data on specific plants from this branch of industry, we identified the percentage of overall CO_2 emissions – which include emissions due to combustion processes in firing ovens and dryers – that can be attributed to the decomposition processes explained above, which is **23.9%** on average.

- Both flat and hollow **glass** production processes involve the release of emissions due to the calcination of limestone, dolomite, sodium carbonate and barium carbonate (among other materials). To calculate the CO_2 emissions caused by combustion processes we needed to subtract the total CO_2 emissions resulting from those decarbonisation processes from the overall total CO_2 emissions obtained from the PRTR databases.

  To identify this figure, we began by using a report from the Ministry of the Environment entitled *Guide to Best Available Techniques in the Spanish Glass Manufacturing Sector* to calculate fuel consumption per tonne of glass produced for both flat and hollow glass. We then applied the corresponding CO_2 emission factors according to the fuel consumed to obtain the percentage of these CO_2 emissions per tonne of glass produced that was exclusively attributable to fuel consumption for the generation of thermal energy. We then examined the specific plants listed in the PRTR for which glass production and CO_2 emissions figures were available and calculated the emissions due to the combustion process. We were then able to identify the percentage of emissions attributable to melting processes, which was an average of **41%**.

3.4.1.2. EMISSION FACTORS AND FUEL CONSUMED

Once we had identified and corrected the CO_2 emissions from industrial plants, we assigned an emission factor to each company in order to identify the fuel consumed to meet its thermal demands. Please note that information on the fuels used is not available for most businesses. We therefore used the National Markets and Competition Commission's *List of Municipalities with Gas Distribution Networks*[25] to give us a

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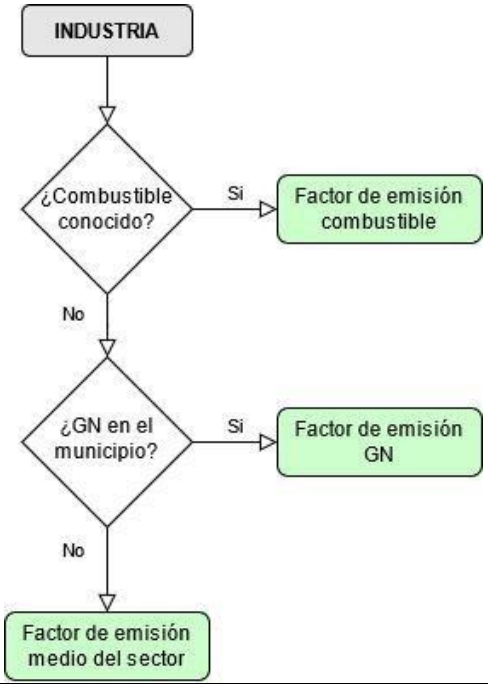
[25] https://www.cnmc.es/sites/default/files/2113971_0.xlsx

rough idea, assuming that all businesses based in municipalities with a natural gas supply according to that report would consume natural gas. When the fuel used by a plant was unknown, we applied the average emission factor for the industrial sector to which it belongs, calculated using the 2018 Final Energy Balances.



KEY	
INDUSTRIA	PLANT
¿Combustible conocido?	Is the fuel known?
Sí	Yes
No	No
Factor de emisión combustible	Emission factor for that fuel
¿GN en el municipio?	Is there natural gas in the municipality?
Factor de emisión GN	Emission factor for natural gas
Factor de emisión medio del sector	Average emission factor for the branch

Figure 5: Allocating the emission factor

Source: authors' own

Once we had assigned an emission factor to each of the plants listed in the PRTR, we were able to directly calculate the fuel consumed using the following formula:

$$Fuel\ (MWh_{LHV}/year) = \frac{t\ CO_2/year}{Emissions\ factor\left(\frac{t\ CO_2}{MWh_{LHV}}\right)}$$

The table below summarises the emission factors considered for the different fuels.

Table 21: Emission factors by fuel

Fuel	Emission factor (t CO_2 per MWh_{LHV})
Natural gas	0.201
Diesel/heating oil	0.263
Coal, anthracite and lignite	0.364
Coke	0.378

Source: Ministry of Ecological Transition and the Demographic Challenge[26]

Where the fuel used was unknown, we used average emission factors for branch of industry, which were based on the 2018 Final Energy Balances and are shown below.

Table 22: Average emission factors by industrial sector

PLANT	Emission factor (t CO_2 per MWh)
Mining and quarrying (non-energy-producing)	0.2667
Food, beverages and tobacco	0.2741
Textile, leather and footwear	0.2648
Pulp, paper and printing	0.2639
Chemical (including petrochemical)	0.3195
Non-metallic minerals	0.3539
Iron, steel and foundries	0.3560
Non-ferrous metals	0.2819
Fabricated metals	0.2688
Transport equipment	0.2582
Construction	0.2667
Wood, cork and furniture	0.2685
Other	0.2683

Source: *based on 2018 Final Energy Balances, IDAE*

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[26] https://www.MITERD.gob.es/es/cambio-climatico/temas/comercio-de-derechos-de-emision/es_2020_anexovii_unfccc_nir_tcm30-379357.pdf

3.4.1.3. THERMAL EFFICIENCY AND CONSUMPTION CORRECTIONS

The calculation explained in the previous section gives us the total amount of fuel consumed. However, cogeneration plants, which produce heat and power simultaneously, can be found in the industrial sector. This means that in order to correctly calculate the thermal demand we have to deduct the fraction of fuel used for power generation from the overall fuel figure.

To find out which plants have a cogeneration facility, we cross-checked the PRTR data against the register of power stations covered by the 'specific' remuneration scheme (and specifically those listed as cogeneration facilities). We obtained the thermal efficiency of cogeneration plants from IDAE's *Statistical report on cogeneration* (2016). Where we knew the type of cogeneration (combined-cycle, gas turbine plus heat recovery boiler, gas engines, etc.), we applied the thermal efficiency for that technology as stated in Table 23. Where we did not know the technology type, the average thermal efficiency for the sector to which the company belongs, as shown in Table 24, was applied. This allowed us to identify thermal demand from the overall quantity of fuel consumed by a cogeneration facility.

The tables below show the thermal values obtained from the statistical report that were applied to plants identified as having cogeneration facilities.

Table 23: Thermal efficiency by cogeneration type

Cogeneration type	Thermal efficiency
Combined-cycle	0.40
Internal combustion engine	0.29
Gas turbine with heat recovery	0.47
Back-pressure turbine	0.61
Condensing turbine	0.60

Source: *Statistical report on cogeneration* (2016), IDAE

Table 24: Thermal efficiency for industrial sectors with cogeneration

Industrial sector	Thermal efficiency
Mining and quarrying	0.38
Manufacturing of other non-metallic mineral products	0.49
Chemical industry	0.44
Agricultural, food and tobacco industries	0.35
Paper and cardboard, publishing and printing industries	0.42
Other industrial sectors	0.32
Production of non-ferrous minerals	0.31

Industrial sector	Thermal efficiency
Refineries	0.50
Services, etc.	0.29
Iron and steel	0.49
Textile, clothing and leather	0.33
Fabricated metals, machinery and equipment manufacturing	0.40
Transport and communication	0.25

Source: *Statistical report on cogeneration* (2016), IDAE

For plants with no cogeneration, our point of reference was Commission Delegated Regulation 2015/2402, which establishes harmonised thermal and electrical efficiency values for the separate production of electricity and heat.

3.4.1.4. CALCULATION OF HEATING DEMAND BY 'POINT CONSUMERS'

Once we had assigned a thermal efficiency to each plant in the PRTR, we were able to directly obtain the thermal demand value.

$$\text{Heating demand (MWh/y)} = \text{Fuel } (\text{MWh}_{\text{LHV}}/\text{y}) \times \text{TE}(\%)$$

We now have the heating demand for the '**point consumers**' in the industrial sector.

3.4.1.5. CALCULATION OF COOLING DEMAND BY 'POINT CONSUMERS'

We only considered cooling demand for certain industrial sectors where we know this demand to be usual and had sufficient information available to characterise it.

We used the following method:

1. Based on the estimated heating demand for the 'point consumers' analysed, we established their electricity consumption using the following ratios, which were identified in audits of plants from the branches in question carried out by the authors of this report:

Table 25: Heat consumption to electricity consumption ratio

Industrial sector	Heating to electricity ratio (kWh-h/kWh-e)
Beverage manufacture	0.2421
Food	0.7963
Pharmaceutical	0.4968
Chemical	0.1612

Source: authors' own

2. We assumed that electric compression machinery is used for all cooling in the industrial sector. Based on the electricity consumption calculated in the previous point and the electricity-consumption-to-cooling-demand ratios, we identified the demand for cooling for the 'point consumers'. The ratios used, obtained from the above-mentioned audits, are shown in Table 26.

Table 26: Industrial cooling demand ratios

Industrial sector	Cooling to electricity ratio (kWh-c/kWh-e)
Beverage manufacture	1.1051
Food	0.6576
Pharmaceutical	1.2392
Chemical	1.0553

Source: authors' own

3. Based on the thermal demand calculated using the method explained in the previous chapter, cooling demand is calculated as follows:

$$\text{Cooling}\left(\frac{\text{MWh-c}}{\text{y}}\right) = \text{Heating}\left(\frac{MWh\text{-h}}{\text{y}}\right) * \text{Heating to elec. ratio}\left(\frac{MWh\text{-e}}{MWh\text{-h}}\right) * \text{Cooling to elec. ratio}\left(\frac{MWh\text{-c}}{MWh\text{-e}}\right)$$

3.4.2. DEMAND CHARACTERISATION FOR 'DISPERSED CONSUMERS' IN THE INDUSTRY SECTOR

Once we had established the consumption and demand of the major industrial consumers listed in the PRTR, we compared the aggregated total of that consumption with the industrial sector values reported in the 2018 Final Energy Balances. We used IDAE's *Assessing the potential of solar thermal power in the industrial sector* to distribute the difference in consumption between the 'point consumers' and the overall industry consumption figure among the remaining industrial sector.

Once we had compared the consumption calculation for each industrial branch with the balances, we adjusted the demand rates to match the balances.

3.4.3. RESULTS OF THE CHARACTERISATION OF DEMAND IN THE INDUSTRY SECTOR

The results obtained for the industrial sector – both 'point' and 'dispersed' consumers – are summarised below.

Table 27: Summary of demand characterisation of the industrial sector

Sector				Industry													
Province				Spain total													
Type				Min. and quarry.	Food, bev. and tob.	Textile	Wood, cork, furn.	Paper	Refineries	Chemical	Non-metallic	Iron and steel	Non-ferr. metals	Fab. metals	Transp. equip.	Other	Total
Technology [MWh]	Hot water	Fossil fuels	Gas boiler	325 637	1 706 412	184 762	317 617	136 010	1 804 770	1 126 535	0	0	0	1 038 944	494 894	3 878 256	11 013 835
			Diesel/heating oil boiler	454 166	519 209	31 342	103 910	22 873	58 597	101 164	0	0	0	117 716	53 574	724 319	2 186 870
			LPG boiler	35 609	79 807	8 089	18 641	6 425	6 358	18 132	0	0	0	26 824	12 366	140 954	353 205
		Renewables	Biomass boiler	0	255 218	0	1 658 981	205 603	0	0	0	0	0	0	0	0	2 119 803
			Solar thermal	160	8 374	1 929	2 466	2 371	92	5 562	0	0	0	5 319	23 734	32 458	82 463
		Cogeneration	Cogeneration	86 168	477 623	8 613	511 703	410 896	1 836 163	164 830	0	0	0	13 833	43 628	15 238	3 568 695
	Steam	Fossil fuels	Gas boiler	325 696	5 462 547	1 336 542	164 317	801 267	4 882 270	9 077 865	0	0	0	1 583 098	812 698	3 906 125	28 352 426
			Diesel/heating oil boiler	454 202	1 415 201	226 020	53 766	162 027	158 623	298 927	0	0	0	171 748	70 013	728 753	3 739 281
			LPG boiler	35 674	247 837	57 982	9 637	53 116	17 200	70 125	0	0	0	39 222	16 173	141 653	688 618
		Renewables	Biomass boiler	0	903 716	0	858 115	1 413 818	0	0	0	0	0	0	0	0	3 175 649
		Cogeneration	Cogeneration	86 168	2 077 381	61 724	264 380	3 449 016	4 967 056	3 523 451	0	0	0	20 207	77 765	15 238	14 542 388
	Low-temperature gases	Fossil fuels	Gas boiler	325 696	368 176	31 082	47 705	225 114	0	5 476 848	4 100 582	0	0	115 253	2 626 496	3 906 094	17 223 047
			Diesel/heating oil boiler	454 202	47 180	5 256	15 610	52 846	0	74 296	860 210	0	0	0	264 346	727 961	2 501 907
			LPG boiler	35 674	8 357	1 348	2 798	19 335	0	17 979	32 377	0	0	0	61 065	141 653	320 585
			Coal boiler	0	0	0	0	0	0	0	3 362 543	0	0	0	0	0	3 362 543
		Renewables	Biomass boiler	0	55 261	0	249 130	447 354	0	0	623 026	0	0	0	0	0	1 374 772
		Cogeneration	Cogeneration	86 168	195 450	1 435	76 756	1 275 506	0	5 033 617	890 451	0	0	12 700	226 028	15 238	7 813 349
	High-temperature gases	Fossil fuels	Gas boiler	0	0	0	0	0	5 181 399	3 639 977	8 950 522	5 703 021	598 659	1 564 429	0	8	25 638 014
			Diesel/heating oil boiler	0	0	0	0	0	83 446	52 178	1 535 774	1 215 066	0	197 081	0	0	3 083 546
			LPG boiler	0	0	0	0	0	9 048	7 516	75 548	101 270	0	44 610	0	0	237 992
			Coal boiler	0	0	0	0	0	0	0	7 122 635	13 921 410	779 068	0	0	0	21 823 113
		Renewables	Biomass boiler	0	0	0	0	0	0	0	1 143 403	0	0	0	0	0	1 143 403
	Cooling	Electricity	Compression machinery	0	12 890 564	0	0	0	0	2 390 615	0	0	0	0	0	321	15 281 499
		Cogeneration	Cogeneration	0	2 607 193	0	0	0	0	695 060	0	0	0	0	0	0	3 302 254
Demand [MWh]	Hot water			901 740	3 046 642	234 735	2 613 319	784 178	3 705 979	1 416 223	0	0	0	1 202 635	628 196	4 791 225	19 324 873
	Steam			901 740	10 106 682	1 682 268	1 350 215	5 879 244	10 025 150	12 970 369	0	0	0	1 814 276	976 650	4 791 769	50 498 362
	Low-temperature gases			901 740	674 425	39 123	391 998	2 020 156	0	10 602 739	9 869 189	0	0	127 953	3 177 935	4 790 947	32 596 204
	High-temperature gases			0	0	0	0	0	5 273 894	3 699 670	18 827 883	20 940 768	1 377 727	1 806 120	0	8	51 926 068
	Cooling			0	15 497 757	0	0	0	0	3 085 675	0	0	0	0	0	321	18 583 753
	Total			2 705 221	29 325 506	1 956 126	4 355 531	8 683 578	19 005 023	31 774 676	28 697 072	20 940 768	1 377 727	4 950 983	4 782 780	14 374 269	**172 929 260**

Source: authors’ own

As Table 27 shows, the branches of industry with the highest thermal demand, accounting for approximately 50% of the Spanish total, are: chemicals; non-metallic minerals; and food, beverages and tobacco.

Natural gas is the leading fuel used in the industrial sector, and is the most widely used for all thermal levels with the exception of high-temperature applications (mainly the non-metallic minerals and iron and steel branches), where it is used in similar proportions to coal.

As shown in the results, we considered electrical equipment to be the main technology used to meet demand for cooling in the industrial sector. Where equipment has a thermal efficiency of over 100%, consumption might be less than demand in cases where cooling demand represents a very high proportion of the total.

Cogeneration technology is a separate case because one of the objectives laid down in the Commission Delegated Regulation is to identify cogeneration facilities and quantify their contribution to demand coverage. In this study, we assumed that on each registered parcel where a cogeneration facility is located, that facility covers 100% of the energy demand for heating and 75% of the demand for cooling.

A comparison between the cogeneration statistics from IDAE's *'Statistical report on cogeneration* (2016)' and the data obtained in the model is shown below.

Table 28: Comparison between cogeneration data from model and official statistics

Industrial sector	No of units	Total electrical capacity (MW)	Net heat generation (GWh p.a.)	Heat generation as per model (GWh p.a.)
	494	**5 195**	***33 765***	**29 227**
Mining and quarrying	9	54	273	259
Manufacturing of other non-metallic mineral products	83	415	2 630	890
Chemical industry	61	1 053	8 161	9 417
Agricultural, food and tobacco industries	186	1 412	6 676	5 358
Paper and cardboard, publishing and printing industries	58	1 011	5 986	5 135
Production of non-ferrous minerals	3	17	51	0
Refineries	12	608	6 641	6 803
Textile, clothing and leather	29	96	369	72
Fabricated metals, machinery and equipment manufacturing	8	73	190	47
Iron and steel	5	118	1 325	0
Other industrial sectors	40	333	1 434	46

Source: authors' own based on IDAE data

The industrial sectors where cogeneration is most present are the food, chemical and non-metallic minerals sectors. Despite having a smaller number of facilities, the refineries branch accounts for a large amount of the heat generation from cogeneration because its cogeneration facilities are large.

3.4.4. FINAL ENERGY CONSUMPTION

The table below shows the final energy consumption calculated for the industrial sector by energy source used:

Table 29: Industrial sector consumption by energy source (GWh)

Consumption [GWh]		Mining & quarrying	Food, bev. and tob.	Textile	Wood, cork, furn.	Paper	Refineries	Chemical	Non-metallic	Iron and steel	Non-ferr. metals	Fab. metals	Transp. equip.	Other	Total
Fuel	Electricity	0	5 859	0	0	0	0	1 087	0	0	0	0	0	0	**6 946**
	Natural gas	1 245	12 933	1 809	1 016	4 365	21 466	30 977	16 943	7 129	748	5 067	5 153	13 582	**122 433**
	Diesel/heating oil	1 760	2 291	293	203	1 681	346	1 211	3 074	1 519	0	568	468	2 524	**15 936**
	LPG	126	380	75	35	90	37	2 313	140	127	0	129	108	491	**4 052**
	Coal	0	0	0	0	0	0	0	13 490	17 402	974	0	0	0	**31 866**
	Biomass	0	2 369	0	3 854	4 021	0	0	2 373	0	0	0	0	3	**12 620**
	Solar thermal	0	8	2	2	2	0	6	0	0	0	5	24	32	**82**
	Total	**3 131**	**23 841**	**2 179**	**5 110**	**10 159**	**21 849**	**35 593**	**36 020**	**26 176**	**1 722**	**5 769**	**5 753**	**16 633**	**193 935**

Source: authors' own

3.5. SUMMARY OF THE DEMAND CHARACTERISATION RESULTS

The results of the demand characterisation process outlined in the previous sections of this report are shown for all sectors in the table below.

Table 30: Expected demand by technology

SECTOR	THERMAL ENERGY USE	SOURCE	TECHNOLOGY	DEMAND COVERAGE (MWh)		
HOUSING	Heating + domestic hot water	Fossil fuels	Coal boiler	10 155	87 585 804	91 404 480
			Petroleum-product-fired boiler	27 900 930		
			Gas boiler	29 288 899		
		Electricity	Heat pump	2 212 681		
			Electric boiler and radiator	9 077 383		
		Cogeneration	Cogeneration	1 175		
		Renewables	Heat pump (renewable share only)	1 601 661		
			Biomass boiler	15 109 067		
			Solar thermal panel	2 383 853		
	Cooling	Electricity	Heat pump	3 818 635	3 818 676	
		Cogeneration	Cogeneration	41		
SERVICES	Heating + domestic hot water	Fossil fuels	Petroleum-product-fired boiler	7 673 886	53 025 577	75 250 052
			Gas boiler	25 845 628		
		Electricity	Heat pump	10 173 601		
			Electric boiler and radiator	2 827 899		
		Cogeneration	Cogeneration	211 443		
		Renewables	Heat pump (renewable share only)	4 483 580		
			Biomass boiler	1 163 274		
			Solar thermal panel	646 265		
	Cooling	Electricity	Heat pump	22 167 045	22 224 475	
		Cogeneration	Cogeneration	57 430		
INDUSTRY	Hot water + steam + low/high-temperature gases	Fossil fuels	Coal boiler	25 185 656	154 345 507	172 929 260
			Petroleum-product-fired boiler	13 112 006		
			Gas boiler	82 227 323		
			Cogeneration	25 924 432		
		Renewables	Biomass boiler	7 813 627		
			Solar thermal panel	82 463		
	Cooling	Electricity	Compression machinery	15 281 499	18 583 753	
		Cogeneration	Cogeneration	3 302 254		
TOTAL						339 583 791

Source: authors' own

The table summarises the demand met by each technology as identified in the modelling of each economic sector described in the previous sections. However, this modelling process does not allow us to differentiate between the demand met by on-site technologies and that met by energy generated centrally and off-site through district heating and cooling systems.

We used data from the 2018 district heating and cooling survey to break expected demand down according to whether it would be met by on-site or off-site technologies.

3.5.1. DEMAND EXPECTED FOR OFF-SITE TECHNOLOGY (DISTRICT HEATING)

The table below shows the information reported in the district heating and cooling statistics required by Article 24(6) of Directive 27/2012/EU. ADHAC's district heating and cooling survey has been used to identify the capacity and generation values shown for the systems listed in those statistics.

