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Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling

Report in compliance with Directive 2012/27/EU of 25 October 2012, Article 14 - Promotion of efficiency in heating and cooling.

Direção-Geral de Energia e Geologia

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1. Introduction

The generation of multiple forms of energy via a single system (e.g. cogeneration, trigeneration) is acknowledged for its strategic importance in the field of energy efficiency, as a means of obtaining multiple benefits in energy, economic and environmental terms. Given the significant impact, including at the level of regional and local management, in-depth research and development has been conducted on how to promote and bring about improvements not just in the technology but in how it is applied. In the specific case of cogeneration in Portugal, the simultaneous generation of electricity and heat using endogenous energy resources in a single system is of particular interest.

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, as amended by Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 (known as the EED – *Energy Efficiency Directive*), establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the headline targets for 2020 and 2030 and to pave the way for further energy efficiency improvements beyond those dates.

Mention should also be made of the European Union's initiative on the voluntary introduction of tradeable guarantees of origin (GOs) for electricity, heating and cooling from renewable sources. These GOs are used by energy supply system operators to meet the mandatory requirements on informing about the origin of the energy they supply, which will have a positive influence on greenhouse gas (GHG) inventories, particularly as regards cogeneration systems.

According to the definitions provided in Article 2-A of the abovementioned Directive, 'cogeneration' means the simultaneous generation in an integrated process of thermal energy and electrical or, if applicable, mechanical energy from a fuel source (biomass, fuel oil, natural gas, propane gas, biogas, industrial waste, etc.), and it is a technology that significantly increases the conversion performance of energy resources, by leading to primary energy savings (PES). 'High-efficiency cogeneration' means cogeneration production resulting in primary energy savings of at least 10% compared to the generation of electricity and heat separately using the same type and quantity of fuel. Cogeneration can be further qualified as small-scale cogeneration and micro-cogeneration, resulting in primary energy savings. In all cases, the savings are calculated in accordance with the methodology set out in Annex III to the Directive.

The definition of 'useful heat' should also be borne in mind, i.e. heat generated in a cogeneration process to meet an economically justifiable demand for heating or cooling, not including consumption in auxiliary internal energy generation systems. There can be no cogeneration without effectively meeting useful heat needs, and it is this - not whether electricity is generated - which defines and determines the potential for cogeneration.

Under Article 14(1) of the EED, all Member States must carry out and notify to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling, addressing the points set out in Annex VIII. This comprehensive assessment must include high-efficiency micro-cogeneration and a cost-benefit analysis covering the entire territory based on climate conditions, economic feasibility and technical suitability. The cost-benefit analysis shall be capable of facilitating the identification of the most efficient solutions to meeting heating and cooling needs in terms of resources and costs.

This obligation was transposed into Portuguese law by Article 26 of Decree-Law 68-A/2015 of 30 April 2015. The purpose of this report is to update this assessment, in response to the Commission's request of 8 April 2019. The sections of the document are generally aligned with the points set out in Annex VIII of the EED. The text includes multiple references to four Annexes accompanying the report, which are in-depth independent studies on various of the aspects assessed.

2. Heating and cooling demand

2.1. Heating and cooling in the national context

Heating and cooling processes in Portugal are responsible for about 15%-18% of final energy consumption, cf. Fig. 1.

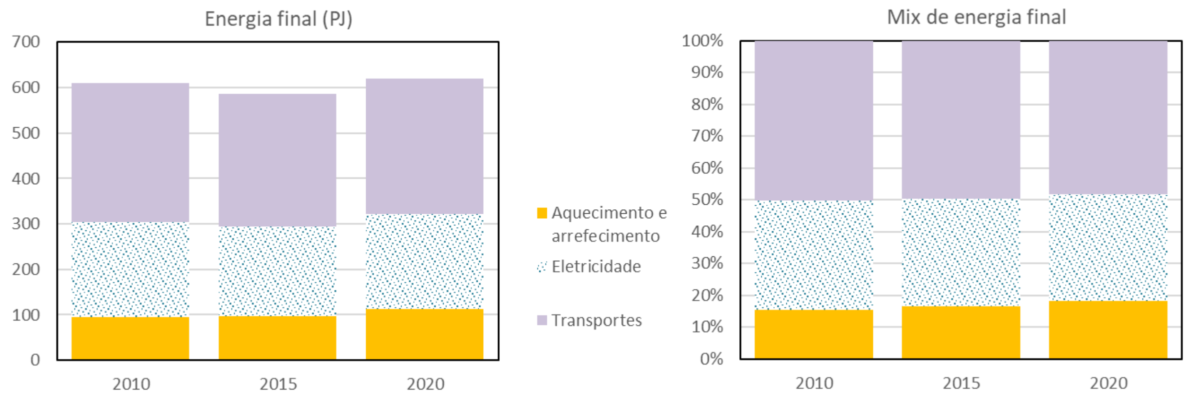

Figure 1 - Final energy consumption in Portugal by broad categories.

The share of renewables in consumption has grown and is expected to reach 42% in 2020 (cf. Table I), in accordance with the energy-emissions scenarios for Portugal (DGEG, 2020 a).

Table I – Consumption (PJ) and share of renewables in heating and cooling

	2010	2015	2020
Heating and cooling	290	263	270
-share of renewables	94	97	113
fraction of renewables	32%	37%	42%

The details at sectoral level are complex and explained in the Annexes to this document.

Heating and cooling in the buildings sector (residential and services) are analysed in the study '*District Heating and Cooling Potential in Portugal*' (DGEG, 2021 a), attached as Annex II.

As regards heating and cooling in the manufacturing sector and for each of its 14 statistical subsectors, see DGEG's study '*Cogeneration Outlook for Portugal*' (DGEG, 2021 b), section 2.1 and pp. 5-19, which is attached as Annex III.

For refineries, cf. p. 20 also of Annex III.

2.2. Geographical information on heating and cooling

For the buildings sector, Annex VIII to the EED provides that ‘municipalities and conurbations with a plot ratio of at least 0.3’ must be identified as representative of significant heating and cooling needs. This methodology might be suitable for countries where the climate is cold to temperate cold, but not for a country like Portugal, which has a variety of temperate climates and more specifically maritime and Mediterranean influences in the most built-up areas where buildings are located. The abovementioned criterion results in an unacceptable overestimation of heating and cooling needs. That is the reason why we have used an alternative method that we believe to be much better. See Chapter 2 of Annex II, particularly sections 2.3 and 2.4, for an explanation of this method and the heating and cooling demand for buildings. The assessment uses GIS-based tools made available very recently, in particular the HotMaps toolbox developed by the HotMaps project (2016). This allowed to better reflect the characteristics of the climate and the building stock and prepare thorough, detailed surveys of heating and cooling needs throughout Portugal.

Chapter 2 of Annex I, cf. section 2.1, identifies the industrial plants and zones with a total annual heating and cooling consumption of more than 20 GWh. Of the total 1 238 plants covered by the Intensive Energy Consumption Management System (SGCIE) and registered on the respective portal, 544 plants in the Lisbon and Porto regions were selected for analysis. Of these, 132 met the minimum conditions, i.e. had heating and/or cooling needs. Of the total 2.6 TWh/year of heating needs identified, 1.5 TWh/year come from plants located in industrial estates. 12 industrial plants with thermal needs of over 20 GWh were identified and a bottom-up analysis was conducted on them using the HotMaps toolbox developed by the HotMaps project (2016). See Chapter 4 of Annex I, cf. Section 4.1, for a description. Of the 12 plants, 10 are located in the Lisbon and Porto metropolitan areas and one is located in a population cluster with average heating needs of over 318 MWh/ha (See Chapter 4 of Annex II, cf. Section 4.1). The temperature of this waste heat source will be lower than 70ºC, given that it is waste heat from compression chiller units in a services building, which means that if a district heating network were to be installed, the temperature of this waste heat source would have to be increased using a heat pump. In addition, Lisbon's temperate climate means its heating needs will not be negligible, so if a district heating network is installed to harness this waste heat, the installation of an absorption chiller will have to be considered. The optimal temperatures of the solutions available on the market work well in the 65-80ºC temperature range. Although the minimum conditions for the installation of a district heating and cooling network appear to be met, the poor thermal quality of the buildings in the area surrounding the waste heat source will be an impediment to economic viability, given the period in which the majority of the buildings were constructed (1960s, 70s and 80s).

There is only one instance of district heating and cooling infrastructure in operation in Portugal. It is located in the Lisbon district of Parque das Nações and it serves 4 000 customers, who received 65 GWh cold water and 40 GWh hot water in 2017. The electricity generated in the cogeneration unit that serves this district heating and cooling network is sold to the grid at a subsidised rate in accordance with Decree-Law 141/2020, which will expire in 2023 (Chapter 5 of Annex I).