Table 31: Spanish district heating and cooling summary for 2018

Principal sector	Number of installations	Capacity		Demand	
		Heating (MW)	Cooling (MW)	Heating (MWh)	Cooling (MWh)
Housing / Services	40	194	29	215 890	20 015
Industry	11	293	208	319 726	174 196
Total	**51**	**487**	**237**	**535 687**	**194 212**

Source: ADHAC report

4. ONLINE HEAT MAP

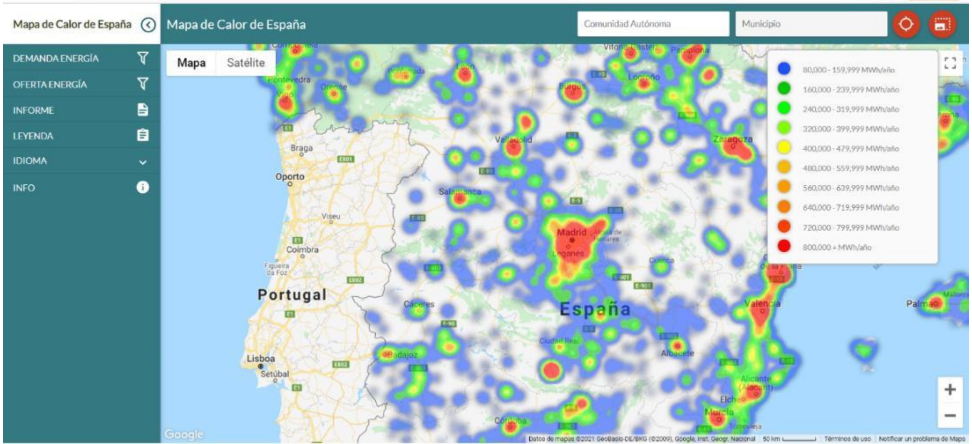
Point 3 of Part I as per Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 requires() Member States to include in these assessments of potential for efficient heating and cooling a map covering their entire national territory and identifying (while preserving commercially sensitive information): heating and cooling demand areas, focusing on energy-dense areas in municipalities and conurbations, and the heating and cooling supply points and district heating transmission installations that are either already in existence or planned for the future.

The application designed in this respect consists of two clearly distinguished modules: one displays the information on a map, and the other allows users to consult and analyse the information it contains.

4.1. MAP VIEW

The online heat map is based on the Google Maps platform and displays the heat demand information compiled in the database, with filters by location or activity type.

The display can be narrowed down to a municipality or to a user-selected area. When a filter is applied, the map shows the thermal demand information for the municipality or specific area selected.



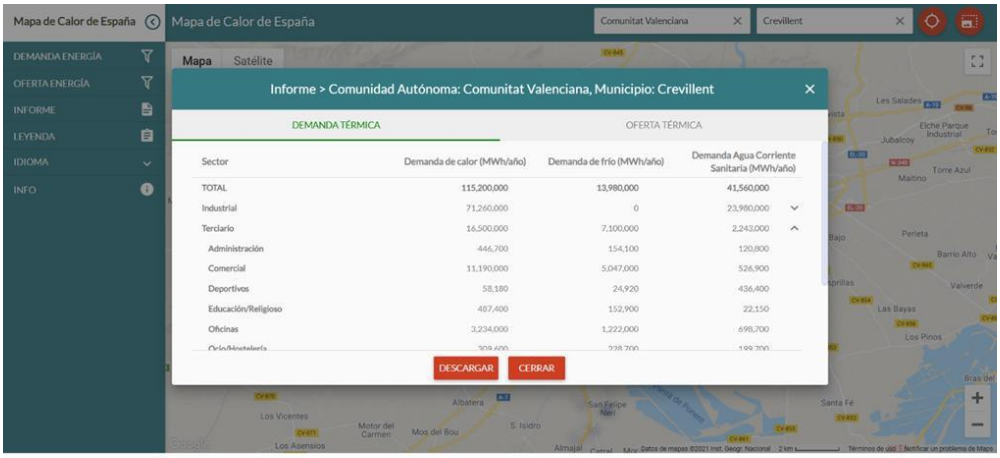
KEY	
Mapa de Calor de España	Heat map of Spain
DEMANDA ENERGÍA	ENERGY DEMAND
OFERTA ENERGÍA	ENERGY SUPPLY
INFORME	REPORT
LEYENDA	KEY
IDIOMA	LANGUAGE
INFO	INFO
Mapa	Map
Satélite	Satellite
xxx-xxx MWh/año	xxx-xxx MWh per year

Figure 6: Example heat map view

The different colours displayed on the heat map represent different levels of demand concentration.

4.2. DATA ANALYSIS AND RESULTS CONSULTATION TOOL

The information shown on the map can be viewed as numerical data, grouped according to the selection made and presented in a report detailing thermal demand, supply and energy-generating potential.



Informe > Comunidad Autónoma: Comunitat Valenciana, Municipio: Crevillent

DEMANDA TÉRMICA | OFERTA TÉRMICA

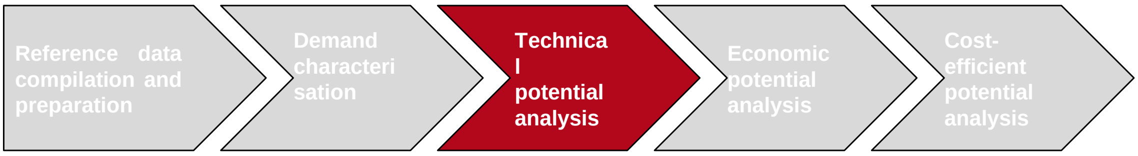
Sector	Demanda de calor (MWh/año)	Demanda de frío (MWh/año)	Demanda Agua Corriente Sanitaria (MWh/año)
TOTAL	115,200,000	13,980,000	41,560,000
Industrial	71,260,000	0	23,980,000
Terciario	16,500,000	7,100,000	2,243,000
Administración	446,700	154,100	120,800
Comercial	11,190,000	5,047,000	526,900
Deportivos	58,180	24,920	436,400
Educación/Religioso	487,400	152,900	22,150
Oficinas	3,234,000	1,222,000	698,700

KEY			
Informe > Comunidad Autónoma: Comunitat Valenciana, Municipio: Crevillent	Report > Autonomous Community: Valencia, Municipality: Crevillent	*Terciario*	Services
DEMANDA TÉRMICA	THERMAL DEMAND	*Administración*	Public authorities
OFERTA TÉRMICA	THERMAL SUPPLY	*Comercial*	Retail
Sector	Sector	*Deportivos*	Sports
Demanda de calor (MWh/año)	Heating demand (MWh per year)	*Educación/Religioso*	Education/religion
Demanda de frío (MWh/año)	Cooling demand (MWh per year)	*Oficinas*	Offices
Demanda Agua Corriente Sanitaria (MWh/año)	Domestic hot water demand (MWh per year)	*Ocio/Hostelería*	Leisure/hospitality
TOTAL	TOTAL	*DESCARGAR*	DOWNLOAD
Industrial	Industry	*CERRAR*	CLOSE

Figure 7: Example breakdown of data from the map view

The heat map can be visited at https://mapadecalor.idae.es/.

5. ANALYSIS OF THE TECHNICAL POTENTIAL



In this chapter we analyse the technical potential of various technologies based on the demand model created as described in the previous chapter.

The analysis of the technical potential is structured as follows:

- a study of the limitations to the development of potential, assessing how the presence of certain technologies may be conditioned by the availability of renewable resources and waste heat from existing installations;
- an examination of the development of technical potential by creating systems for the analysis of each of the technologies studied.

5.1. STUDY OF THE LIMITATIONS TO THE DEVELOPMENT OF POTENTIAL

Before examining the technical potential of the different technologies under analysis, we have to take account of a number of aspects that restrict the possibility of installing these technologies. There are two factors that directly influence the choice of one technology over another:

- **Fuel and renewable energy source availability:** The availability of some renewable sources of energy for heat generation is limited. The main renewable fuel sources considered are biogas produced in waste water treatment plants and landfills and available biomass from forestry or agriculture. We have also considered the resource availability for those renewable energy sources with the potential to generate heat, such as solar thermal and geothermal.
- **Waste heat supply:** We have studied the potential to make use of waste heat produced in industrial and power generation processes at a range of plants. Whether this type of resource can be utilised will therefore depend on there being a plant already in place that produces utilisable heat. We will examine the following plants in this section:
    - thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MW;
    - heat and power cogeneration installations with a total thermal input exceeding 20 MW;
    - waste incineration plants;
    - industrial installations with a total thermal input exceeding 20 MW that can provide waste heat.

5.1.1. SUPPLIERS OF FUELS AND RENEWABLE SOURCES

There are a multitude of plants throughout Spain that generate by-products that can be used as fuel to cover thermal demand either on-site or through district heating and cooling. The main fuel from waste is biogas generated at waste water treatment plants and landfill sites due to the decomposition of organic matter, either naturally (at landfill sites) or through anaerobic digestion (at waste water treatment plants).

There are other renewable sources of fuel, such as biomass from forestry and agriculture, solar energy and geothermal energy.

5.1.1.1. BIOGAS FROM WASTE WATER TREATMENT PLANTS AND LANDFILL SITES

We quantified the amount of biogas generated at waste water treatment plants and landfill sites, using the IDAE report *State of play and potential for biogas generation: technical study for the 2011-2020 Renewable Energy Plan*, which details the potential for biogas production by Autonomous Community.

Table 32: Potentially available biogas from waste water treatment plants by Autonomous Community

Autonomous Community	Total energy-generating potential (GWh)
Andalusia	169.8
Aragon	43.0
Asturias	3.5
Balearic Islands	111.6
Canary Islands	14.0
Cantabria	8.1
Castile and Leon	70.9
Castile-La Mancha	88.4
Catalonia	405.8
Valencia	447.7
Extremadura	16.3
Galicia	64.0
Madrid	398.8
Murcia	3.5
Navarre	19.8
Basque Country	27.9
Rioja	15.1
TOTAL	**1 908.1**

Source: State of play and potential for biogas generation: technical study for the 2011-2020 Renewable Energy Plan, IDAE

We obtained a list of waste water treatment plants and their incoming loads from *Urban Waste Water Treatment Directive – reported data*.

The amount of biogas potentially available from landfill sites according to *State of play and potential for biogas generation: technical study for the 2011-2020 Renewable Energy Plan* has been distributed proportionally between the landfill sites with biogas capture systems listed in the 2017 *Annual Waste Management Report* from the Ministry of Ecological Transition and the Demographic Challenge. This document details the domestic and commercial waste from households and the service sector managed by the public authorities. We distributed the biogas quantity in proportion with the waste managed by each site (incoming load). For landfill sites equipped with biogas power generation facilities, we subtracted the biogas used for power generation from the site’s overall available biogas figure.

Once the biogas used for power generation had been discounted, we obtained the potentially available quantities of biogas shown in Table 33.

Table 33: Potential biogas availability from waste water treatment plants and landfill sites

Waste heat source	No of facilities	Available biogas (GWh per year)
Available biogas	**147**	**1 536**
WASTE WATER TREATMENT PLANTS	111	722
LANDFILL SITES	36	811

Source: authors’ own

5.1.1.2. AVAILABILITY OF BIOMASS FROM FORESTRY OR AGRICULTURE

We assessed Spanish biomass potential based on an IDAE study entitled *Potential for energy generation from biomass (Technical study for the 2011-2020 Renewable Energy Plan)*, which provides biomass maps and information on the different types of biomass available in different areas. Note that this study focuses on biomass from existing sources (agriculture and forestry).

Table 34: Biomass potential

Origin		Biomass (GWh per year)
Existing forests	Forest residues	7 399
	Whole-tree harvesting	39 700
Agricultural residues	Herbaceous	74 333
	Woody	
Total		121 432

Source: authors’ own based on ‘Potential for energy generation from biomass (Technical study for the 2011-2020 Renewable Energy Plan)’

A large variety of fuel types can be made from these resources. In the interests of simplification we considered two:

- **Pellets:** boiler pellets for use in the housing and service sectors and for small-scale industrial establishments. We considered two quality grades:

premium-grade pellets – whole-tree pellets with a maximum estimated potential of around 20 TWh, prioritised for housing and service sector use in rural areas in our distribution;

industrial-grade pellets – made from agricultural residues, with a maximum potential of 70 TWh, and prioritised for industry in rural areas and large establishments in the service sector.

- **Unprocessed wood chips**: these are produced from wood that cannot be used to make pellets, have a potential of approximately 30 TWh and would be used in large industrial plants or in district heating and cooling networks.

Finally, we considered that any potential waste biomass produced in industrial sectors such as the wood, paper and food branches is fully utilised in the sector itself, as the initial estimates are much lower than the biomass consumption reported in the 2018 Final Energy Consumption Balances.

5.1.1.3. POTENTIAL FOR GENERATING HEAT USING SOLAR THERMAL POWER

Solar energy generation has been estimated using standardised tables showing generation per m² of solar installation for each province. We downloaded hourly direct and diffuse radiation profiles on an optimised slope using the PVGIS application[27].

The heat output per installed m² is considered similar for both of the types of solar thermal installations under analysis (concentrated and conventional).

Table 35: Heat generation by thermal solar technology per m² and installed kilowatt

Province	Heat generation (kWh per m² per year)	Heat generation (kWh per KW per year)
A Coruña	632	903
Álava	701	1 001
Albacete	888	1 269
Alicante	922	1 317
Almería	928	1 325
Ávila	835	1 193
Badajoz	936	1 337
Barcelona	835	1 193
Burgos	745	1 065
Cáceres	907	1 296
Cádiz	959	1 370
Cantabria	642	917
Castellón	827	1 181
Ceuta	918	1 311
Melilla	934	1 334
Ciudad Real	897	1 282

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[27] https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY

Province	Heat generation (kWh per m² per year)	Heat generation (kWh per KW per year)
Madrid	919	1 313
Navarre	712	1 017
Córdoba	935	1 335
Cuenca	864	1 235
Girona	813	1 162
Granada	921	1 316
Guadalajara	864	1 234
Guipúzcoa	672	960
Huelva	967	1 381
Huesca	760	1 085
Balearic Islands	857	1 225
Jaén	937	1 338
La Rioja	746	1 066
Las Palmas	1 088	1 554
León	700	999
Lleida	794	1 135
Lugo	635	908
Málaga	920	1 314
Ourense	721	1 030
Palencia	767	1 096
Pontevedra	763	1 090
Asturias	605	864
Murcia	936	1 338
Salamanca	825	1 178
Santa Cruz De Tenerife	1 071	1 530
Segovia	845	1 207
Sevilla	939	1 342
Soria	799	1 142
Tarragona	813	1 161
Teruel	846	1 209
Toledo	882	1 260
Valencia	828	1 183
Valladolid	783	1 118
Vizcaya	665	950
Zamora	799	1 141
Zaragoza	782	1 116

Source: IDAE report

5.1.1.4. POTENTIAL FOR DIRECT-USE GEOTHERMAL ENERGY

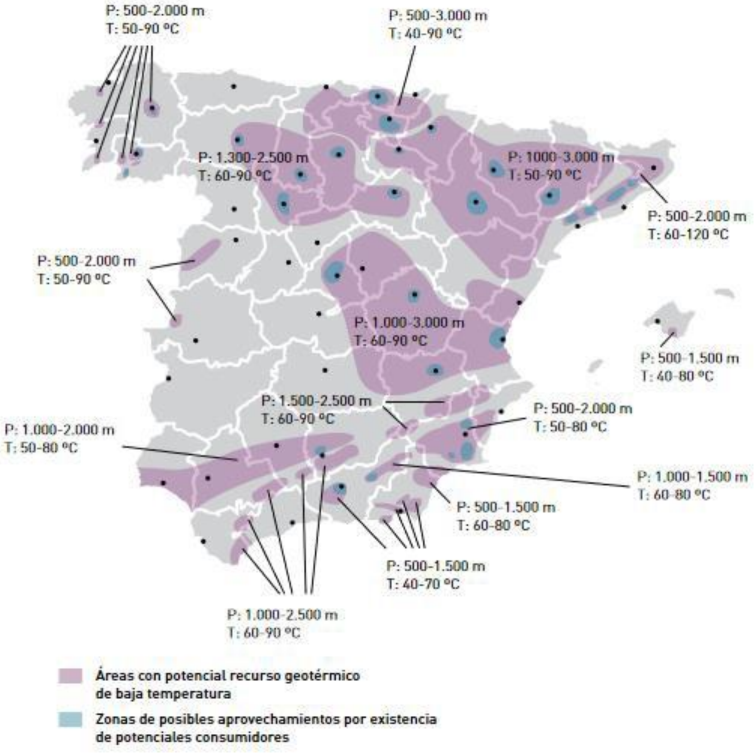
In order to estimate the potential for direct-use geothermal energy, we consulted an IDAE study entitled *Assessment of potential for geothermal energy – 2011-2020 Renewable Energy Plan*. We considered all medium- and low-enthalpy areas reported as potential geothermal reservoirs for the direct use of geothermal energy via deep geothermal wells.

Table 36: Geothermal resource classification

Enthalpy	Temperatures	Technology	Application
Very low	< 30 °C	With or without heat pump	Heat pump for heating/air conditioning
Low	30-100 °C	Heat exchangers and/or heat pumps	Heating/air condition and low-temperature industrial processes
Medium	100-150 °C	Heat exchangers/binary-cycle plants	Electricity, heating/air conditioning and industrial processes
High	> 150 °C	-	Electricity

Source: adapted from the 'Geothermal Manual' produced by IDAE and the Spanish Geology and Mining Institute

The main low-enthalpy geothermal reservoirs are shown on the map below.



KEY	
P	Depth
T	Temperature
Áreas con potencial recurso geotérmico de baja temperatura	Areas with a potential low-temperature geothermal reservoir
Zonas de posibles aprovechamientos por existencia de potenciales consumidores	Areas with potential consumers for utilisation of the reservoir

Figure 8: Map of low-temperature geothermal resources and areas of possible utilisation

Source: Assessment of potential for geothermal energy – 2011-2020 Renewable Energy Plan

That study includes the estimated geothermal capacity of each reservoir and the capacity of the resource in densely populated areas.

Table 37: Summary of geothermal resources by reservoir

Reservoir/basin	Geothermal resource (H_R) (TWh)	Geothermal resource in populated areas (H_R) (TWh)
Duero	72 400	4 700
Ebro	238 600	900
Tajo-Mancha-Júcar	739 100	52 000
Guadalquivir	26 100	500
Norte-Cantábrica	436 600	92 000
Total	**1 512 800**	**150 100**

Source: Assessment of potential for geothermal energy – 2011-2020 Renewable Energy Plan

As the table shows, compared with the actual annual demand identified in this study, there is large amount of untapped energy in these reservoirs (> 150 000 TWh in populated areas).

This energy can be extracted using deep geothermal wells, but this depends on the presence of aquifers in the reservoirs and the need to ensure a separation between the injection well and the production wells to avoid significant alterations in aquifer temperatures.

5.1.2. SUPPLIERS OF WASTE HEAT FROM POWER STATIONS

The power stations considered in this study as potential generators of usable waste heat are:

- combined-cycle power plants
- waste incineration power plants
- solar thermal power plants
- biogas and biomass power plants

To identify the amount of waste heat based on installed capacity, we made assumptions as to the average number of hours the plants operate each year and the amount of usable waste heat produced, as summarised in the table below.

Table 38: Summary of waste heat available in each facility type

Technology	Capacity (MW)	Hours of operation	Thermal output capacity (MWt/MWe)
Combined-cycle plant	N/A	1 000	0.35
Waste incineration and biomass plants	10	7 500	1.11
	25		1.25

Technolog y	Capacity (MW)	Hours of operation	Thermal output capacity (MWt/MWe)
	50		1.31
Solar thermal plants	N/A	2 500	1.31
Biogas plants	N/A	7 500	0.77

Source: authors' own

We obtained these values using simulations of a Rankine cycle using a steam turbine and assuming that a maximum of 50% of the steam is extracted in the condenser. This steam turbine cycle is the most commonly used system in incineration, biomass and solar thermal power plants, but represents only part (around 30%) of the installed capacity in combined-cycle facilities.

We considered that the use of engines with around 45% electrical efficiency would be the most likely set-up at biogas power plants. We assumed that the utilisable heat from exhaust gases and the cooling of the high-temperature water loop would represent 35% of the capacity of the fuel used.

Tapping into waste heat reduces power generation capacity by between 10% and 20% depending on the pressure used for heat extraction. In this study we have considered a reduction in power generation capacity of 15%[28] of the waste heat capacity used, assuming that heat is recovered at a temperature of around 100 °C.

5.1.2.1.WASTE HEAT FROM THERMAL POWER STATIONS UNDER THE 'ORDINARY' REMUNERATION SCHEME

We obtained details of the type, capacity and power generation for the power stations under the 'ordinary' remuneration scheme from the 2019 *Spanish Electricity System Report* published by Spain's TSO, Red Eléctrica de España. To calculate waste heat from combined-cycle plants we used the method recommended by the JRC in *Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level*.

There is the possibility of retrofitting power stations in order to tap into their 'unusable' heat from power generation to supply a district heating system.

The types of power stations from the 'ordinary' remuneration scheme capable of supplying waste heat are combined-cycle, conventional thermal and nuclear power stations, as they all have steam turbines from which high-temperature steam can be obtained in return for a reduction in power generation.

In this study we have considered only the use of waste heat from combined-cycle power stations. Although the NECP does not contain any plans to increase the installed capacity of this technology, we expect the power stations in existence today to remain in place, so part of the steam they generate could be used to supply a district heating system.

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[28] Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level

Table 39: Waste heat available at power stations under the 'ordinary' remuneration scheme

Waste heat source	No of facilities	Waste heat (GWh per year)
Combined-cycle	72	9 235

Source: authors' own

5.1.2.2. POWER PLANTS USING COGENERATION, WASTE INCINERATION AND RENEWABLES

From the power plants covered by the 'specific' remuneration scheme we identified cogeneration plants (group a) and power stations that use alternative fuels such as municipal or industrial waste (group c), biomass (groups b.6 and b.8) or biogas (group b.7) to generate electricity. We can also add the solar thermal power plants (group b.1.2) that operate with a steam cycle similar to that used in other types of thermal power station and are an untapped source of waste heat.

Cogeneration plants usually serve a specific industrial establishment and are generally designed to be the right size to make use of all the heat they generate. We have therefore not considered any waste heat from this type of facility. Cogeneration plants have therefore been identified in this section but not considered as waste heat sources.

The estimated amount of waste heat from these sources is shown below.

Table 40: Waste heat available at power stations under the 'specific' remuneration scheme (>5 MWt)

Waste heat source	No of facilities	Waste heat (GWh per year)
Waste incineration	46	6 433
Biomass	92	6 140
Biogas	166	1 420
Solar thermal	51	7 709

Source: authors' own

5.1.2.3. WASTE HEAT FROM INDUSTRIAL FACILITIES

There are specific branches of the industrial sector that require very high heat for their production process and are therefore likely to have available waste heat at lower temperatures. Waste heat is also produced in electrolysis processes such as those used to make primary aluminium. In these types of industrial facility waste heat is generated by the facility itself and is located at specific points in the process, such as the points where gases are expelled from chimneys or electrolytic cells.

The industrial sectors considered in this study as potential generators of usable waste heat are:

- cement production
- glass production
- aluminium production
- metals and foundries

We considered the following ratios between available waste heat from industrial facilities and heat demand:

Table 41: Waste heat by industrial sector

Industrial sector	Waste heat as % of heat
Cement	8.17%
Aluminium	22.91%
Glass	6.84%
Metals and foundries	1.26%

Source: authors' own

Below is a summary of the waste heat available in the industrial sector from the 'point consumers' identified in the demand characterisation with a thermal capacity over 20 MW:

Table 42: Waste heat available in various industrial sectors

Waste heat source	No of facilities	Waste heat (GWh per year)
Branch	**66**	**2 656**
Cement	32	1 312
Aluminium	7	973
Glass	13	199
Metals and foundries	14	172

Source: authors' own

5.2. DEVELOPMENT OF TECHNICAL POTENTIAL BY CREATING SYSTEMS FOR THE ANALYSIS OF EACH OF THE TECHNOLOGIES STUDIED

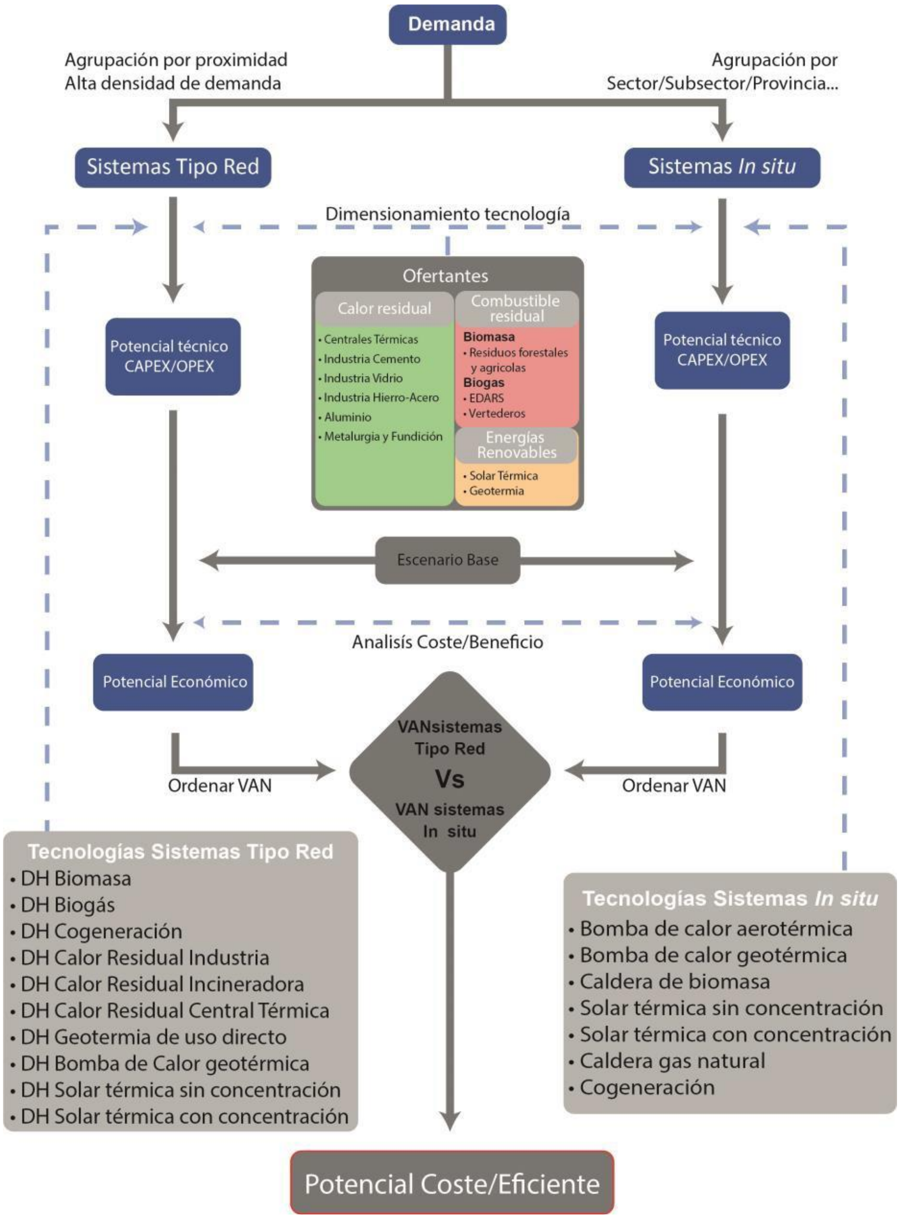
Taking into account both the characterisation of demand and the different factors that can limit the potential of certain technologies, we developed a method for examining the technical potential of each of the efficient technologies analysed, consisting of:

- **Creating systems**, forming clusters of demand and supply centres, giving a smaller set of systems that can be used to study the viability of the technologies, with two types of system considered in this demand clustering approach:
    - **Systems with (individual or centralised) on-site supply**, demand is grouped based on similarity in terms of economic sector and sub-sector and establishment size, obtaining a representative average demand;
    - **District-type systems (with off-site supply),** clusters of demand and waste heat suppliers are formed on the basis of geographical proximity, obtaining the overall demand for a geographical area.
- **Sizing technologies**, a process which starts by identifying the capacity of the technology in question, the demand covered, the fuel consumption and the costs of installation (CAPEX) and operation and maintenance (OPEX) necessary to cover each system's demand by a certain technology, thus arriving at the technology's technical potential. The technologies studied depend on the type of system:
    - Systems with on-site supply:
        - concentrated and conventional solar thermal
        - ground-source and air-source heat pump
        - biomass boiler
        - high-efficiency cogeneration
        - natural gas boiler
    - District systems (with off-site supply):
        - district heating using biogas boilers
        - district heating using biomass boilers
        - district heating and cooling using a ground-source heat pump
        - district heating and cooling using industrial waste heat
        - district heating and cooling using waste heat from thermal power stations (combined-cycle, waste incineration and renewable energy)
        - district heating using direct-use geothermal energy
        - district heating and cooling high-efficiency cogeneration

- district heating and cooling using concentrated and conventional solar thermal power

Once we had sized up each of these technologies for all of the systems, we performed a cost-benefit analysis for each solution identified in order to calculate its economic potential.

The different steps involved in the method used for this study, up to the calculation of cost-efficient potential, are illustrated in Figure 9.



KEY							
Demanda	Demand	*Aluminio*	Aluminium	*Potencial Económico*	Economic potential	*DH Solar térmica con concentración*	District heating, concentrated solar thermal
Agrupación por proximidad	Grouping by proximity	*Metalurgia y Fundición*	Metals and foundries	*Ordenar VAN*	Rank by NPV	*Tecnologías Sistemas in situ*	'On-site' technology systems
Alta densidad de demanda	High density of demand	*Combustible residual*	Waste as fuel	*VAN sistemas Tipo Red vs VAN sistemas in situ*	NPV district systems vs NPV on-site systems	*Bomba de calor aerotérmica*	Air-source heat pump
Agrupación por Sector/Subsector/Provincia	Grouping by sector/sub-sector/province	*Biomasa*	Biomass	*Tecnologías Sistemas Tipo Red*	'District' technology systems	*Bomba de calor geotérmica*	Ground-source heat pump
Sistemas Tipo Red	'District' systems	*Residuos forestales y agrícolas*	Forest and agricultural residues	*DH Biomasa*	District heating, biomass	*Caldera de biomasa*	Biomass boiler
Sistemas In situ	'On-site' systems	*Biogás*	Biogas	*DH Biogás*	District heating, biogas	*Solar térmica sin concentración*	Conventional solar thermal
Dimensionamiento tecnología	Technology sizing	*EDARS*	Waste water treatment plants	*DH Cogeneración*	District heating, cogeneration	*Solar térmica con concentración*	Concentrated solar thermal

Potencial técnico CAPEX/OPEX	Technical potential CAPEX/OPEX	*Vertederos*	Landfill sites	*DH Calor Residual Industria*	District heating, industrial waste heat	*Caldera gas natural*	Natural gas boiler
Ofertantes	Suppliers	*Energías Renovables*	Renewables	*DH Calor Residual Incineradora*	District heating, incinerator	*Cogeneración*	Cogeneration
Calor residual	Waste heat	*Solar Térmica*	Solar thermal	*DH Calor Residual Central Térmica*	District heating, waste heat from thermal power station	*Potencial Coste/Eficiente*	Cost-efficient potential
Centrales Térmicas	Thermal power stations	*Geotermia*	Geothermal	*DH Geotermia de uso directo*	District heating, direct-use geothermal		
Industria Cemento	Cement industry	*Escenario Base*	Reference case	*DH Bomba de Calor geotérmica*	District heating, ground-source heat pump		
Industria Vidrio	Glass industry	*Análisis Coste/Beneficio*	Cost-benefit analysis	*DH Solar térmica sin concentración*	District heating, conventional solar thermal		

Figure 9: Illustration of the technical and economic potential calculation method

Source: *authors' own*

5.2.1. CREATING THE SYSTEMS

More than 21 million records were obtained from the Land Register during the demand characterisation – too many for individual processing. We therefore grouped records into a smaller number of systems, each comprising a large number of demands, so that they could be studied in batches.

To analyse on-site implementation technologies for each property, we grouped the demands by type of demand, i.e. by sector and economic sub-sector. When analysing the geographical areas where district heating can be implemented, the demands were grouped based on geographical proximity.

5.2.2. SYSTEMS WITH ON-SITE SUPPLY

In order to study solutions located on-site, we grouped together demands with similar characteristics that could influence the sizing of any of the technologies.

In other words, the same types of demand (demands with the same sector, sub-sector and province code, from properties built in the same period, in the climatic zone and with the same CNAE code) will have a common demand rate and hourly demand profile.

Another important factor influencing technology sizing is the capacity range of the demand to be met. To account for the influence of the size of the installation, we used average annual capacity to distinguish the demands of different properties within the same demand type, using three brackets:

- **minor demand**, with average demand capacity below 50 kW;
- **medium demand**, with average demand capacity between 50 kW and 5 MW;
- **major demand**, with average demand capacity above 5 MW.

Finally, within each type we distinguished whether the property is in a rural or urban municipality.

- **rural** municipalities with a population of less than 20 000;
- **urban** municipalities with a population of 20 000 or more.

Applying all the parameters set out above, we identified over a hundred different demand types for the on-site systems.

We allocated an hourly demand profile for each type (heating, cooling and domestic hot water) to each on-site supply system.

5.2.3. DISTRICT SYSTEMS (WITH OFF-SITE SUPPLY)

District-type systems need to supply a group of individual demanders that are geographically close to one another but vary in terms of type of demand.

The method we used to identify the areas where there is potential demand for the establishment of district heating and cooling systems was as follows:

- We began by discretising the territory using a 0.001° latitude and longitude grid, with the result being a total of 1 726 846 points where there is a demand for heat.
- We then identified the points with demand of more than 20 kWh/m², and the grid was reduced to the 281 812 high-demand-density points to be studied.
- We then grouped these points using a proximity-driven clustering algorithm. We also calculated the length of the district system that would be needed to link up the different points in the system using an algorithm that finds the shortest route between points. This step reduced the data set to 5 455 district systems. Off-site supply technologies and the pipework costs involved in installing district heating were assessed for these 5 455 systems.

The data for each district-type system include the number of demand profiles and the type of demand for the properties in that system. This enabled us to identify the demand profile of the system as a whole on the basis of the individual profiles. It also facilitates comparison between the district heating solutions and the on-site technologies studied.

The demand types considered for district heating and/or cooling were as follows:

- **single family homes;**
- **flats in small blocks with a central system for the whole building;**
- in the **service sector**, only medium or major demand (> 50 kW capacity), assuming the installation of a centralised facility;
- **Industrial sector.**

We considered that the district heating and cooling networks would carry the following thermal fluids:

- **hot water** for domestic hot water and space heating in the service and housing sectors and for low-temperature industrial processes (typically with a network flow temperature of 80 °C and a return temperature of 60 °C).
- **cold water** for air conditioning in the service and housing sectors (typically with a network flow temperature of 7 °C and a return temperature of 12 °C).

Where over 20% of a district system’s total demand was cooling for air conditioning, we considered that heating and cooling would be provided by a four-pipe network.

In district heating and cooling systems, renewable or efficient energy has to account for a minimum amount of overall demand coverage, so we limited our analysis to the following:

- **systems in which renewables cover over 50% of demand** – district heating systems based on renewables (biomass, biogas, geothermal, solar, heat pump or waste heat from industry, incinerators or thermal power plants) must cover at least 50% of demand in order to be considered efficient;
- **systems in which efficient technology covers over 75% of demand** – district heating systems based on cogeneration must cover at least 75% of demand in order to be considered efficient.

Once we had created the district-type systems, we identified the points of supply of waste heat or fuel or geothermal resources in the area.

In order to allocate the resources of a supply point to a particular system, we assessed all types of district heating systems within a certain radius. All supply points capable of meeting the criteria for consideration as an efficient district heating network – i.e. able to cover 50% of the heat demand – were then taken into account. Once we had identified the systems we then ranked them using the following formula, which prioritises higher demand and shorter distance:

$$K = \mathrm{C}_\mathrm{d}/(D\,\mathrm{C}_d)\sqrt{\mathrm{C}_S} \tag{1}$$

Where C_d is capacity demanded, C_S capacity supplied and D the distance from the point of supply and the energy-demanding system.

We also analysed systems located above geothermal reservoirs, examining the feasibility of tapping into these geothermal resources for the systems located on top of them.

5.2.3.1. CLUSTERING ALGORITHM AND TRENCH LENGTH

The clustering algorithm we used was the Agglomerative Clustering method from the sklearn library in Python. This is one of a series of hierarchical algorithms where objects are grouped by proximity in pairs forming a bottom-up tree. The tree can be cut at a specified height (maximum distance) to obtain the clusters (corresponding clusters).

In our model we chose to use the 'Ward' option to minimise variation between clusters. In other words the clusters generated were similar in size.

We used this algorithm directly on the coordinates, cutting off at a distance of 0.05° in latitude/longitude. Through this procedure we identified a total of 5 455 clusters spread across Spain.

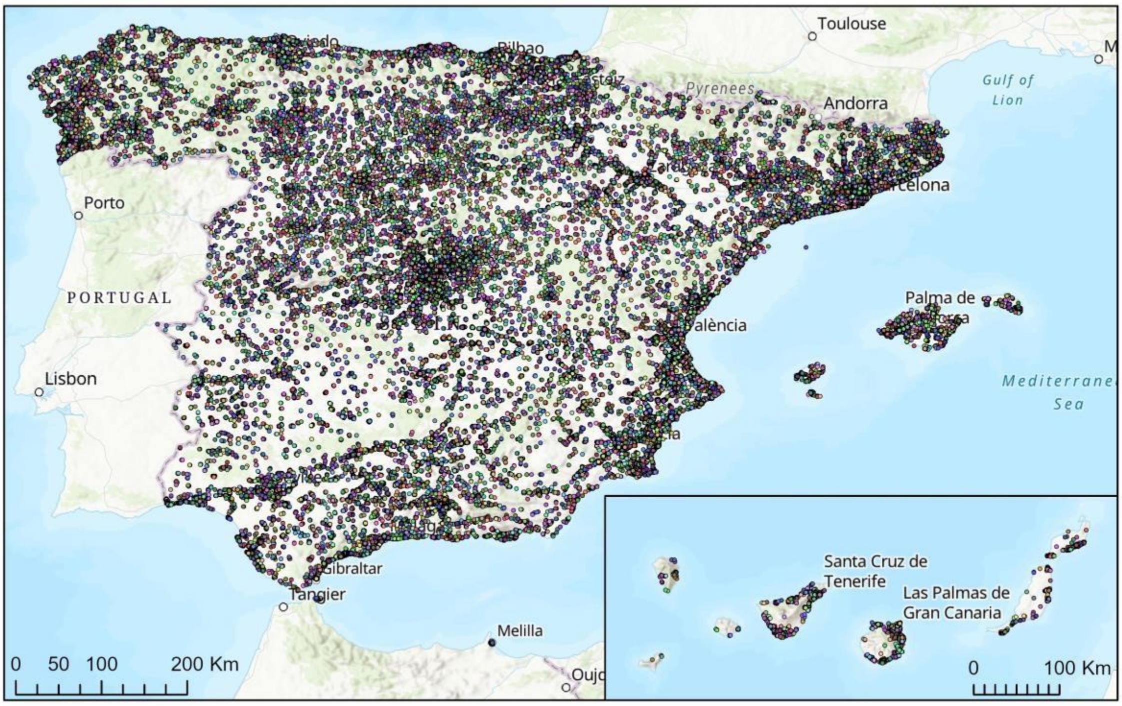
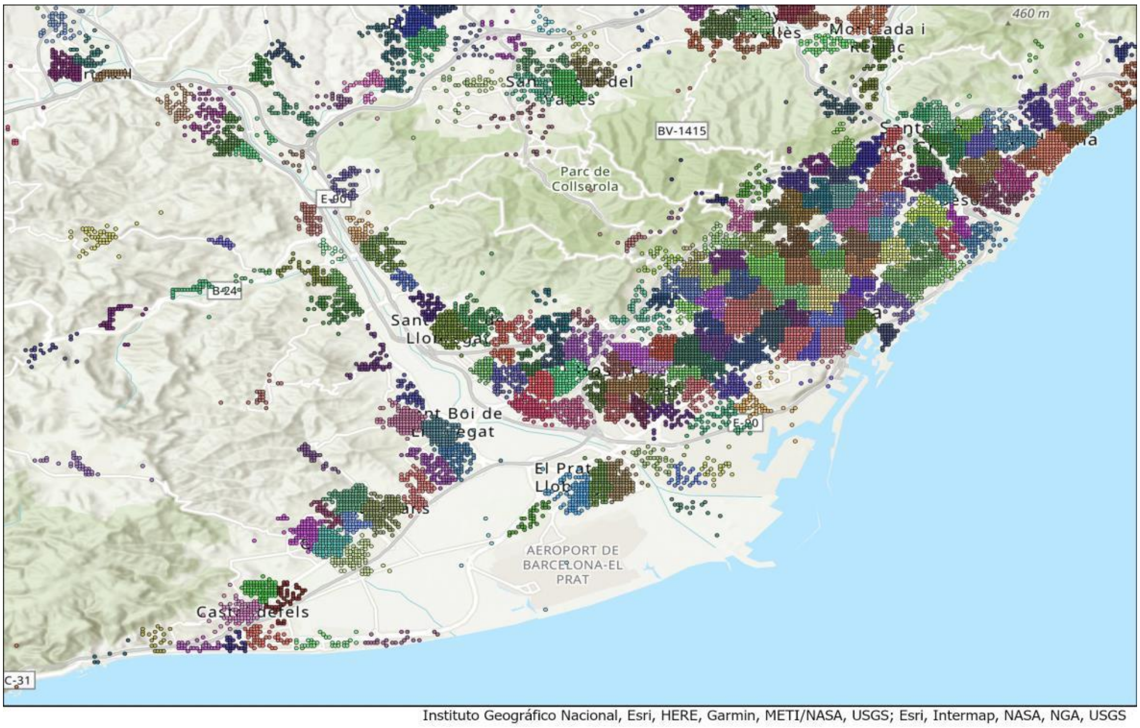


Figure 10: Map of Spain with identified district-type systems

Source: authors' own

By way of example, Figure 11 shows how the various high demand density points in the metropolitan area of Barcelona, with some regularity in terms of size and coverage of the municipalities and industrial estates nearby, have been grouped into a cluster by the algorithm.



KEY	
AEROPORT DE BARCELONA-EL PRAT	BARCELONA-EL PRAT AIRPORT
Instituto Geográfico Nacional, Esrl, HERE, Garmin, METI/NASA, USGS; Esri, Intermap, NASA, NGA, USGS	National Geographical Institute, ESRL, HERE, Garmin, METI/NASA, USGS; Esri, Intermap, NASA, NGA, USGS

Figure 11: Close-up of clusters in the Barcelona metropolitan area

Source: authors' own

To estimate a characteristic network length for each system, we aimed to identify the shortest path joining the different points of the grid covered by that system, which is an example of the 'Travelling Salesman Problem' (TSP), which re resolved using the python_tsp library. More specifically, we used the tsp_simulated_annealing function to find a satisfactory route connecting a large number of points within a reasonable timeframe by stochastic methods.

The routes generated are circular (starting and ending at the same point), usually longer than a real-life district heating network, and are in branched tree-type structures rather than one-line circular paths.

5.2.4. TECHNOLOGY SIZING

Once a system's demand profile had been identified, we sized up the different technological options available for that system, considering a number of factors:

- the hourly demand curve analysis
- the effect of storage systems
- analysis of the technologies associated with on-site supply
- analysis of the technologies used for off-site 'district' supply

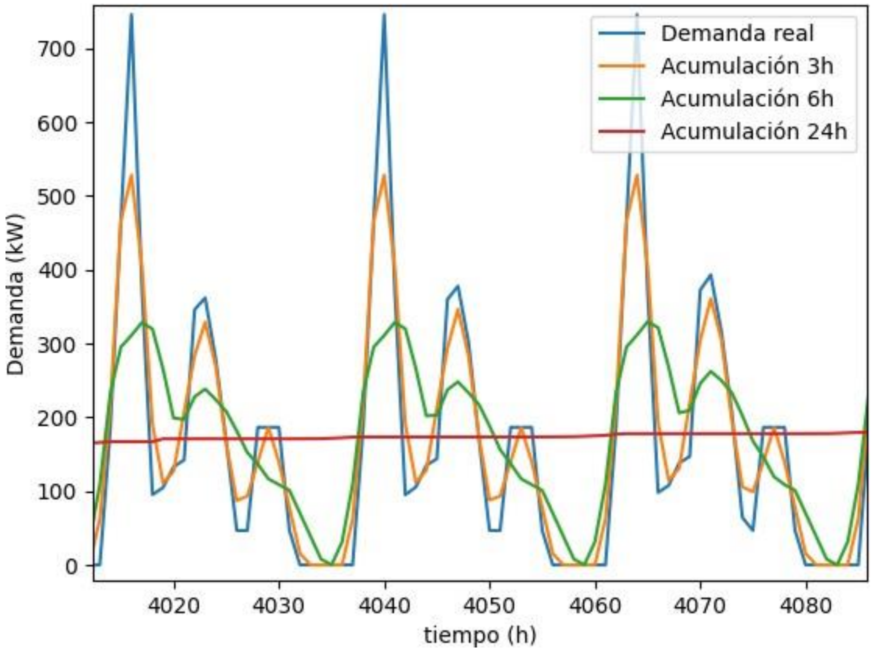
5.2.4.1. HOURLY DEMAND CURVE ANALYSIS

We used the hourly demand curve to size up the design capacity of each technology to cover a percentage (varying depending on the solution and/or technology) of overall demand.

Certain technologies with reduced installation costs and the capacity to regulate output are scaled to cover 100% of demand, or less if demand peaks are expected to be covered by back-up technology. The technologies that do not have output regulation capacity or have very high installation costs are scaled to a size that allows them to operate for a large number of hours or to utilise a certain percentage of the energy available.

5.2.4.2. STORAGE SYSTEM EFFECTS

To simulate the effect of storage systems – particularly relevant for off-site technologies (associated with district heating systems) – in the technology sizing process, we smoothed out the demand profile by calculating an average for each demand point over a specific interval of time.



KEY	
Demanda (kW)	Demand (kW)
Tiempo (h)	Time (h)
Demanda real	Actual demand
Acumulación xh	Storage x hours

Figure 12: Effect of storage systems on the demand profile

Source: authors' own

Storage capacity is the gap between the demand curve and the smoothed demand curve. As this gap cycles between positive and negative, the required total storage capacity in kWh was calculated as the difference between the maximum and minimum points.

5.2.5. TECHNOLOGIES ASSOCIATED WITH ON-SITE SUPPLY SYSTEMS

The assumptions we made when sizing up technologies for on-site supply systems are described below.

5.2.5.1. CONVENTIONAL SOLAR THERMAL

The sizing process for conventional solar thermal technology began with the hourly solar radiation curve or profile for a 1 m^2 surface at optimum tilt angle. We used the PVGIS application[29] to obtain the hourly direct and diffuse radiation profiles applicable to this optimally tilted surface for the capitals of each of Spain's provinces.

Our initial assumption was that conventional solar technology can meet the demand for domestic hot water in the housing and service sectors, and the demand for low-temperature heat (hot water <100 °C) for industry.

We did not consider this technology for the purposes of heating spaces, as there is a seasonal mismatch between supply and demand, so any installation would have to be oversized. We also did not consider it for cooling purposes, as the temperatures that could be achieved are considered low for absorption cooling. The options we have ruled out are, although technically possible, not in general use.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 43: Outline of conventional solar thermal power technology

Technology	Flat-plate solar
Sizing criteria	To meet 60% of domestic hot water demand in the housing sector To utilise 70-90% of the energy available in services and industry
Yield	860-1550 kWh per kW depending on province
Storage	24h in housing, 24h in services, 3h in industry
CAPEX	EUR 1 000 per kW (≤50 kW), EUR 760 per kW (>50 kW < 5MW), EUR 600 per kW (>5 MW)
OPEX	EUR 5.33 per MWh
Useful life	25 years

Source: authors' own

The results of our analysis of the technical potential of this technology are shown in the table below:

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[29] https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY

Table 44: Technical potential results for conventional solar technology

Conventional solar		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Total (GWh)
Technical potential	**Housing**	15.944	17 053	15 339	15 339
	Services	7.926	7 117	8 160	8 160
	Industry	5.375	4 169	4 638	4 638
	Total	29.245	28 339	28 137	28 137

Source: authors' own

5.2.5.2. CONCENTRATED SOLAR THERMAL

The sizing process for concentrated solar thermal technology began with the hourly solar radiation curve or profile for a 1 m² surface at optimum tilt angle. We used the PVGIS application[30] to obtain the hourly radiation profiles applicable to this optimally tilted surface for the capitals of each of Spain's provinces.

Our assumption is that concentrated solar technology would be used to meet the following demands:

- **service sector** – domestic hot water demand, as well as cooling demand via absorption systems when cooling accounts for over 10% of overall demand;
- **industrial sector** – heating demand for both medium-temperature (steam) and low-temperature processes (hot water), as well as cooling demand via absorption systems when cooling accounts for over 10% of overall demand.

We did not consider this technology for the purposes of heating spaces, as there is a seasonal mismatch between supply and demand, so any installation would have to be oversized. Installations of this kind do, however, exist.

We limited the use of concentrated solar installations to the following systems:

- **service sector** – the systems with 'medium' or 'major' demand, i.e. exceeding 50 kW.
- **industrial sector** – the systems with 'medium' or 'major' demand, i.e.

exceeding 50 kW. We did not consider the possibility of this technology being installed

on-site to cover demand in the housing sector.

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[30] https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 45: Outline of concentrated solar thermal power technology

Technology	Concentrated solar
Sizing criteria	To utilise 70-90% of the energy available
Efficiency	860-1 550 kWh per kW depending on province
Storage	6h in services, 3h in industry
CAPEX	EUR 750 per kW
OPEX	EUR 5.33 per MWh
Useful life	25 years

Source: authors' own

The results of our analysis of the technical potential of this technology are shown in the table below:

Table 46: Technical potential results for concentrated solar technology

Concentrated solar		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	-	-	-	-	-	-
	Services	2.364	2 504	1 964	-	654	2 618
	Industry	16.839	13 511	1 606	12 093	2 668	16 367
	Total	19.204	16 015	3 571	12 093	3 322	18 985

Source: authors' own

5.2.5.3. AIR-SOURCE HEAT PUMP

To size up the installed capacity of air-source heat pumps for on-site supply, we assumed that this technology would be capable of covering all heating, air conditioning and domestic hot water needs in the housing and service sectors. We did not consider this technology for heating or cooling purposes in the industrial sector.

This technology becomes more efficient as the thermal level of demand decreases (i.e. the smaller the difference between the outdoor air temperature and the temperature required). We assumed the following seasonal performance factors (SPF):

Table 47: Performance factors used for air-source heat pumps

Demand	SPF
Space heating	3.5
Air conditioning	3.5
DHW	2.8

Source: PNIEC report

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 48: Sizing summary: air-source heat pump technology

Technology	Heat pump
Sizing criteria	To cover 100% of demand
Performance	3.5 HT / AC 2.8 DHW
Storage	6h
CAPEX	EUR 1 370 per kWt (≤50 kW), EUR 850 per kWt (>50 kW)
OPEX	EUR 16 per MWh (≤ 50 kW) EUR 10 per MWh (> 50 kW)
Useful life	25 years

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 49: Technical potential results for air-source heat pump technology

Air-source heat pump		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	77.399	105 969	25 381	62 289	3 824	91 494
	Services	37.378	45 923	10 900	42 150	22 236	75 287
	Industry	-	-	-	-	-	-
	Total	114.777	151 891	36 282	104 439	26 060	166 781

Source: authors' own

5.2.5.4. GROUND-SOURCE HEAT PUMP

To size up the installed capacity of ground-source heat pumps for on-site supply, we assumed that this technology would be capable of covering all heating, air conditioning and domestic hot water needs in the housing and service sectors. We did not consider this technology for heating or cooling purposes in the industrial sector.

As this technology requires drilling into the ground, we only considered this type of installation for following systems, assuming that the type of building would be compatible with it:

- **Housing sector** – single-family homes and large blocks of flats built since 2007;
- **Service sector** – the systems with ‘medium’ or ‘major’ demand, i.e. exceeding 50 kW.

This technology becomes more efficient as the thermal level of demand decreases (i.e. the smaller the difference between the ground temperature and the temperature required). We assumed the following seasonal performance factors (SPF):

Table 50: Performance factors used for ground-source heat pumps

Demand	SPF
Space heating	5.1
Air conditioning	5.5
DHW	4.0

Source: PNIEC report

The sizing criteria are summarised in the table below:

Table 51: Sizing summary: ground-source heat pump technology

Technology	Ground-source heat pump
Sizing criteria	To cover 100% of demand
Efficiency	5.1 HT 5.5 AC 4.0 domestic hot water
Storage	6h
CAPEX	EUR 2 250 per kWt (≤50 kW), EUR 1 750 per kWt (>50 kW)
OPEX	EUR 16 per MWh (≤ 50 kW) EUR 10 per MWh (> 50 kW)
Useful life	25 years

Source: authors’ own

The results of our technical potential analysis for this technology are shown in the table below:

Table 52: Technical potential results for ground-source heat pump technology

Ground-source heat pump		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	45.882	103 197	9 882	36 882	1 807	48 571
	Services	10.165	17 280	4 721	12 510	5 981	23 213
	Industry	-	-	-	-	-	-
	Total	56.047	120 478	14 603	49 392	7 788	71 783

Source: authors' own

5.2.5.5. BIOMASS BOILERS

To size up the installed capacity of biomass boilers for on-site supply, we assumed that this technology would be capable of covering all heating and domestic hot water needs in the housing and service sectors, as well as all heat production needs for medium-temperature (steam) and low-temperature (hot water) processes in the industrial sector.

In this study we considered two representative fuel types:

- **Pellets**, which were considered:

  - for minor demand (< 50 kW) in the housing and service sectors in rural areas only;
  - for medium and major demand (> 50 kW) in the service sector in both rural and urban areas;
  - for small and medium-sized industrial plants (< 5 MW) in rural areas only.

- **Unprocessed wood chips**, which were considered for large industrial plants (> 5 MW).

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 53: Sizing summary: biomass technology

Technology	Biomass
Sizing criteria	To cover 100% of demand
Efficiency	0.80 (≤ 5 MW) 0.85 (> 5 MW)
Storage	0h
CAPEX	EUR 400 per kWt (≤ 5 MW) EUR 350 per kWt (> 5 MW)

Technology	Biomass
OPEX	EUR 20 per MWh (≤ 5 MW) EUR 12 per MWh (> 5 MW)
Useful life	25 years

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 54: Technical potential results for biomass

Biomass boilers		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	37.677	15 071	8 868	30 168	-	39 036
	Services	12.209	4 885	6 282	18 681	-	24 963
	Industry	13.400	5 550	13 952	41 178	-	55 129
	Total	63.286	25 505	29 102	90 026	-	119 128

Source: authors' own

5.2.5.6. HIGH-EFFICIENCY COGENERATION

To size up the installed capacity of cogeneration technology for on-site supply, we assumed that this technology would be capable of covering part of heating and domestic hot water needs in the service sector or the demand for hot water and steam for low- and medium-temperature industrial processes. We also assumed it could provide cooling through absorption systems.

We assumed electrical efficiency of 35% and an overall efficiency of between 75% and 80%. In installations of over 5 MW, we also considered that additional heat would be provided by post-combustion, at almost 100% efficiency.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 55: Sizing summary: cogeneration technology

Technology	Simple gas turbine cycle
Sizing criteria	To utilise 90% of the thermal energy available
Efficiency	0.35 electrical 0.40-0.45 thermal
Storage	0h
CAPEX	EUR 1 000 per kWe (≤5 MW), EUR 1 800 per kWe (< 5 MW)
OPEX	EUR 15 per MWh (> 5 MW) EUR 20 per MWh (< 5 MW)
Useful life	25 years

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 56: Technical potential results for cogeneration

Cogeneration		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	-	-	-	-	-	-
	Services	2.482	15 337	3 064	4 993	471	8 528
	Industry	9.955	13 672	10 458	42 204	15 080	67 742
	Total	12.438	29 008	13 523	47 197	15 551	76 270

Source: authors' own

5.2.5.7. NATURAL GAS BOILER

As we were using the natural gas boiler as a representative non-renewable, economically competitive technological solution, we sized it up as an on-site supply option for all of the systems.

We considered this technology capable of covering 100% of the demand for heating, air conditioning and domestic hot water in the housing and service sector, or for low- and medium-temperature industrial processes (hot water and steam). This technology is outlined in the table below:

Table 57: Sizing summary: gas boiler technology

Technology	GAS BOILER
Sizing criteria	To cover 100% of demand
Efficiency	0.9

Technology	GAS BOILER
Storage	0h
CAPEX	EUR 150 per kW (< 50kW) EUR 75 per kW (> 50kW)
OPEX	EUR 5.3 per MWh
Useful life	25 years

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 58: Technical potential results for natural gas boilers

Natural gas boilers		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	80.129	12 009	25 385	62 289	-	87 673
	Services	28.320	3 666	10 901	42 150	-	53 052
	Industry	17.752	1 607	19 378	50 553	-	69 930
	Total	126.201	17 283	55 664	154 992	-	210 655

Source: authors' own

5.2.6. THE SIZING OF DISTRICT HEATING AND COOLING NETWORKS

A district heating and cooling network consists of:

- a central plant generating thermal energy from renewables, waste heat or high-efficiency cogeneration, or a combination of these;
- a network of distribution pipes;
- substations connecting consumers to the system;
- storage systems (hot or cold water storage tanks).

Conventional technology can be used as back-up to cover peak demand and secure energy supply regardless of the availability of the technology considered for the central boiler plant. The investment cost for a district heating and cooling network will therefore be the sum of each system component. This section details how we identified the investment costs for the network of distribution pipes and heat exchanger substations in the study, because they are the same regardless of the type of network.

We provide details of the investment cost for the central boiler plant individually for each of the technologies studied, i.e. each renewable energy source, waste heat and high-efficiency cogeneration. This cost needs to be added to the costs of the pipeline network and exchanger substations.

As well as the main characteristics defined when sizing up each technology, as summarised in Chapter 5.2.5, for each system we identified:

- the network type (two-pipe or four-pipe);
- the CAPEX to install the pipe network and heat exchanger substations;
- back-up technologies.

A network length, calculated as explained in Chapter 5.2.3, has been established for each district system.

In order to size up each type of district network covered by this study, we considered that their demand would consist of the individual demands represented by the following properties within the area studied:

- **single-family homes;**
- **flats in small or large blocks** with communal heating systems;
- demand for average capacity of more than 50 kW in the **services and industrial sectors**.

We considered only the part of the demand corresponding to domestic hot water and space heating, as well as hot water for industrial processes, ruling out the use of these systems to cover the industrial demand for higher temperatures. For cooling, we considered only demand for air conditioning purposes, excluding industrial cooling processes. Depending on the type of technology studied and demand for cooling, we identified whether a two-pipe or four-pipe network would be used.

- **Two-pipe systems** are heating-only networks, where the main technology does not produce cooling or cooling demand accounts for less than 20% of overall network demand;
- **Four-pipe systems** are heating and cooling networks, where the main technology can produce cooling and cooling demand accounts for more than 20% of overall network demand.

The table below outlines our assumptions in terms of trenching costs:

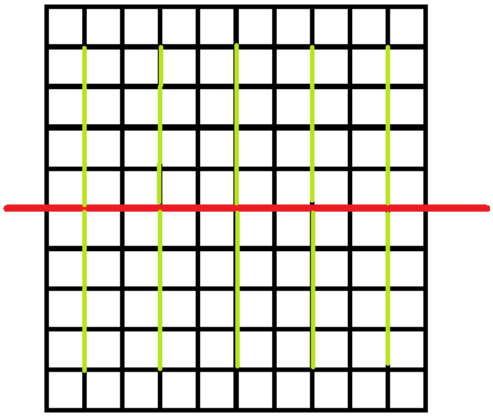
Table 59: Costs associated with district heating

Trenching cost	District heating and cooling
Two-pipe	EUR 400 per metre
Four-pipe	EUR 600 per metre

Source: authors' own

Using the demand points forming the grid to calculate trench length gives a good estimate of this as long as each point in the grid (around one hectare) represents few demanders, as is the case with blocks of flats or other large buildings in the housing and industrial sectors. However, in areas with a high density of single-family homes, we need to consider an additional cost on top of the cost of connection and distribution sub-network costs.

Figure 13: System used to estimate connections in single-family home areas



Red: main pipe; green: connections; black: 10 x 10 m² parcels

Source: authors' own

This simplified analysis of 10 x 10 m² parcels within a one-hectare area gives a trench length for connections of 4 m per single-family home, which needs to be added onto overall trench length.

In addition to the network cost, our assumptions regarding the capital expenditure on the heat exchanger were:

- EUR 400 per kW for single-family homes;
- EUR 125 kW for flats in large blocks and medium demand (50 kW-5 MW) in the services and industrial sectors;
- EUR 75 per kW for major demand (> 5 MW) in the services and industrial sectors.

We considered the following costs of operating and maintaining heat exchanger substations:

- EUR 15 per MWh for single-family homes;
- EUR 12.5 per MWh for flats in large blocks and medium demand (> 50 kW) in the services and industrial sectors;
- EUR 5.33 per MWh for major demand (> 5 MW) in the services and industrial sectors.

Finally, we established the costs of laying the main pipeline from the central boiler plant to the district heating network on the basis of peak network capacity.

- EUR 400 per metre for small networks with capacity below 1 MW;
- EUR 900 per metre for networks with capacity of 1-10 MW;
- EUR 1 700 per metre for networks with capacity over 10 MW;
- EUR 250 per metre for biogas pipelines.

For networks involving a new central boiler plant being built, we considered that the main pipeline would be 500 metres long. For solutions with an energy-supplying plant already in place, we considered the distance between that plant and the district heating network's central plant.

District heating and cooling networks typically use water tanks for storage. The assumptions we considered for modelling those tank systems were:

- **12-hour storage** for district networks based on conventional or concentrated solar energy;
- **9-hour storage** for the other technologies.

We assumed a cost of EUR 200 per m³ for storage systems.

All district heating systems are backed up by conventional systems to cover peak demand. The back-up systems we considered were natural gas boilers for heating and compression machinery for cooling. In some technologies, we considered that absorption cooling systems could be used to provide cooling from heat.

Table 60: Summary of the additional costs of district heating and cooling technology

Technology	CAPEX	OPEX
Natural gas boiler	EUR 75 per kW	EUR 5.33 per MWh
Compression machinery	EUR 850 per kW	EUR 10 per MWh
Absorption cooling system	EUR 550 per kW < 5 MW EUR 250 per kW > 5 MW	EUR 10 per MWh EUR 5.33 per MWh

Source: authors' own

5.2.6.1. DISTRICT HEATING USING BIOGAS

We considered the use of biogas boilers to supply district heating networks located within 10 km of a biogas supply site, assuming constant biogas production throughout the year. From all the systems, we selected those in which at least 50% of the system's heat demand could be covered by biogas. The sizing criteria are summarised in the table below:

Table 61: Sizing summary: district heating network using biogas

Technology	District heating using biogas
Sizing	To cover 50-85% of demand
Efficiency	0.9
Storage	9h
CAPEX	EUR 75 per kW
OPEX	EUR 5.33 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 62: Technical potential results for district heating using biogas

District heating, biogas		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.080	495	91	210	-	301
	Services	0.054	292	119	178	-	297
	Industry	0.004	44	25	-	-	25
	Total	0.139	831	235	388	-	623

Source: authors' own

5.2.6.2. DISTRICT HEATING USING BIOMASS

We have sized up biomass boilers to cover 85% of demand in the relevant district heating networks, considering their use for heating purposes only.

The sizing criteria are summarised in the table below:

Table 63: Sizing summary: district heating network using biomass

Technology	District heating using biomass
Sizing	To cover 85% of demand
Efficiency	0.85
Storage	9h
CAPEX	EUR 350 per kW
OPEX	EUR 12 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 64: Technical potential results for district heating using biomass

District heating, biomass		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	4.537	17 940	3 284	11 645	-	14 929
	Services	1.574	5 370	2 925	5 167	-	8 092
	Industry	1.274	2 503	8 805	-	-	8 805
	Total	7.385	25 814	15 014	16 812	-	31 826

Source: authors' own

5.2.6.3. DISTRICT HEATING USING A GROUND-SOURCE HEAT PUMP

We considered that ground-source heat pump technology could cover demand for domestic hot water, space heating and air conditioning. We sized it to cover 85% of demand.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 65: Sizing summary: district heating network using ground-source heat pump technology

Technology	District heating using ground-source heat pump
Sizing	To cover 85% of demand
Efficiency	5.1 for heating / 5.5. for cooling
Storage	9h
CAPEX	EUR 1 700 per kW
OPEX	EUR 10 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 66: Technical potential results for district heating using a ground-source heat pump

District heating using a ground-source heat pump		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	5.338	28 948	4 261	14 101	83	18 445
	Services	3.048	20 055	4 282	9 607	2 095	15 985
	Industry	1.343	5 103	9 273	-	-	9 273
	Total	9.729	54 106	17 816	23 708	2 179	43 703

Source: authors' own

5.2.6.4. DISTRICT HEATING USING INDUSTRIAL WASTE HEAT

We considered technology for systems located within 5 km of an industrial facility that could supply waste heat. This radius is increased to 10 km[31] when waste heat capacity exceeds 10 MW.

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[31] https://publications.jrc.ec.europa.eu/repository/handle/JRC104752

We assumed that the heat supply profile would be constant, and these systems could cover heat demand directly and cooling demand through absorption cooling systems.

We divided the available heat capacity between those systems for which between 50% and 85% of demand could be covered by the available capacity, ranking the systems using equation (1) from section 5.2.3 until the available capacity at the heat-supplying site has been used up.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 67: Sizing summary: district heating network using industrial waste heat

Technology	District heating using waste heat from industry
Sizing	To cover 50-85% of demand
Efficiency	1
Storage	9h
CAPEX	EUR 75 per MW
OPEX	EUR 5.33 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 68: Technical potential results for district heating using industrial waste heat

District heating using waste heat from industry		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.046	384	67	130	1	198
	Services	0.031	218	58	114	18	190
	Industry	0.028	132	203	-	-	203
	Total	0.105	734	327	244	19	591

Source: authors' own

5.2.6.5. DISTRICT HEATING USING WASTE HEAT FROM POWER PLANTS THAT USE COMBINED-CYCLE TECHNOLOGY, WASTE INCINERATION OR RENEWABLES

This technology is analysed in systems located within 5 km of a combined-cycle plant offering waste heat. This radius is increased to 10 km when waste heat capacity exceeds 10 MW.

We assumed a constant supply of heat throughout the year and divided the available heat capacity between those systems for which between 50% and 85% of demand could be covered by the available capacity, ranking the systems using equation (1) until the available capacity at the heat-supplying site has been used up.

We estimate that power generation is reduced by 0.15 MWh of electricity for every MWh of heat extracted from the power plant.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 69: Sizing summary: district heating network using waste heat from combined-cycle/waste incineration power plants

Technology	District heating using heat from combined-cycle/incineration plant
Sizing	To cover 85% of demand
Efficiency	1
Storage	9h
CAPEX	EUR 75 per kW
OPEX	EUR 5.33 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the tables below:

Table 70: Technical potential results for district heating using waste heat from combined-cycle plants

District heating using waste heat from combined-cycle plants		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.114	941	134	293	6	433
	Services	0.182	1 417	297	499	163	959
	Industry	0.130	308	1 046	-	-	1 046
	Total	0.426	2 666	1 478	792	169	2 438

Source: authors' own

Table 71: Technical potential results for district heating using waste heat from incineration plants and from biogas and biomass power plants

District heating using waste heat from incineration plants and from biogas and biomass power plants		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.228	1 665	242	625	7	874
	Services	0.222	1 680	284	729	197	1 210
	Industry	0.185	447	1 456	-	-	1 456
	Total	0.634	3 792	1 982	1 354	204	3 541

Source: authors' own

Waste incinerators account for 54% of the potential shown in Table 71, while biomass plants represent 30% and biogas plants 16%.

5.2.6.6. DISTRICT HEATING USING DIRECT-USE GEOTHERMAL ENERGY

This type of technology is considered for all district-type systems that are located totally or partially on top of a low-enthalpy geothermal reservoir.

We considered the use of this energy source for space heating and domestic hot water. We ruled out the possibility of using it for district cooling through an absorption system. This technology is sized to cover 50-85% of thermal demand at 4 500 annual hours of operation.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 72: Sizing summary: district heating network using direct-use geothermal energy

Technology	District heating using direct-use geothermal energy
Sizing	To cover 50-85% of demand
Efficiency	1
Storage	12h
CAPEX	EUR 1 000 per kW
OPEX	EUR 20 per MWh

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 73: Technical potential results for district heating using direct-use geothermal energy

District heating using direct-use geothermal		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.171	419	224	629	-	853
	Services	0.502	1 090	501	2 155	-	2 656
	Industry	0.299	452	2 330	-	-	2 330
	Total	0.972	1 961	3 054	2 784	-	5 839

Source: authors' own

5.2.6.7. DISTRICT HEATING USING COGENERATION

We considered cogeneration technology for all of the systems based on district heating. The thermal demands that this technology is capable of covering are demand for domestic hot water, heat demand for space heating and cooling demand for air conditioning using an absorption system.

We ruled out all solutions that are not capable of covering 75% of demand. Just as we did for on-site cogeneration, we took post-combustion processes into account for installations generating more than 5 MW thermal energy.

The sizing criteria and other parameters considered for this technology are summarised in the table below:

Table 74: Sizing summary: district heating network using cogeneration

Technology	District heating using cogeneration
Sizing	To utilise 90% of the thermal energy available
Efficiency	0.35 electrical efficiency 75-80% overall efficiency
Storage	9h
CAPEX	EUR 1 000 per MW (> 5 MW), EUR 1 800 per MW (< 5 MW)
OPEX	EUR 15 per MWh (> 5 MW) EUR 29 per MWh (< 5 MW)

Source: authors' own

The results of our technical potential analysis for this technology are shown in the table below:

Table 75: Technical potential results for district heating using cogeneration

District heating using cogeneration		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.023	115	47	98	3	148
	Services	0.140	1 095	556	367	124	1 047
	Industry	1.024	2 020	7 226	-	-	7 226
	Total	1.187	3 231	7 828	465	127	8 421

Source: authors' own

5.2.6.8. DISTRICT HEATING USING CONVENTIONAL AND CONCENTRATED SOLAR THERMAL POWER

We sized this technology for all the district-type systems studied.

We considered that **conventional solar power** could be used to meet demand for hot water and space heating, but not cooling demand.

We considered that **concentrated solar power** could be used to meet demand for hot water, space heating, and cooling using absorption systems.

We using the hourly radiation profile for sizing purposes, using the same method followed for on-site solar power. The technology was sized to cover 50% of thermal demand.

The sizing criteria are summarised in the table below:

Table 76: Sizing summary: district heating network using conventional solar power

Technology	District heating using conventional solar power
Sizing criteria	To utilise 70% of the energy available
Efficiency	860-1550 kWh per kWh depending on the province
Storage	12h
CAPEX	EUR 760 per kW (< 5 MW) EUR 600 per kW (> 5 MW)
OPEX	EUR 5.33 per MWh
Useful life	25 years

Source: authors' own

Table 77: Sizing summary: district heating network using concentrated solar power

Technology	Concentrated solar
Sizing criteria	To utilise 70% of the energy available
Efficiency	860-1 550 kWh per kWh depending on province
Storage	12h
CAPEX	EUR 750 per kW
OPEX	EUR 5.33 per MWh
Useful life	25 years

Source: authors' own

The results of our technical potential analysis for these technologies are shown in the tables below:

Table 78: Technical potential results for district heating using conventional solar power

District heating using conventional solar thermal power		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.105	236	69	27	0	96
	Services	1.462	2 133	1 096	228	0	1 324
	Industry	3.667	2 859	2 910	0	0	2 910
	Total	5.233	5 227	4 075	255	0	4 330

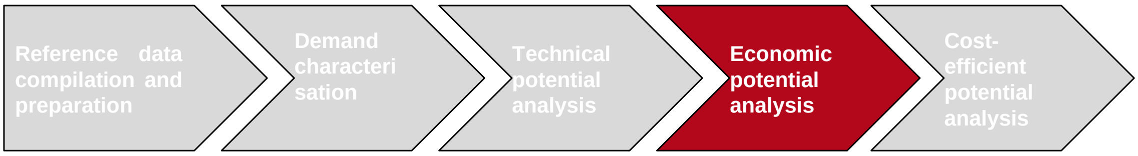
Source: authors' own

Table 79: Technical potential results for district heating using concentrated solar power

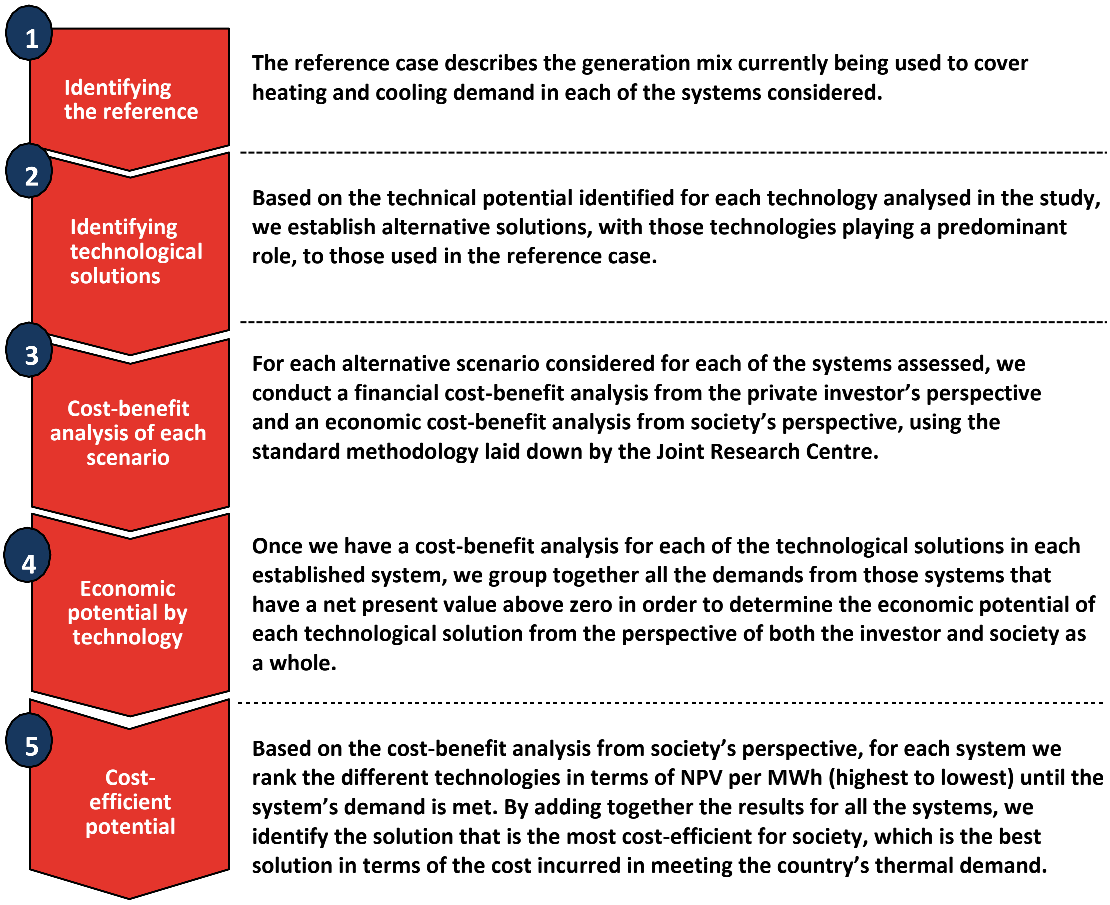
District heating using concentrated solar thermal power		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)
Technical potential	**Housing**	0.288	634	147	103	26	276
	Services	3.514	6 053	1 334	837	1 152	3 323
	Industry	1.352	1 403	1 228	0	0	1 228
	Total	5.155	8 090	2 708	941	1 178	4 827

Source: authors' own

6. ECONOMIC POTENTIAL ANALYSIS



Now that we have analysed the technical potential to meet the demand identified for each of the technologies studied, in this chapter we shall analyse the economic potential in order to determine the financial viability of installing each of these technologies. We developed a tool for this analysis, following the European Commission's guidelines and methodology. Our method is structured into five main blocks:



The reference case describes the generation mix currently being used to cover heating and cooling demand in each of the systems considered.

Based on the technical potential identified for each technology analysed in the study, we establish alternative solutions, with those technologies playing a predominant role, to those used in the reference case.

For each alternative scenario considered for each of the systems assessed, we conduct a financial cost-benefit analysis from the private investor's perspective and an economic cost-benefit analysis from society's perspective, using the standard methodology laid down by the Joint Research Centre.

Once we have a cost-benefit analysis for each of the technological solutions in each established system, we group together all the demands from those systems that have a net present value above zero in order to determine the economic potential of each technological solution from the perspective of both the investor and society as a whole.

Based on the cost-benefit analysis from society's perspective, for each system we rank the different technologies in terms of NPV per MWh (highest to lowest) until the system's demand is met. By adding together the results for all the systems, we identify the solution that is the most cost-efficient for society, which is the best solution in terms of the cost incurred in meeting the country's thermal demand.

Figure 14: Cost-benefit analysis method

Source: Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level, Joint Research Centre

The cost-benefit analysis tool makes it possible to assess investment decisions by examining how such decisions cause variation between the costs and benefits of the reference case and those corresponding to the alternative scenarios involving the different technological solutions studied.

The next points examine each of the steps shown in Figure 14 in further detail.

6.1. IDENTIFYING THE REFERENCE CASE

The reference case is the foundation on which we build our cost-benefit analysis. It needs to reflect the mix of thermal generation technologies used at present, i.e. how heating and cooling demand is currently being met in each of the three segments of consumption considered (housing, services and industry).

This reference case is defined by the demand characterisation we performed in the first part of this report, including the distribution of technologies by sector and climate zone shown in Table 80 and the subsequent tables.

Table 80: Distribution of heating technology in the housing and service sectors by climate zone

Technologies	Housing			Services		
	Atlantic/North	Continental	Mediterranean	Atlantic/North	Continental	Mediterranean
Heating						
Petroleum-product-fired boiler	30.81%	37.3%	20.6%	12.7%	15.1%	13.1%
Gas boiler	30.64%	33.7%	35.2%	48.7%	51.6%	49.2%
Biomass boiler (domestic)	21.82%	20.6%	30.8%	-	-	-
Heat pump	9.43%	4.7%	7.6%	38.6%	33.2%	37.7%
Other (electricity)	7.30%	3.6%	5.8%	-	-	-
Cooling						
Heat pump	100.00%	100.0%	100.0%	100.0%	100.0%	100.0%
Domestic hot water						
Coal boiler	0.2%	-	-	-	-	-
Petroleum-product-fired boiler	37.5%	32.6%	33.4%	13.0%	16.0%	22.5%
Gas boiler	36.1%	42.5%	24.6%	51.5%	53.7%	51.2%
Biomass boiler (domestic)	1.5%	0.2%	-	-	-	-
Solar thermal	2.8%	6.7%	13.0%	-	-	-
Other (electricity)	21.9%	17.9%	29.0%	35.5%	30.2%	26.3%

Source: authors' own

Table 81: Distribution of heating technology by branch of industry

Technology \ Industry	Min. + quarr. (non-energy)	Food, bev. and tobacco	Textile, leather and footw.	Pulp, paper and printing	Chemical (incl. petrochem.)	Non-metallic minerals	Iron, steel and foundries	Non-ferrous metals	Fabricated metals	Transport equipment	Construction	Wood, cork and furniture	Other branches
Heating													
Coal boiler	-	-	-	-	-	38.8%	66.5%	-	-	-	-	-	-
Petroleum-product-fired boiler	60.2%	16.8%	16.9%	18.9%	5.4%	8.1%	6.3%	-	11.6%	8.8%	17.6%	4.9%	17.6%
Conventional systems (natural gas)	39.8%	71.1%	83.1%	44.1%	94.6%	47.0%	27.2%	-	88.4%	91.2%	82.4%	20.8%	82.4%
Solar thermal	-	-	-	-	-	-	-	-	-	0.1%	-	-	-
Biomass boiler	-	12.1%	-	37.1%	-	6.1%	-	-	-	0.1%	-	74.4%	-
Cooling													
Geothermal	-	-	0.0%	-	-	-	-	-	-	-	-	-	-
Heat pump	-	-	16.8%	-	-	-	-	-	-	-	-	-	-
Other (electricity)	100.0%	-	-	100.0%	100.0%	-	-	-	-	-	100.0%	-	100.0%
Biogas (industrial)	-	-	71.1%	-	-	-	-	-	-	-	-	-	-
Hot water for industrial processes													
Coal boiler	-	-	-	-	-	-	-	-	-	-	-	-	-
Petroleum-product-fired boiler	20.1%	3.7%	16.9%	8.5%	8.5%	-	12.1%	-	12.1%	-	20.1%	4.9%	20.1%
Gas boiler	69.9%	1.5%	83.1%	91.5%	91.5%	-	87.9%	-	87.9%	-	69.9%	20.8%	69.9%
Biomass boilers	10.0%	-	-	-	-	-	-	-	-	-	10.0%	74.4%	10.0%

Source: authors' own

6.1.1. PROJECTING THE FUTURE TECHNOLOGY MIX

Having identified how the different technologies are distributed, we needed to project the reference case over the period covered by this study (2020 to 2050), which required estimating the trend in heating and cooling demand calculated for the reference year (2018).

We chose to calculate these future values using the baseline scenario from the NECP, which simulates the trend in estimated demand if the policies and measures existing when the NECP was drawn up remain in place. This scenario was chosen because it gives a better idea of how the reference case is influenced by the policies in place at the end of 2019, a year before the year for which we are required to conduct this comprehensive assessment (2020)[32].

In order to project future heating and cooling demand from the reference year, we calculated two cumulative growth rates, one for 2020-2030 and the other for 2030-2050.

Below we provide details of the trends calculated, broken down by activity sector (housing, services and industry) for the entire timespan covered by this project.

6.1.1.1. HOUSING SECTOR

Demand for both heating and cooling in the housing sector is expected to increase compared to the 2018 figures. Demand for heating and domestic hot water will be up 3% in 2050 compared to 2018 (from 87 586 GWh per year to 90 562 GWh per year) and cooling demand will be up 56% in 2050 compared to 2018 (from 4 181 GWh per year to 6 515 GWh per year).

Table 82 shows the expected trend in thermal demand in the housing sector.

Table 82: Heating and cooling demand forecast for the housing sector

HOUSING	2020	2025	2030	2035	2040	2045	2050
Heating demand (GWh)	88 529	90 264	91 198	90 995	90 907	90 809	90 562
Cooling demand (GWh)	4 181	4 769	5 357	5 905	6 498	6 512	6 515

Source: authors' own based on the NECP baseline scenario

6.1.1.2. SERVICE SECTOR

The expected growth in heating demand in the service sector up to 2050 is very similar to the expected growth in cooling demand. Demand for heating and domestic hot water will be up 14% in 2050 compared to 2018 (from 53 026 GWh per year to 60 336 GWh per year) and cooling demand will be up 12% in 2050 compared to 2018 (from 22 224 GWh per year to 24 909 GWh per year).

Table 83 shows the expected trend in thermal demand in the service sector.

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[32] See point 8(a)(ii) of the version of Annex VIII established by Commission Delegated Regulation 2019/826, ref. No 7.

Table 83: Heating and cooling demand forecast for the service sector

SERVICES	2020	2025	2030	2035	2040	2045	2050
Heating demand (GWh)	55 072	56 834	57 585	58 162	58 614	59 219	60 336
Cooling demand (GWh)	23 081	23 764	24 020	24 201	24 327	24 514	24 909

Source: authors' own based on the NECP baseline scenario

6.1.1.3. INDUSTRY SECTOR

Unlike the housing and service sectors, the industrial sector is expected to see cooling demand remain unchanged up to 2050. On the other hand, a 25% increase is forecast in heating demand from 2018 to 2050, mainly linked to the growth in industrial production expected over that period. More specifically, heating demand is expected to increase by 30%, from 154 346 GWh per year in 2018 to 200 649 GWh per year in 2050.

Table 84 shows industrial sector heating and cooling demand up to 2050.

Table 84: Heating and cooling demand forecast for the industrial sector

INDUSTRY	2020	2025	2030	2035	2040	2045	2050
Heating demand (GWh)	160 840	168 737	174 836	180 435	185 703	191 876	200 649
Cooling demand (GWh)	18 584	18 584	18 584	18 584	18 584	18 584	18 584

Source: authors' own based on the NECP baseline scenario

We used the NECP baseline scenario projections of the energy demand coverage by fuel type to prepare our fuel use projections. We then calculated cumulative growth rates for each fuel and applied them to the estimated demand for 2018 in each sector.

Where we could not find an annual growth rate (coal in the housing and service sectors), we opted to use linear regression to plot the trend between the reference years in order to identify the annual growth rate. This gave us the year-on-year growth in demand at 2050 for each of the fuels studied.

Table 85: Annual cumulative growth rates in demand coverage using each fuel/renewable energy source

Fuel	Housing + Services		Industry	
	2018-2030	2030-2050	2018-2030	2030-2050
Coal	-	0%	0%	0%
Oil	-10%	-19%	0%	0%
Natural gas	3%	0%	0%	3%
Biomass	0%	-4%	2%	-1%
Solar thermal	-1%	1%	0%	0%
Geothermal	0%	0%	0%	0%
Electricity	2%	1%	0%	0%
- Heat pump	2%	1%	0%	0%
- Other	2%	1%	0%	0%
Biogas	-6%	0%	0%	4%

Source: authors' own based on PNIEC data

We then applied the efficiency rates from the NECP baseline scenario for each technology and sector in order to calculate overall fuel consumption in 2030 and 2050 for each of the sectors analysed.

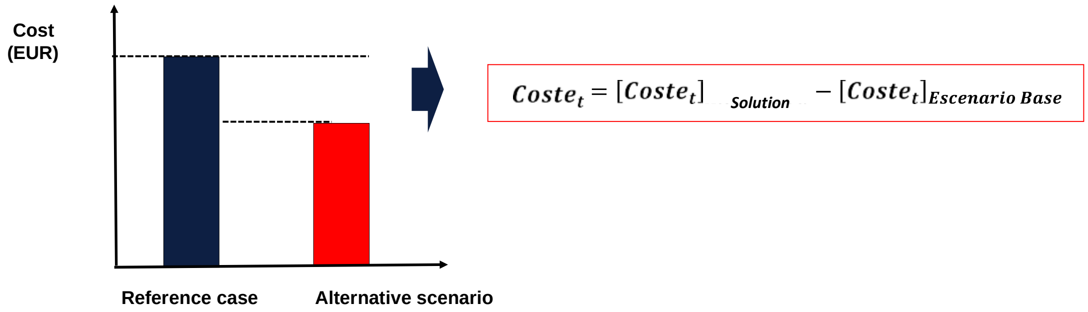
6.2. IDENTIFYING THE TECHNOLOGICAL SOLUTIONS FOR EACH SYSTEM

Once we had performed projections of the reference case we considered the various technological solutions capable of achieving a certain degree of penetration in each of the systems studied. We assessed each of the solutions for the entire timespan in order to be able to make a year-on-year comparison.

6.3. COST-BENEFIT ANALYSIS FOR EACH SYSTEM

Cost-benefit analysis makes it possible to assess investment decisions by examining the variation between the costs and benefits of the reference case and those corresponding to the alternative scenarios involving each of the technological solutions proposed, as illustrated below:

Figure 15: Example of the assessment made in cost-benefit analysis



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

Source: *Cost-benefit analysis and interpretation of results, JRC*

As we are evaluating a switch in technology, any costs and benefits that do not vary from one scenario to the other are not taken into account.

Each of these technological solutions has been assessed both from an investor's perspective and from the perspective of society as a whole, following the standard method established by the Joint Research Centre.

In order to carry out the economic analysis from the perspective of society as a whole, we began with the project cash flows from the investor's perspective for each of the technological solutions, disregarding direct taxes. We then added the ways in which implementing the technological solution in question would impact society as a whole, namely:

the environmental impact;

the impact on the country's energy reliance; the

macroeconomic impact.

We then applied a discount rate of 5% to these flows to arrive at the NPV, which is the crucial factor in deciding whether to accept or reject a particular technological solution.

6.3.1. ECONOMIC PARAMETERS

We considered the following parameters in our cost-benefit analysis:

- a **discount rate** of 5%;
- a **project useful life** of 30 years, calculating the net present value of each system from 2020 to 2050.

6.3.2. COST-BENEFIT ANALYSIS INPUTS

The inputs needed for the cost-benefit analysis are the data obtained in the analysis of the technical potential of each technological solution.

6.3.3. QUANTIFYING THE INVESTMENT

For each of the solutions proposed, we need to quantify the amount of capital to be invested, both in the main systems or equipment and in any connection infrastructure needed to link up the heating and/or cooling supply or to tap into sources of waste heat or fuels. The total investment associated with each alternative scenario is the sum, stated in EUR million, of all investments in the new technology or technologies installed.

6.3.4. QUANTIFYING THE COSTS

Each of the costs that have to be taken into consideration are detailed below[33].

6.3.4.1. CAPITAL COSTS

These are the costs of the resources used to make a specific investment, as represented by the CAPEX line in the technical potential analysis. These costs are detailed in Annex 7.

6.3.4.2. ADDITIONAL INVESTMENTS

For those technologies with a useful life that is shorter than the timespan studied in this project, we have included a cost representing the impact of the investment needed to extend the useful life.

6.3.4.3. REPLACEMENT COSTS

These are the costs linked to replacing the technologies in the reference scenario with new technological solutions. We have used a replacement rate of 4% to calculate replacement costs.

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[33] To improve the readability of this report, we have decided to list all the sources from which we obtained these values in Annex 7.

6.3.4.4. OPERATION AND MAINTENANCE COSTS

This includes the expenditure needed to ensure that the installation is working properly, i.e. the cost of operating and maintaining the equipment and fittings.

The savings in the cost of maintaining the technologies being replaced were also taken into account in our calculation of operation and maintenance costs.

6.3.4.5. FUEL AND ELECTRICITY PURCHASES

These are the costs involved in purchasing fuels to generate thermal energy and/or electricity, depending on the case being analysed, and are calculated using:

- the fuel or electricity purchase price (EUR per MWh);
- expected fuel or electricity consumption (MWh per year).

We used a range of sources of information, depending on the fuel type, to calculate purchase prices for the reference year (2018).

As the NECP does not contain specific data for fossil fuels, petroleum products and natural gas, we used information from the International Energy Agency (IEA). For coal, however, we used data from the NECP.

Turning to the renewable sources of energy, for biomass we used data from IDAE's *Report on Biomass Prices for Thermal Use*[34], and our data source for biogas was the Naturgy Foundation's *Renewable Gases Report*.

Finally, for electricity pricing we used the statistics published by Eurostat, basing the trend on the 'pool' price trend detailed in the NECP.

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[34] https://www.idae.es/sites/default/files/estudios_informes_y_estadisticas/informe_precios_biomasa_usos_termicos_2 t_2020.pdf

Table 86: Fuel purchase prices for the reference year (2018)

Technology	Purchase price (EUR per MWh)
Coal	9.48
Petroleum products	45.78
Natural gas (domestic use)	65.31
Natural gas (industrial use)	25.03
Biomass (domestic use)	38.20
Biomass (industrial use)	14.00
Electricity (domestic use)	139.25
Electricity (industrial use)	97.10
Solar thermal	0.00
Geothermal	0.00
Biogas	20.00
Waste heat	0.00

Source: IEA, Eurostat, IDAE, Naturgy Foundation

6.3.4.6. EMISSION ALLOWANCE COSTS

As well as assessing the environmental impact as part of the cost-benefit analysis from society's perspective, we also considered emission allowances as a cost to the private investor for certain types of investment.

Given the volatility of emission allowance prices, our reference price was the average spot auction price for 2019, which was EUR 24.75 per tonne of CO_2.

6.3.4.7. ENVIRONMENTAL IMPACT

Generating energy has a major impact on the environment, mainly through the release of pollutant particles, but also because this activity takes up land and resources. This diminishes the general public's well-being, a factor that needs to be taken into consideration in the cost-benefit analysis from society's perspective.

The Joint Research Centre suggests basing this assessment on the *Impact pathway approach*, part of the EU and US Department of Energy's joint ExternE (*External Costs of Energy*) project, which aims to model the causal relationships between the pressure placed on the environment and the impact on different receivers by assessing changes in environmental quality. This study states that the impact on society of the various technologies used to supply heat and power need to be assessed by examining what are known as 'environmental damage factors'.

To assess the economic impact of this damage we used *Subsidies and costs of EU energy* (Alberici et al., 2014), a study that identifies the environmental damage factor associated with the output of one unit of energy generated by each of the different technologies (EUR per MWh). These environmental damage factors are used to assess the environmental cost to society of introducing each of the technological solutions compared to the reference case.

The incremental environmental cost (EC) of a solution is established based on the increase in energy generation attributable to the technology (ΔE) used in the technological solution in comparison to the reference case, multiplied by the environmental damage factor (EDF) of the selected technology, using the following formula:

$$[\Delta \mathrm{EC}_{y,t}]_{Alt} = [\Delta E_{y,t}]_{Alt} * \mathrm{EDF}_{y,t} \tag{2}$$

Where:

$[\Delta \mathrm{EC}_{y,t}]_{Alt}$ is the environmental cost associated with the increase in energy generation by technology *y,* in year *t,* in the technological solution (MWh).

$[\Delta E_{y,t}]_{Alt}$ is the difference between the energy generated by technology *y*, in year *t,* in the technological solution and in the reference case (MWh).

$\mathrm{EDF}_{y,t}$ is the environmental damage factor per unit of energy generated by technology *y* (EUR/MWh).

The environmental cost of each scenario in a given year is the total environmental damage caused during generation by all the technologies used in that technological solution that year, as shown below:

$$[\Delta \mathrm{EC}_{Total,t}]_{Alt} = [\sum_{y=1}^{n} \Delta \mathrm{EC}_{y,t}]_{Alt} \tag{3}$$

Although the EDFs may change over the years, the 2014 study by Alberici *et al.* does not provide any details of trends. We have opted for stability and a conservative approach, leaving these parameters unchanged over the entire period.

6.3.4.8. COSTS ARISING FROM THE EFFECTS OF ENERGY RELIANCE

To assess the externalities arising from energy reliance, we need to estimate the impact on the economy caused by the increase in the price of imported fuels (Arnold *et al* (2007), in the context of the *External Costs of Energy* project).

To identify the impact of energy reliance on Spain's economy, we first need to find out the elasticity of the economy in response to fuel price increases by applying the following formula:

$$e_t = \frac{\Delta \mathrm{GDP}/\mathrm{GDP}}{\Delta P/P} \tag{4}$$

Where:

e_t is the GDP in year *t*

$\frac{\Delta \mathrm{GDP}}{\mathrm{GDP}}$ is the percentage change in GDP between years *t* and *t-1* (%)

$\frac{\Delta P}{P}$ is the percentage change in fuel prices between years *t* and *t-1* (%)

The impact on the economy in year *t* by MJ of fuel consumed is therefore measured as follows:

$$\Delta GDP_{per\ unit} = \frac{e_t \cdot \mathrm{GDP}_t}{F_t} \tag{5}$$

Where:

$\Delta\mathrm{GDP}_{per\ unit}$ is the impact on the GDP per unit of fuel consumed (EUR/MJ)

e represents GDP elasticity

GDP is the economy's GDP in year *t* (EUR)

F is overall fuel consumption in year *t* (MJ)

Based on the difference in fuel consumption in one year in the technological solution scenario compared to the reference case, as well as price trends, we can use the following formula to assess the GDP variation as a cost associated with the energy reliance for each technological solution:

$$[\Delta\mathrm{GDP}_t]_{Alt} = \Delta\mathrm{GDP}_{per\ unit,t} \cdot \left[\left(\frac{\Delta P}{P}\right)_{t\ Alt.}\right] \cdot ([F_t]_{Alt} - [F_t]_{EB}) \tag{6}$$

However, in order to include this in the cost-benefit analysis from society's perspective we need to convert GDP into a measurement of well-being. GDP is therefore converted to Net Domestic Product (NDP) based on the ratio established by Weitzman, taking fixed capital consumption (FCC) into account.

$$[\Delta\mathrm{NDP}_t]_{Alt} = \Delta\mathrm{GDP}_t * \left(1 - \frac{\mathrm{F}CC_t}{\mathrm{GDP}_t}\right) \tag{7}$$

This calculation gives us the cost of energy reliance, which then feeds into the overall cost-benefit analysis of a technological solution.

6.3.5. QUANTIFYING THE REVENUE

The benefits of implementing a project could come in the form of a reduction in costs or an increase in revenue compared to the reference case. As we will explain in greater detail below, for this study we only considered the revenue from the sale of electricity and not the revenue associated with thermal energy.

6.3.5.1. REVENUE FROM SELLING ELECTRICITY

We calculate the revenue from the sale of electricity based on:

- electricity generated (MWh);
- electricity selling prices (EUR per MWh).

Based on the average annual day-ahead and intraday market prices for 2018 provided by the National Markets and Competition Commission[35] we established a selling price of EUR 57.27 per MWh.

6.3.5.2. RESIDUAL VALUE

We did not consider residual value in this study.

6.3.6. MACROECONOMIC IMPACT

Following the method developed by the Joint Research Centre, we have to assess the macroeconomic impact of implementing each of the technological solutions proposed compared to the reference case.

The method used to determine the macroeconomic impact focuses on the supply side, allowing us to assess how GDP would vary as a result of the direct and indirect effects of a change in demand in certain economic sectors. These effects are assessed as follows:

- **Direct contribution to GDP (technology contribution)**, which is the impact of growth in end demand created by an increase in production by the sector itself. In other words, it calculates the proportion corresponding to the activities of all the companies that focus most of their efforts on producing goods or providing services related to the technology of the sector being analysed.

  We calculate the direct effects using the matrix of direct coefficients, taking the following partial contributions to GDP into account:

  > The installations' contribution to GDP, a parameter that is influenced only by any new installations to be built to satisfy demand, and calculated using the following formula:
  >
  > $\Delta GDP_{INSTALLATIONS} = \Delta MW$ installed in that year * CAPEX * CAPEX labour costs *
  > % margin on equipment manufacture and sale
  >
  > The contribution of operation and maintenance to GDP, a parameter affected by facilities already in existence that require regular maintenance, determined as follows:

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[35] CNMC as per its Spanish acronym: https://www.cnmc.es/

$\Delta GDP_{O\&M}$ = Total MW installed * OPEX * OPEX labour costs * % margin on installation operation

The contribution of exports and imports to GDP, a parameter affected by net exports and therefore by equipment manufacture and sales.

- **Indirect effect ('impact on other sectors')**, which is the effect of the change in direct consumption on the other sectors that supply inputs to the specific sector. In other words, this effect encompasses both the activities of the sectors closely related to the technologies being studied, and the other economic sectors which experience knock-on effects of activity in the sector analysed.

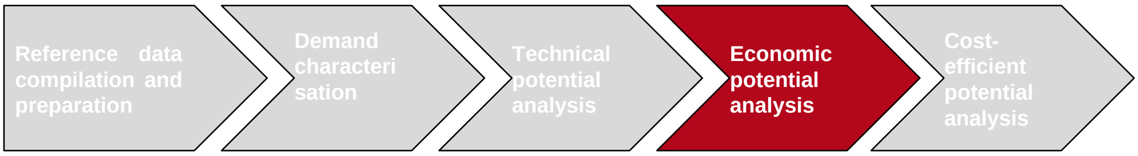
  The indirect effects are calculated using the Leontief inverse matrix, which gives us the indirect impact of implementing a given technology.

The direct and indirect effects on GDP are added up and converted to NDP, with the resulting value feeding into the overall cost-benefit analysis as revenue assessed for each individual year.

6.3.7. COMBINING THE RESULTS

Having determined the above costs and benefits, we can calculate the project cash flows. Cash flow is used to calculate the indicators of the merits of a project, such as the NPV, making it possible to identify the proposed solution that is the most advantageous in terms of how it performs economically.

7. ECONOMIC POTENTIAL ANALYSIS RESULTS BY TECHNOLOGY



This section presents the results of the economic potential analysis from both the investor's and society's perspective for each technology proposed as an alternative, determined on the basis of the cost-benefit analysis. We will begin with the details of the on-site supply technologies before moving on to the district-type solutions.

Addressing each technology in turn, we present our results in two tables, the first summarising the results of the technical-economic potential analysis, and the second presenting an associated sensitivity analysis based on various variables.

The explanation of these two tables is as follows:

- **Summary of results of the technical and economic potential analysis**

This table shows total installable capacity for each technology, the investment required to install it, and demand for heating, cooling and domestic hot water. As well as technical potential these results tables also detail:

_the economic potential from the investor's perspective, including only the demands from systems with a positive NPV from the investor's perspective;

_the economic potential from society's perspective, including only the demands from systems with a positive NPV from society's perspective.

The results for both technical and economic potential are broken down by sector into housing, services and industry.

- **Sensitivity analysis**

We have performed this sensitivity analysis in order to assess the impact of the most important variables on the end results.

This section therefore analyses the effect of increases and decreases in certain input variables by applying a percentage change (the exact percentage depending on the variable in question). Details of the variables analysed and the variations are shown in the table below.

Table 87: Variables selected for the sensitivity analysis and percentage change applied

Variable	Reduction	Increase
CAPEX	-25%	25%
OPEX	-25%	25%
Fuel purchase price	-20%	20%
Electricity purchase price	-20%	20%
Electricity selling price	-20%	20%
Emission allowance price	-10%	50%

Source: authors' own

We applied the cost-benefit tool to each technology, each time adjusting the above variables by the stated percentages. We assessed the sensitivity analysis on the basis of:

- economic potential from society's perspective (in GWh), by technology;
- solutions with overall cost-efficient potential.

The results for each technology are presented in tables with three columns: a central column showing the values considered in the study (i.e. unchanged), and then two others showing the effect of adjusting the specific variable analysed (reduction to the left and increase to the right).

Each row in the table identifies which of the variables from the list is being analysed, and is then divided into two sub-rows, with the variation shown in relative terms in the top one and in absolute terms in the bottom one.

To make the table easier to interpret, we have colour-coded the results:

- values shown in ochre-shaded cells are close to the results from the reference case so the potential is not at all sensitive to modification;
- values shown in green-shaded cells indicate that the variable analysed has a beneficial impact on the technology's potential;
- values shown in red-shaded cells indicate that the variable analysed has a detrimental impact on the technology's potential.

By way of example, Table 88 shows the format we have used to present the sensitivity analysis results. In this case, if there were no change in any value this technology would have a potential of 27 601 GWh. From the CAPEX line we can see that a 25% reduction in the cost of installing this technology (as per Table 87) would increase the potential by 2% to 28 033 GWh. A 25% increase in CAPEX, however, would reduce the potential to 24 650 GWh, representing a drop of 11%.

Table 88: Sensitivity analysis – example results table

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	2%	27 601	-11%
	28 033		24 650
OPEX	0%		0%
	27 605		27 572
Fuel purchase price	-5%		1%
	26 345		27 945
Electricity purchase price	0%		1%
	27 496		27 846
Electricity selling price	0%		0%
	27 601		27 601
	28 018		24 759

Source: authors' own

7.1. TECHNOLOGIES FOR ON-SITE SYSTEMS

7.1.1. CONVENTIONAL SOLAR THERMAL

If implemented, the economically viable potential of this technology from society's perspective would generate **27.6 TWh** of heating, or **9%** of the heating demand estimated for 2018. A total investment of **EUR 27.473 billion** would be required to carry out all the projects that are economically viable.

Table 89: Results for the technical and economic potential of conventional solar technology

Conventional solar		Capacity (GW)	Investment (EUR m)	DHW (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	15.944	17 053	15 339	15 339	-	-
	Services	7.926	7 117	8 160	8 160	-	-
	Industry	5.375	4 169	4 638	4 638	-	-
	Total	29.245	28 339	28 137	28 137	-	-
Economic potential – investor	**Housing**	15.055	16 102	14 752	14 752	5 693	-
	Services	7.818	7 001	8 085	8 085	5 941	-
	Industry	0.908	559	951	951	111	-
	Total	23.781	23 662	23 788	23 788	11 745	-
Economic potential – society	**Housing**	15.458	16 533	15 032	15 032	-	7 651
	Services	7.926	7 117	8 160	8 160	-	7 969
	Industry	5.047	3 824	4 408	4 408	-	2 064
	Total	28.431	27 473	27 601	27 601	-	17 684

Source: authors' own

Table 90: Sensitivity analysis – conventional solar thermal power

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	2%	27 601	-11%
	28 033		24 650
OPEX	0%		0%
	27 605		27 572
Fuel purchase price	-5%		1%
	26 345		27 945
Electricity purchase price	0%		1%
	27 496		27 846
	28 018		24 759

Source: authors' own

7.1.2. CONCENTRATED SOLAR THERMAL

If implemented, the economically viable potential of this technology from society's perspective would generate **15.7 TWh** of heating, or **5%** of the heating demand estimated for 2018, and **3.3 TWh** of cooling, or **7%** of the cooling demand estimated for 2018. A total investment of **EUR 16.013 billion** would be required to carry out all the projects that are economically viable.

Table 91: Results for the technical and economic potential of concentrated solar technology

Concentrated solar		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	-	-	-	-	-	-	-	-
	Services	2.364	2 504	1 964	0	654	2 618	-	-
	Industry	16.839	13 511	1 606	12 093	2 668	16 367	-	-
	Total	19.204	16 015	3 571	12 093	3 322	18 985	-	-
Investor potential	**Housing**	-	-	-	-	-	-	-	-
	Services	2.224	2 328	1 944	0	556	2 500	1 610	-
	Industry	0.561	431	113	472	17	603	102	-
	Total	2.785	2 759	2 057	472	573	3 103	1 712	-
Potential for society	**Housing**	-	-	-	-	-	-	-	0
	Services	2.364	2 504	1 964	0	654	2 618	-	2 815
	Industry	16.837	13 510	1 606	12 091	2 668	16 366	-	7 291
	Total	19.201	16 013	3 571	12 091	3 322	18 984	-	10 106

Source: authors' own

Table 92: Sensitivity analysis – concentrated solar thermal power

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	0% 18 985	18 984	-1% 18 849
OPEX	0% 18 984		0% 18 984
Fuel purchase price	0% 18 946		0% 18 985
Electricity purchase price	0% 18 975		0% 18 984

Source: authors' own

7.1.3. AIR-SOURCE HEAT PUMP

If implemented, the economically viable potential of this technology from society's perspective would generate **123.5 TWh** of heating, or **42%** of the heating demand estimated for 2018, and **15.8 TWh** of cooling, or **35%** of the cooling demand estimated for 2018. A total investment of **EUR 120.771 billion** would be required to carry out all the projects that are economically viable.

Table 93: Results for the technical and economic potential of air-source heat pump technology

Air-source heat pump		**Capacity (GW)**	**Investment (EUR million)**	**DHW (GWh)**	**Heating (GWh)**	**Cooling (GWh)**	**Total (GWh)**	**NPV for investor (EUR m)**	**NPV for society (EUR m)**
Technical potential	**Housing**	77.399	105 969	25 381	62 289	3 824	91 494	-	-
	Services	37.378	45 923	10 900	42 150	22 236	75 287	-	-
	Industry	-	-	-	-	-	-	-	-
	Total	114.777	151 891	36 282	104 439	26 060	166 781	-	-
Investor potential	**Housing**	1.451	1 932	2 627	672	450	3 749	420	-
	Services	10.628	10 247	7 293	15 365	5 690	28 348	7 249	-
	Industry	-	-	-	-	-	-	-	-
	Total	12.079	12 179	9 920	16 037	6 140	32 097	7 669	
Potential for society	**Housing**	67.302	92 137	24 161	55 812	3 482	83 455	-	25 164
	Services	24.271	28 635	10 167	33 359	12 324	55 851	-	18 512
	Industry	-	-	-	-	-	-	-	-
	Total	91.573	120 771	34 328	89 172	15 807	139 306	-	43 675

Source: authors' own

Table 94: Sensitivity analysis – air-source heat pump

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	13% 157 518	139 306	-16% 117 021
OPEX	5% 146 385		-5% 132 807
Fuel purchase price	-16% 116 858		11% 154 104
Electricity purchase price	2% 142 046		-4% 134 425

Source: authors' own

7.1.4. GROUND-SOURCE HEAT PUMP

If implemented, the economically viable potential of this technology from society's perspective would generate **46.2 TWh** of heating, or **16%** of the heating demand estimated for 2018, and **5.3 TWh** of cooling, or **12%** of the cooling demand estimated for 2018. A total investment of **EUR 71.248 billion** would be required to carry out all the projects that are economically viable.

Table 95: Results for the technical and economic potential of ground-source heat pump technology

Ground-source heat pump		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	45.882	103 197	9 882	36 882	1 807	48 571	-	-
	Services	10.165	17 280	4 721	12 510	5 981	23 213	-	-
	Industry	-	-	-	-	-	-	-	-
	Total	56.047	120 478	14 603	49 392	7 788	71 783	-	-
Investor potential	**Housing**	0.153	343	371	62	66	499	49	-
	Services	3.973	6 755	3 683	6 012	2 433	12 128	3 075	-
	Industry	-	-	-	-	-	-	-	-
	Total	4.126	7 098	4 054	6 073	2 499	12 626	3 124	
Potential for society	**Housing**	25.388	57 090	6 086	23 843	746	30 675	-	4 784
	Services	8.329	14 159	4 654	11 643	4 591	20 888	-	9 841
	Industry	-	-	-	-	-	-	-	-
	Total	33.717	71 249	10 740	35 486	5 337	51 563	-	14 626

Source: authors' own

Table 96: Sensitivity analysis – ground-source heat pump

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	23%	51 563	-52%
	63 385		24 959
OPEX	1%		-7%
	51 942		48 202
Fuel purchase price	-51%		7%
	25 403		55 314
Electricity purchase price	0%		0%
	51 498		51 606

Source: authors' own

7.1.5. BIOMASS

If implemented, the economically viable potential of this technology from society's perspective would generate **46.2 TWh** of heating, or **34%** of the heating demand estimated for 2018. A total investment of **EUR 23.270 billion** would be required to carry out all the projects that are economically viable.

Table 97: Results for the technical and economic potential of biomass

Biomass boilers		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	37.677	15 071	8 868	30 168	-	39 036	-	-
	Services	12.209	4 885	6 282	18 681	-	24 963	-	-
	Industry	13.400	5 550	13 952	41 178	-	55 129	-	-
	Total	63.286	25 505	29 102	90 026	-	119 128	-	-
Investor potential	**Housing**	25.838	10 335	6 963	22 705	-	29 668	2 471	-
	Services	12.209	4 885	6 282	18 681	-	24 963	7 471	-
	Industry	7.092	3 014	6 027	27 600	-	33 627	4 869	-
	Total	45.139	18 234	19 272	68 986	-	88 258	14 811	-
Potential for society	**Housing**	37.677	15 071	8 868	30 168	-	39 036	-	14 975
	Services	12.209	4 885	6 282	18 681	-	24 963	-	14 392
	Industry	7.811	3 315	7 106	28 304	-	35 410	-	16 278
	Total	57.697	23 270	22 256	77 153	-	99 409	-	45 645

Source: authors' own

Table 98: Sensitivity analysis – biomass

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	0% 99 409	99 409	-1% 98 233
OPEX	5% 104 857		-1% 98 233
Fuel purchase price	-1% 98 233		0% 99 409
Electricity purchase price	0% 99 409		0% 99 409

Source: authors' own

7.1.6. HIGH-EFFICIENCY COGENERATION

If implemented, the economically viable potential of this technology from society's perspective would generate **8.1 TWh** of heating, or **13%** of the heating demand estimated for 2018, and **7 TWh** of cooling, or **16%** of the cooling demand estimated for 2018. A total investment of **EUR 3.553 billion** would be required to carry out all the projects that are economically viable.

Table 99: Results for the technical and economic potential of cogeneration

Cogeneration		**Capacity (GW)**	**Investment (EUR million)**	**DHW (GWh)**	**Heating (GWh)**	**Cooling (GWh)**	**Total (GWh)**	**NPV for investor (EUR m)**	**NPV for society (EUR m)**
Technical potential	**Housing**	-	-	-	-	-	-	-	-
	Services	2.482	15 337	3 064	4 993	471	8 528	-	-
	Industry	9.955	13 672	10 458	42 204	15 080	67 742	-	-
	Total	12.438	29 008	13 523	47 197	15 551	76 270	-	-
Investor potential	**Housing**	-	-	-	-	-	-	-	-
	Services	-	-	-	-	-	-	-	-
	Industry	1.747	2 041	1 240	7 683	3 220	12 143	1 258	-
	Total	1.747	2 041	1 240	7 683	3 220	12 143	1 258	-
Potential for society	**Housing**	-	-	-	-	-	-	-	-
	Services	0.004	6	5	0	0	6	-	0
	Industry	2.430	3 547	1 408	6 665	6 962	15 035	-	1 576
	Total	2.434	3 553	1 413	6 666	6 962	15 041	-	1 577

Source: authors' own

Table 100: Sensitivity analysis – cogeneration

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	52% 22 933	15 041	-15% 12 838
OPEX	146% 36 971		-15% 12 839
Fuel purchase price	271% 55 842		-91% 1 378
Electricity purchase price	-85% 2 313		106% 31 022
Energy sale price	-92% 1 211		284% 57 780

Source: authors' own

7.1.7. NATURAL GAS BOILER

If implemented, the economically viable potential of this technology from society's perspective would generate **66.1 TWh** of heating, or **22%** of the heating demand estimated for 2018. A total investment of **EUR 1.596 billion** would be required to carry out all the projects that are economically viable.

Table 101: Results for the technical and economic potential of natural gas boilers

Natural gas boilers		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	80.129	12 009	25 385	62 289	-	87 673	-	-
	Services	28.320	3 666	10 901	42 150	-	53 052	-	-
	Industry	17.752	1 607	19 378	50 553	-	69 930	-	-
	Total	126.201	17 283	55 664	154 992	-	210 655	-	-
Investor potential	**Housing**	0.964	143	949	664	-	1 612	16	-
	Services	4.677	484	6 979	7 766	-	14 744	758	-
	Industry	15.994	1 435	16 764	49 202	-	65 967	5 603	-
	Total	21.635	2 062	24 691	57 632	-	82 323	6 377	-
Potential for society	**Housing**	0.206	30	221	112	-	333	-	3
	Services	1.864	199	4 494	1 993	-	6 487	-	489
	Industry	15.112	1 368	15 980	43 323	-	59 303	-	3 629
	Total	17.182	1 596	20 695	45 428	-	66 123	-	4 120

Source: authors' own

Table 102: Sensitivity analysis – natural gas boilers

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	3% 68 159	66 123	-21% 51 967
OPEX	1% 66 694		-1% 65 747
Fuel purchase price	31% 86 600		-8% 60 921
Electricity purchase price	-8% 60 941		35% 89 410

Source: authors' own

7.2. TECHNOLOGIES FOR DISTRICT HEATING SYSTEMS

7.2.1. DISTRICT HEATING USING INDUSTRIAL WASTE HEAT

If implemented, the economically viable potential of this technology from society's perspective would generate **0.55 TWh** of heating, or **0.19%** of the heating demand estimated for 2018, and **0.02 TWh** of cooling, or **0.04%** of the cooling demand estimated for 2018. A total investment of **EUR 639 million** would be required to carry out all the projects that are economically viable.

Table 103: Results for the technical and economic potential of district heating using industrial waste heat

District heating using waste heat from industry		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.046	384	67	130	1	198	-	-
	Services	0.031	218	58	114	18	190	-	-
	Industry	0.028	132	203	-	-	203	-	-
	Total	0.105	734	327	244	19	591	-	-
Investor potential	**Housing**	0.010	55	19	31	0	50	55	-
	Services	0.018	76	37	75	3	114	138	-
	Industry	0.017	40	124	-	-	124	127	-
	Total	0.045	171	179	106	3	288	319	-
Potential for society	**Housing**	0.042	321	59	120	0	179	-	0.042
	Services	0.030	193	55	111	16	182	-	0.030
	Industry	0.028	126	201	-	-	201	-	0.028
	Total	0.100	639	315	231	16	562	-	0.100

Source: authors' own

Table 104: Sensitivity analysis – district heating using waste heat from industry

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	5%	562	-7%
	591		521
OPEX	2%		-1%
	571		559
Fuel purchase price	-2%		2%
	553		571
Electricity purchase price	-1%		2%
	559		571

Source: authors' own

7.2.2. DISTRICT HEATING USING WASTE HEAT FROM COMBINED-CYCLE PLANTS

If implemented, the economically viable potential of this technology from society's perspective would generate **2 TWh** of heating, or **0.67%** of the heating demand estimated for 2018, and **0.09 TWh** of cooling, or **0.2%** of the cooling demand estimated for 2018. A total investment of **EUR 1.551 billion** would be required to carry out all the projects that are economically viable.

Table 105: Results for the technical and economic potential of district heating using waste heat from combined-cycle plants

District heating using waste heat from combined-cycle plants		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.114	941	134	293	6	433	-	-
	Services	0.182	1 417	297	499	163	959	-	-
	Industry	0.130	308	1 046	-	-	1 046	-	-
	Total	0.426	2 666	1 478	792	169	2 438	-	-
Investor potential	**Housing**	0.007	28	15	23	0	39	14	-
	Services	0.067	288	121	245	25	390	137	-
	Industry	0.094	77	805	-	-	805	244	-
	Total	0.168	393	941	268	25	1 233	396	-
Potential for society	**Housing**	0.078	460	81	209	2	291	-	126
	Services	0.131	860	239	431	87	756	-	474
	Industry	0.123	231	1 009	-	-	1 009	-	606
	Total	0.333	1 551	1 329	639	88	2 056	-	1 206

Source: authors' own

Table 106: Sensitivity analysis – district heating using waste heat from combined-cycle plants

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	9% 2 251	2 056	-11% 1 822
OPEX	1% 2 080		-2% 2 009
Fuel purchase price	-10% 1 856		5% 2 154
Electricity purchase price	-2% 2 015		1% 2 070

Source: authors' own

7.2.3. DISTRICT HEATING USING WASTE HEAT FROM INCINERATION OR RENEWABLE ENERGY PLANTS

If implemented, the economically viable potential of this technology from society's perspective would generate **3 TWh** of heating, or **1.02%** of the heating demand estimated for 2018, and **0.15 TWh** of cooling, or **0.33%** of the cooling demand estimated for 2018. A total investment of **EUR 2.607 billion** would be required to carry out all the projects that are economically viable.

Table 107: Results for the technical and economic potential of district heating using waste heat from incineration and renewable energy plants

District heating using waste heat from incineration, biogas and biomass		**Capacity (GW)**	**Investment (EUR million)**	**DHW (GWh)**	**Heating (GWh)**	**Cooling (GWh)**	**Total (GWh)**	**NPV for investor (EUR m)**	**NPV for society (EUR m)**
Technical potential	**Housing**	0.228	1 665	242	625	7	874	-	-
	Services	0.222	1 680	284	729	197	1 210	-	-
	Industry	0.185	447	1 456	-	-	1 456	-	-
	Total	0.634	3 792	1 982	1 354	204	3 541	-	-
Investor potential	**Housing**	0.048	177	53	149	0	203	62	-
	Services	0.091	381	136	353	33	522	223	-
	Industry	0.144	156	1 182	-	-	1 182	474	-
	Total	0.283	713	1 371	502	33	1 907	760	-
Potential for society	**Housing**	0.180	1 034	187	506	3	696	-	376
	Services	0.187	1 214	250	655	144	1 049	-	668
	Industry	0.178	360	1 416	-	-	1 416	-	963
	Total	0.546	2 607	1 853	1 161	147	3 161	-	2 007

Source: authors' own

The system based on waste heat from incinerators accounts for 50% of economic potential from society's perspective and 60% from the investor's perspective, waste heat from biomass represents 30% and 28%, respectively, and waste heat from biogas 17% and 12%, respectively.

Table 108: Sensitivity analysis – district heating using waste heat from incineration and renewable energy plants

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	6%	3 161	-10%
	3 345		2 854
OPEX	1%		-1%
	3 189		3 132
Fuel purchase price	-5%		2%
	3 019		3 240
Electricity purchase price	-2%		0%
	3 114		3 175
	3 359		2 795

Source: authors' own

7.2.4. DISTRICT HEATING USING DIRECT-USE GEOTHERMAL ENERGY

If implemented, the economically viable potential of this technology from society's perspective would generate **5.8 TWh** of heating, or **2%** of the heating demand estimated for 2018. A total investment of **EUR 1.961 billion** would be required to carry out all the projects that are economically viable.

Table 109: Results for the technical and economic potential of district heating using direct-use geothermal energy

District heating using direct-use geothermal		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.171	419	224	629	-	853	-	-
	Services	0.502	1 090	501	2 155	-	2 656	-	-
	Industry	0.299	452	2 330	-	-	2 330	-	-
	Total	0.972	1 961	3 054	2 784	-	5 839	-	-
Investor potential	**Housing**	0.164	391	216	602	-	818	548	-
	Services	0.496	1 069	493	2 134	-	2 628	2 010	-
	Industry	0.293	435	2 292	-	-	2 292	468	-
	Total	0.954	1 896	3 002	2 736	-	5 738	3 026	-
Potential for society	**Housing**	0.171	419	224	629	-	853	-	999
	Services	0.502	1 090	501	2 155	-	2 656	-	3 293
	Industry	0.299	452	2 330	-	-	2 330	-	1 719
	Total	0.972	1 961	3 054	2 784	-	5 839	-	6 011

Source: authors' own

Table 110: Sensitivity analysis – district heating using direct-use geothermal

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	0% 5 839	5 839	0% 5 839
OPEX	0% 5 839		0% 5 839
Fuel purchase price	0% 5 839		0% 5 839
Electricity purchase price	0% 5 839		0% 5 839

Source: authors' own

7.2.5. DISTRICT HEATING USING BIOMASS

If implemented, the economically viable potential of this technology from society's perspective would generate **31.2 TWh** of heating, or **11%** of the heating demand estimated for 2018. A total investment of **EUR 24.408 billion** would be required to carry out all the projects that are economically viable.

Table 111: Results for the technical and economic potential of district heating using biomass

District heating, biomass		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	4.537	17 940	3 284	11 645	-	14 929	-	-
	Services	1.574	5 370	2 925	5 167	-	8 092	-	-
	Industry	1.274	2 503	8 805	-	-	8 805	-	-
	Total	7.385	25 814	15 014	16 812	-	31 826	-	-
Investor potential	**Housing**	0.774	2 083	822	2 406	-	3 228	937	-
	Services	1.139	3 249	2 328	3 924	-	6 252	2 764	-
	Industry	0.720	690	5 461	-	-	5 461	700	-
	Total	2.633	6 022	8 611	6 330	-	14 941	4 400	-
Potential for society	**Housing**	4.356	16 679	3 150	11 227	-	14 376	-	6 902
	Services	1.569	5 333	2 918	5 156	-	8 075	-	6 538
	Industry	1.259	2 396	8 735	-	-	8 735	-	4 128
	Total	7.184	24 408	14 803	16 383	-	31 186	-	17 569

Source: authors' own

Table 112: Sensitivity analysis – district heating using biomass

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	2% 31 742	31 186	-6% 29 237
OPEX	1% 31 411		-1% 30 721
Fuel purchase price	-3% 30 333		1% 31 534
Electricity purchase price	-1% 30 826		1% 31 359

Source: authors' own

7.2.6. DISTRICT HEATING USING BIOGAS

If implemented, the economically viable potential of this technology from society's perspective would generate **0.5 TWh** of heating, or **0.2%** of the heating demand estimated for 2018. A total investment of **EUR 571 million** would be required to carry out all the projects that are economically viable.

Table 113: Results for the technical and economic potential of district heating using biogas

District heating, biogas		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.080	495	91	210	-	301	-	-
	Services	0.054	292	119	178	-	297	-	-
	Industry	0.004	44	25	-	-	25	-	-
	Total	0.139	831	235	388	-	623	-	-
Investor potential	**Housing**	0.018	56	20	60	-	80	20	-
	Services	0.036	117	66	129	-	194	76	-
	Industry	0.001	3	4	-	-	4	1	-
	Total	0.055	176	89	189	-	278	97	-
Potential for society	**Housing**	0.061	290	68	166	-	234	-	112
	Services	0.052	256	113	173	-	286	-	205
	Industry	0.003	24	18	-	-	18	-	6
	Total	0.117	571	199	339	-	538	-	322

Source: authors' own

Table 114: Sensitivity analysis – district heating using biogas

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	9%	538	-11%
	589		481
OPEX	3%		-2%
	553		529
Fuel purchase price	-4%		4%
	518		562
Electricity purchase price	-2%		3%
	525		553

Source: authors' own

7.2.7. DISTRICT HEATING USING A GROUND-SOURCE HEAT PUMP

If implemented, the economically viable potential of this technology from society's perspective would generate **29.7 TWh** of heating, or **10%** of the heating demand estimated for 2018, and **0.7 TWh** of cooling, or **1.5%** of the cooling demand estimated for 2018. A total investment of **EUR 28.216 billion** would be required to carry out all the projects that are economically viable.

Table 115: Results for the technical and economic potential of district heating using a ground-source heat pump

District heating using a ground-source heat pump		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	5.338	28 948	4 261	14 101	83	18 445	-	-
	Services	3.048	20 055	4 282	9 607	2 095	15 985	-	-
	Industry	1.343	5 103	9 273	-	-	9 273	-	-
	Total	9.729	54 106	17 816	23 708	2 179	43 703	-	-
Investor potential	**Housing**	0.233	741	315	820	0	1 135	194	-
	Services	0.715	2 216	892	2 868	0	3 760	823	-
	Industry	0.005	16	28	-	-	28	5	-
	Total	0.952	2 972	1 235	3 688	0	4 923	1 022	-
Potential for society	**Housing**	3.184	14 346	2 494	8 855	9	11 358	-	2 882
	Services	2.077	10 467	3 221	7 096	646	10 964	-	3 945
	Industry	1.131	3 403	8 040	-	-	8 040	-	1 766
	Total	6.392	28 216	13 755	15 951	655	30 361	-	8 593

Source: authors' own

Table 116: Sensitivity analysis – district heating using a ground-source heat pump

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	29% 39 078	30 361	-26% 22 423
OPEX	12% 33 979		-10% 27 173
Fuel purchase price	-30% 21 277		21% 36 736
Electricity purchase price	2% 30 896		-3% 29 513

Source: authors' own

7.2.8. DISTRICT HEATING USING COGENERATION

If implemented, the economically viable potential of this technology from society's perspective would generate **8.1 TWh** of heating, or **3%** of the heating demand estimated for 2018, and **7 TWh** of cooling, or **16%** of the cooling demand estimated for 2018. A total investment of **EUR 3.414 billion** would be required to carry out all the projects that are economically viable.

Table 117: Results for the technical and economic potential of district heating using cogeneration

District heating using cogeneration		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.023	115	47	98	3	148	-	-
	Services	0.140	1 095	556	367	124	1 047	-	-
	Industry	1.024	2 020	7 226	-	-	7 226	-	-
	Total	1.187	3 231	7 828	465	127	8 421	-	-
Investor potential	**Housing**	0.000	0	0	0	0	0	0	-
	Services	0.000	0	0	0	0	0	0	-
	Industry	0.000	0	0	-	-	0	0	-
	Total	0.000	0	0	0	0	0	0	-
Potential for society	**Housing**	0.000	0	1	2	0	3	-	0
	Services	0.001	2	3	8	0	11	-	0
	Industry	0.435	406	3 410	-	-	3 410	-	58
	Total	0.437	409	3 414	10	0	3 424	-	58

Source: authors' own

Table 118: Sensitivity analysis – district heating using cogeneration

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	24%	3 424	-66%
	4 261		1 174
OPEX	34%		-100%
	4 598		0
Fuel purchase price	46%		-100%
	4 996		0
Electricity purchase price	0%		0%
	3 424		3 424
Energy sale price	-100%		56%
	0		5 343

Source: authors' own

7.2.9. DISTRICT HEATING USING CONVENTIONAL SOLAR THERMAL POWER

If implemented, the economically viable potential of this technology from society's perspective would generate **4.2 TWh** of heating, or **1.4%** of the heating demand estimated for 2018. A total investment of **EUR 4.686 billion** would be required to carry out all the projects that are economically viable.

Table 119: Results for the technical and economic potential of district heating using conventional solar power

District heating using conventional solar thermal power		Capacity (GW)	Investment (EUR million)	DHW (GWh)	Heating (GWh)	Cooling (GWh)	Total (GWh)	NPV for investor (EUR m)	NPV for society (EUR m)
Technical potential	**Housing**	0.105	236	69	27	-	96	-	-
	Services	1.462	2 133	1 096	228	-	1 324	-	-
	Industry	3.667	2 859	2 910	0	-	2 910	-	-
	Total	5.233	5 227	4 075	255	-	4 330	-	-
Investor potential	**Housing**	0.018	21	10	6	-	16	4	-
	Services	0.860	938	673	106	-	778	259	-
	Industry	0.699	459	669	0	-	669	50	-
	Total	1.577	1 418	1 352	111	-	1 463	313	-
Potential for society	**Housing**	0.082	142	50	24	-	74	-	40
	Services	1.398	1 902	1 047	218	-	1 265	-	1 128
	Industry	3.582	2 642	2 836	0	-	2 836	-	1 644
	Total	5.062	4 686	3 932	241	-	4 174	-	2 812

Source: authors' own

Table 120: Sensitivity analysis – district heating using conventional solar thermal power

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	3%	4 174	-5%
	4 286		3 970
OPEX	0%		0%
	4 190		4 157
Fuel purchase price	-2%		1%
	4 106		4 230
Electricity purchase price	-1%		1%
	4 142		4 208

Source: authors' own

7.2.10. DISTRICT HEATING USING CONCENTRATED SOLAR THERMAL POWER

If implemented, the economically viable potential of this technology from society's perspective would generate **3.5 TWh** of heating, or **1.2%** of the heating demand estimated for 2018, and **1.1 TWh** of cooling, or **2.5%** of the cooling demand estimated for 2018. A total investment of **EUR 7.399 billion** would be required to carry out all the projects that are economically viable.

Table 121: Results for the technical and economic potential of district heating using concentrated solar power

District heating using concentrated solar thermal power		**Capacity (GW)**	**Investment (EUR million)**	**DHW (GWh)**	**Heating (GWh)**	**Cooling (GWh)**	**Total (GWh)**	**NPV for investor (EUR m)**	**NPV for society (EUR m)**
Technical potential	**Housing**	0.288	634	147	103	26	276	-	-
	Services	3.514	6 053	1 334	837	1 152	3 323	-	-
	Industry	1.352	1 403	1 228	-	-	1 228	-	-
	Total	5.155	8 090	2 708	941	1 178	4 827	-	-
Investor potential	**Housing**	0.066	98	31	28	5	63	10	-
	Services	1.892	2 773	707	475	612	1 794	325	-
	Industry	0.039	53	36	-	-	36	4	-
	Total	1.997	2 924	774	503	617	1 893	339	-
Potential for society	**Housing**	0.247	470	122	93	21	236	-	128
	Services	3.404	5 652	1 288	817	1 113	3 218	-	2 328
	Industry	1.313	1 277	1 191	-	-	1 191	-	655
	Total	4.964	7 399	2 601	910	1 135	4 645	-	3 110

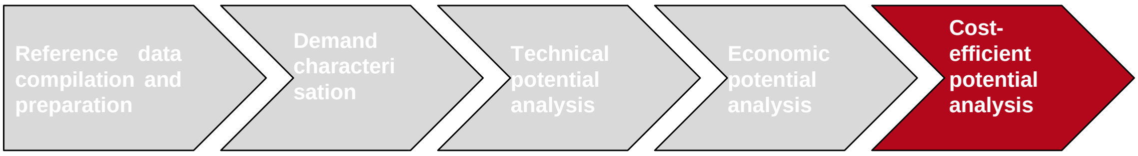
Source: authors' own

Table 122: Concentrated solar thermal

	Economic potential – society (GWh)		
Variable	**Reduction**	**Reference case**	**Increase**
CAPEX	3%	4 645	-6%
	4 775		4 385
OPEX	0%		0%
	4 668		4 627
Fuel purchase price	-1%		1%
	4 591		4 676
Electricity purchase price	-1%		1%
	4 583		4 689

Source: authors' own

8. ANALYSIS OF THE COST-EFFICIENT POTENTIAL



Now that we have analysed the technical and economic potential of each system with each of the technological alternatives considered, in this chapter we assess the cost-efficient potential, identifying the best solution for each system and aggregating the results for all the systems to identify the overall cost-efficient potential.

This analysis has been performed from society's perspective, considering that each system analysed covers the energy demand and prioritising the technological solutions with the highest NPV-to-MWh ratios by starting with the solution with the highest ratio, followed by the next-highest and so on until the system's entire demand has been covered.

To study the cost-efficient potential, we began by analysing, for each system, the solutions involving an on-site supply, ranking them from highest to lowest in terms of NPV-to-MWh ratio and selecting the most cost-effective option.

If this did not cover 100% of demand, we moved on to the second most cost-effective solution, again checking whether total demand was met as a result. We repeated this process until the demand was fully covered or until the next technology to be included has a negative NPV-to-MWh ratio, in which case we assumed that the existing solution should be maintained because it is more cost-effective.

In areas where district heating is a possibility, we ranked the various technological alternatives by their cost-effectiveness per MWh and selected the highest-ranking option. We then performed a comparison between the district heating solution and the on-site supply solutions for the establishments that would be part of the heating network to determine which solution is more cost-effective.

We then calculated the average NPV-to-MWh ratio for the most cost-effective on-site supply solutions for all of the systems covered by the district heating network, and compared this to the NPV-to-MWh ratio calculated for the district heating network itself. The selected option is therefore the one that is most cost-effective from among the [*text missing*].

In summary, the cost-efficient analysis consists of selecting, for each system, the technology that is the most cost-effective for society according to its economic potential expressed as the ratio of NPV to MWh of energy generated. The results of this analysis are shown below.

8.1. RESULTS OF THE ANALYSIS OF THE COST–EFFICIENT POTENTIAL

We have analysed the best combination for each system on the basis of how it performs in terms of NPV-to-MWh for society. This results are presented in Table 123.

Air-source heat pumps represent 41% of cost-efficient potential, and feature prominently in the on-site solutions for the housing and service sectors.

Biomass represents 23% of the cost-efficient potential in on-site solutions and 7% in district heating solutions.

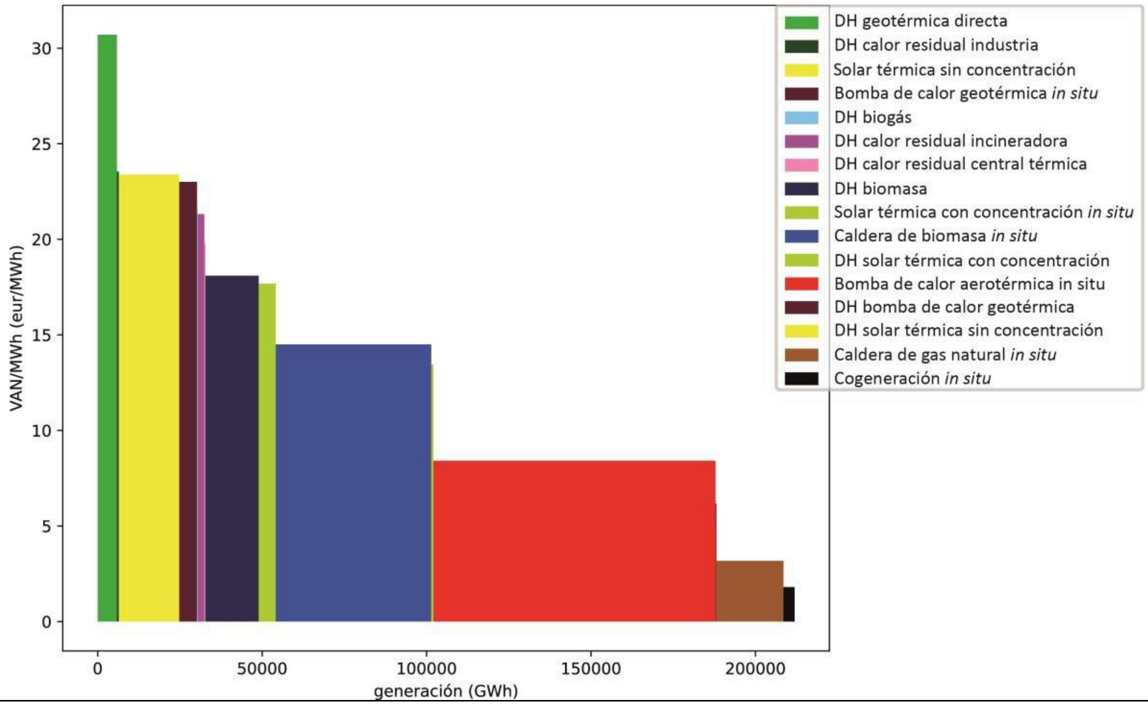
Third in the list of technological solutions for on-site and district heating applications is solar power in both concentrated and conventional form. It accounts for 12% of the cost-efficient potential and features in the results for the housing, service and industrial sectors.

Natural gas, whether in on-site installations using boilers or cogeneration, or as the back-up technology for district systems, represents 11% of the cost-efficient potential in industrial sector demand that cannot be met using renewable technology.

Table 123: Cost-efficient potential results in terms of NPV for society

	Type	**Cost-efficient potential (GWh)**	**Back-up generation (GWh)**	**Total generation (GWh)**	**NPV (EUR m)**	**NPV per MWh (EUR)**	**Housing (GWh)**	**Services (GWh)**	**Industry (GWh)**
Air-source heat pump	*On-site*	85 784	0	85 784	721	8	37 630	48 154	0
Biomass	*On-site*	47 255	0	47 255	685	15	29 466	7 009	10 780
Natural gas	*On-site*	20 344	0	20 344	65	3	0	0	20 344
Conventional solar	*On-site*	18 375	0	18 375	430	23	12 125	4 048	2 200
District heating, biomass	District	13 781	2 387	16 168	293	18	6 414	3 767	3 600
Ground-source heat pump	*On-site*	5 378	0	5 378	124	23	493	4 885	0
Concentrated solar	*On-site*	5 191	0	5 191	92	18	0	147	5 044
District heating, direct-use geothermal	District	4 985	850	5 835	179	31	853	2 656	1 477
High-efficiency cogeneration	*On-site*	3 008	367	3 375	6	2	0	0	3 008
District heating, incinerator waste heat	District	1 734	308	2 041	44	21	281	305	1 149
District heating, industrial waste heat	District	448	152	600	14	24	129	127	192
District heating, concentrated solar	District	354	317	671	9	13	15	308	31
District heating, thermal waste heat	District	307	46	353	7	20	46	103	159
District heating, ground-source heat pump	District	233	41	274	2	6	36	185	12
District heating, biogas	District	173	32	206	4	22	85	87	2
District heating, conventional solar	District	24	21	46	0	5	0	1	23
Total		**207 374**	**4 521**	**211 896**	**2 675**	**13**	**87 572**	**71 781**	**48 020**

Source: authors' own



KEY			
VAN/MWh (eur/MWh)	NPV per MWh (EUR/MWh)	*DH biomasa*	District heating using biomass
Generación (GWh)	Generation (GWh)	*Solar térmica con concentración in situ*	On-site concentrated solar thermal
DH geotérmica directa	District heating, direct-use geothermal	*Caldera de biomasa in situ*	On-site biomass boiler
DH calor residual industria	District heating, industrial waste heat	*DH solar térmica con concentración*	District heating, concentrated solar thermal
Solar térmica sin concentración	Conventional solar thermal	*Bomba de calor aerotérmica in situ*	On-site air-source heat pump
Bomba de calor geotérmica in situ	On-site ground-source heat pump	*DH bomba de calor geotérmica*	District heating, ground-source heat pump
DH biogás	District heating using biogas	*DH solar térmica sin concentración*	District heating, conventional solar thermal
DH calor residual incineradora	District heating, incinerator waste heat	*Caldera de gas natural in situ*	On-site natural gas boiler
DH calor residual central térmica	District heating, waste heat from thermal power station	*Cogeneración in situ*	On-site cogeneration

Figure 16: NPV by generation and technology in the cost-efficient analysis (key in order of appearance)

Source: authors' own

8.2. SENSITIVITY ANALYSIS

In this section we analyse the sensitivity of the cost-efficient potential to a number of significant variables. We have included graphs showing the principal and minority technologies separately.

This analysis allows us to see how each technology is affected depending on the variation experienced in different parameters (acting independently). In certain conditions this even causes some to move places in the rankings. One notable example is how fuel price fluctuations affect competition between the air-source heat pump and biomass boiler technologies.

We can also see from the minority technologies graph how some technologies would be pushed out by cogeneration in the event of either a drop in fuel prices or higher electricity selling prices.

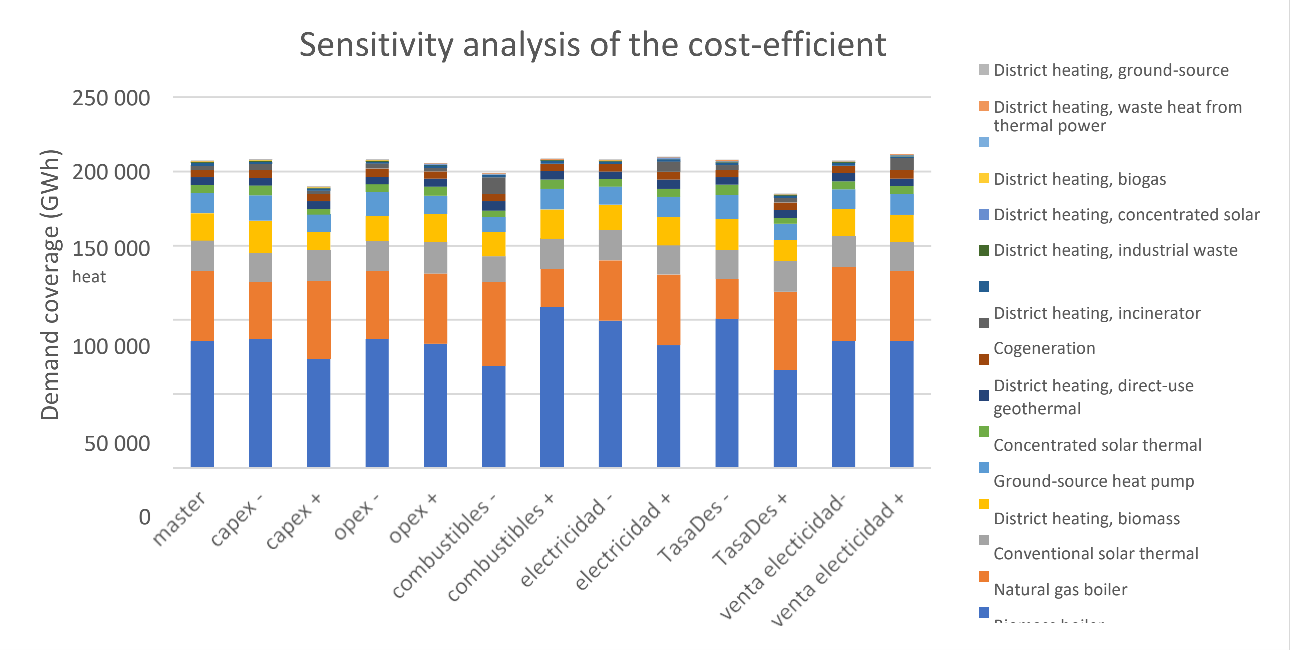


Figure 17: Generation by each technology based on the parameters used in the sensitivity analysis of the cost-efficient solution

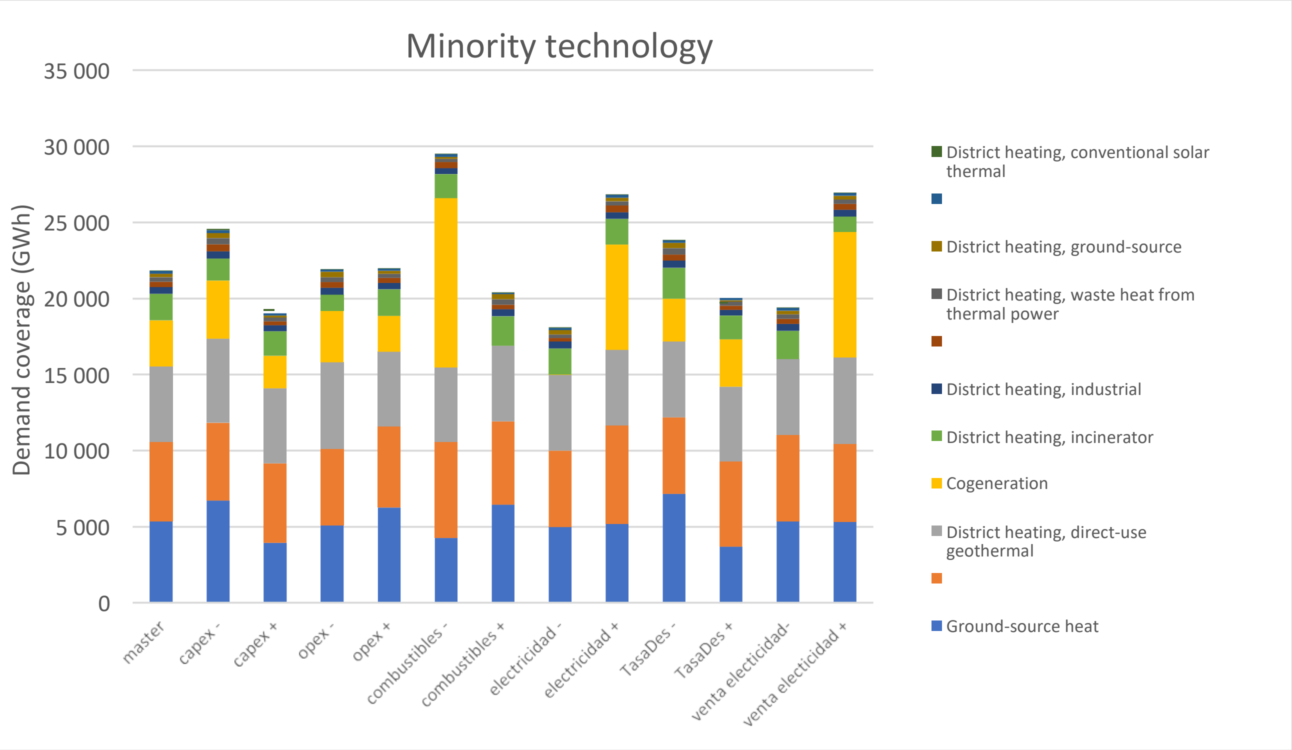


Figure 18: Generation by minority technologies in the sensitivity analysis of the cost-efficient solution

KEY (17&18)	
Demanda cubierta (GWh)	Demand coverage (GWh)
master	master
capex	capex
opex	opex

combustibles	fuels
electricidad	electricity
TasaDes	discount rate
venta electricidad	electricity sales

8.3. PRIMARY ENERGY SAVINGS, RENEWABLES SHARE AND CO_2 EMISSIONS

We compared the cost-efficient scenario with the reference case in order to examine how the share of renewable energy, primary energy savings and CO_2 emissions are affected by the scenario identified in the analysis of the most cost-effective solution for society. This comparison was limited to the thermal levels for which technological alternatives have been studied, so this analysis does not cover demand for medium-high and high temperatures in the industrial sector.

Table 124: Expected demand in the reference case by technology

Technology	Housing	Services	Industry*	Total
Natural gas	29 289	25 846	39 366	94 501
Diesel/heating oil	17 563	7 064	5 926	30 554
LPG	10 338	609	1 042	11 989
Coal	10	0	0	10
Biomass	15 109	1 163	5 295	21 568
Solar thermal	2 384	646	82	3 113
Heat pump – renewable	2 402	6 725	0	9 128
Heat pump – non-renewable	5 230	30 099	15 281	50 611
Electric water heater	9 077	2 828	0	11 905
Cogeneration	1	269	21 413	21 683
Total	**91 404**	**75 250**	**88 407**	**255 062**

**Only demand for heating at low and medium temperatures and industrial cooling are considered for the industrial sector.*
Source: authors' own

The energy consumption values associated with this demand in the reference case are shown below.

Table 125: Reference case fuel consumption

Fuel	Housing	Services	Industry*	TOTAL
Natural gas	34 458	29 776	62 797	**127 031**
Diesel/heating oil	20 663	8 352	7 955	**36 969**
LPG	12 162	718	1 581	**14 461**
Coal	12	0	0	**12**
Biomass	26 981	1 667	8 674	**37 322**
Solar thermal	2 384	646	82	**3 113**
Electricity	12 165	18 248	6 946	**37 359**
Total	**108 824**	**59 406**	**88 036**	**256 267**

**Only demand for heating at low and medium temperatures and industrial cooling are considered for the industrial sector.*
Source: authors' own

The various emission factors used in our calculation of CO_2 emissions, depending on the fuel used, are shown in the table below. The other fuels are assumed to have zero CO_2 emissions. We considered an emission factor for the electricity grid of 0.245 tCO_2 per MWh[36].

Table 126: Emission factors by energy source

Fuel	Emission factor (t CO_2 per MWh)
Natural gas	**0.201**
Diesel/heating oil	**0.263**
Coal, anthracite and lignite	**0.364**
LPG	**0.227**
Coke	**0.378**
Electricity	**0.245**

Source: CO_2 emission factors and LHV for fuels - Ministry of Ecological Transition and the Demographic Challenge[37]

We used the following conversion factors to calculate primary energy values:

Table 127: Primary energy conversion factors by energy source

Final energy to primary energy conversion factors (kWh prim. / kWh final)	
Electricity	**2.044**
Diesel/heating oil	**1.066**
LPG	**1.066**
Natural gas	**1**
Coal	**1.084***
Biomass (pellets and chips)	**1**
Geothermal	**1**
Solar thermal	**1**
Biogas	**1**
Industrial waste heat	**0**
Waste heat from power plants (thermal and incineration)	**0.307****

Source: Eurostat 2018 Energy Balances. As the statistics do not provide a breakdown of coal consumption by product or detail the flows in each subsector, we were unable to extract a general factor for coal. Instead, we used the value stated in the 'technical information document' supplementing Spain's Thermal Building Installations Regulation[38] *(**), calculated using the reduction in power generation and the factor for switching to electricity for primary energy.*

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[36] www.ree.es › files › 4_Emisiones_CO2_11_2018

[37] https://www.MITERD.gob.es/es/cambio-climatico/temas/comercio-de-derechos-de-emision/es_2020_anexovii_unfccc_nir_tcm30-379357.pdf

[38] https://energia.gob.es/desarrollo/EficienciaEnergetica/RITE/Reconocidos/Reconocidos/Otros%20documentos/Factores_emision_CO2.pdf

To identify the share of renewables covering demand, the demands met by the following technologies have been considered as renewables:

Table 128: Share of demand met by renewable sources by technology

Fuel	Renewable %
Biomass	**100%**
Solar thermal	**100%**
Heat pump – renewable	**100 * (1-1 / SPF[39])%**
Waste heat	**100%**
Biogas	**100%**

Source: Directive 2018/2001/EC on the promotion of the use of energy from renewable sources

Taking all of the above parameters into account, we applied the corresponding calculations to the reference case. The results were as follows:

Table 129: Results of the calculations of CO_2 emissions, primary energy consumption and share of renewables in the reference case

Sector	CO_2 emissions		Primary energy consumption		Renewables share	
	Thous. tCO_2 p.a.	tCO_2 / MWh usef. e	GWh p.a.	Prim. e/Usef. e	GWh	Renewable %
Housing	**18 106**	**0.198**	**123 692**	**1.35**	**19 095**	**21%**
Services	**12 815**	**0.170**	**79 056**	**1.05**	**6 293**	**8%**
Industry	**16 775**	**0.190**	**95 917**	**1.08**	**5 378**	**6%**
TOTAL	**47 696**	**0.187**	**298 664**	**1.17**	**30 766**	**12%**

Source: authors' own

We performed the same calculations on the final cost-efficient scenario in order to determine the impact of the new technologies on these parameters. The results of this analysis are shown below:

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[39] SPF = Seasonal Performance Factor

Table 130: **Results of the calculations of CO_2 emissions, primary energy consumption and share of renewables in the cost-efficient scenario**

Sector	CO_2 emissions		Primary energy consumption		Renewables share	
	Thous. tCO_2 p.a.	tCO_2 / MWh usef. e	GWh p.a.	Prim. e/Usef. e	GWh	Renewable %
Housing	**3 596**	**0.039**	**85 855**	**0.94**	**70 621**	**77%**
Services	**4 495**	**0.060**	**56 157**	**0.75**	**48 223**	**64%**
Industry	**13 099**	**0.148**	**94 654**	**1.07**	**24 667**	**28%**
TOTAL	**21 191**	**0.083**	**236 666**	**0.93**	**143 511**	**56%**

Source: authors' own

A comparison of the two scenarios reveals the full societal impact of the cost-efficient scenario identified in this study in terms of the three parameters analysed (CO_2 emissions, primary energy consumption and the share of renewables). This comparison is shown in the table below.

Table 131: **Results of the calculations of CO_2 emissions, primary energy consumption and share of renewables – comparison between reference case and cost-efficient scenario**

Scenario	CO_2 emissions		Primary energy consumption		Renewables share	
	Thous. tCO_2 p.a.	tCO_2 / MWh usef. e	GWh p.a.	Prim. e/Usef. e	GWh	Renewable %
Reference case	**47 696**	**0.187**	**298 664**	**1.17**	**30 766**	**12%**
Cost-efficient scenario	**21 192**	**0.083**	**236 666**	**0.93**	**143 511**	**56%**
Variation	**-26 504**	**-0.104**	**-61 998**	**-0.24**	**112 745**	**44%**
%	**-55.57%**		**-20.76%**		**366.46%**	

Source: authors' own

In other words, if all the alternatives defined in the cost-efficient scenario were installed, the impact on these parameters according to the model defined would be:

- Savings of more than 55% in CO_2 emissions, equivalent to over 26 million tonnes of CO_2 each year;
- A reduction of more than 20% in primary energy consumption, equivalent to around 62 000 GWh each year;
- Significant growth in the use of renewables, reaching a share of over 56% and generation of over 140 000 GWh, compared to a 12% share and generation of 30 700 GWh in the simulated reference case.
  In other words, the use of renewables would quadruple.