There are 3 incineration power plants in operation in mainland Portugal, generating 578 GWh of electrical energy (Chapter 2 of Annex I, cf. Section 2.2). One of these units, located in Loures, could potentially serve the Parque das Nações district heating and cooling network (Chapter 3 of Annex III, cf. 3.6).

There are 18 dedicated thermal power plants in operation in mainland Portugal, generating 23.9 TWh of electrical energy (Chapter 2 of Annex I, cf. Section 2.2). Although these plants are located at a distance from urban centres and therefore at a distance from potential waste heat consumers, 6 thermal power plants on the outskirts (distance of between 7 and 10 km) of urban centres were analysed. Two of these power plants are located 7 km from a population cluster with average heating needs lower than 318 MWh/ha.

See Chapter 2 of Annex I, cf. 2.1, for a description of the macro characteristics of the cogeneration facilities. There were 133 cogeneration power plants in operation in 2019, with a total installed capacity of 1.66 GW generating 6.9 TWh. Of all the cogeneration units in operation, 18 have an installed capacity of more than 25 MW and half of those are in the pulp, paper and board manufacturing sector. 45% of the cogeneration units and 28% of the installed capacity are located in the North region.

As well as the types of potential heat demand points listed in Annex VIII to the EED, mapping was conducted to identify industrial plants in the pulp & paper, recycling, steel products, glass products, and cement & lime subsectors, which could be other sources of waste heat - see Chapter 3 of the study 'Waste Heat in Portugal - 2020 Edition' (DGEG 2021, c), which is attached as Annex IV.

2.3. Forecasting heating and cooling demand evolution

See Chapter 2 of Annex II, cf. Section 2.5, for an explanation of how the heating and cooling demand is expected to evolve in the buildings sector. The HotMaps tool provided a benchmark scenario for all of the relevant parameters with a view to making a forecast. This benchmark scenario was adjusted in accordance with a number of public policies and measures that are expected to have a major impact on the building stock: the National Energy and Climate Plan for 2030 (NECP, 2020); the recast EPBD Directive (EPBD, 2018), which is currently being transposed into Portuguese law (Buildings Energy Certification System [*Sistema de Certificação Energética dos Edifícios*-SCE], including the National Strategy for Long-term Building Renovation [*Estratégia de Longo Prazo para a Renovação de Edifícios*], which has already been approved (ELPRE, 2021);   and the EU 'Renovation Wave' strategy (EC, 2020). A forecast was made by updating the heating needs to take account of renovation rates and their impact on thermal performance for each construction period. The built surface area was also adjusted in accordance with population trends.

See Annex III, Section 2.1 and pp. 5-19 for a discussion on the forecast for heating and cooling demand in the manufacturing industry and in each of its 14 statistical subsectors. For refineries, cf. p. 20.

3. Cogeneration in the national energy system

See Chapter 2 of Annex I, cf. Section 2.1, for energy generation in cogeneration facilities. Electricity generated by cogeneration facilities accounted for a 14% share of the total electricity generated in 2019. In terms of electricity generation in Portugal, the analysis carried out indicates that the generation of heat and electrical energy in cogeneration facilities loses efficiency when the share of electricity generated from renewable sources is higher than 19%. In the last 11 years, the minimum share of electricity from renewable sources was around 40% in years that were unfavourable in hydrological terms. In 2019, this figure was 55%.

Biomass accounts for 44% of the total energy consumed to generate energy in cogeneration facilities. More detailed analysis reveals that just one subsector, i.e. pulp, paper and board manufacturing, is responsible for 98% of the biomass consumed for the purposes of generating energy in cogeneration facilities. Most of the biomass consumed in this subsector (89% of the total) consists of sulphite liquors, a by-product of the paper pulp production process. 11% of the cogeneration units and 42% of the installed capacity are in this subsector, which accounted for the largest share of energy generated in cogeneration facilities (60% of the total energy generated in 2019). In this subsector, the E/T ratio is 3.2. Another subsector with a high concentration of generation in cogeneration facilities is the manufacture of coke and refined petroleum products, with 17% of energy generated by 3% of the installed units and 18% of the total installed capacity. Meanwhile, the textiles, clothing and footwear manufacturing subsector, with 32% of cogeneration units corresponding to 11% of installed capacity, generated just 4% of the total energy generated in cogeneration facilities in 2019. In that subsector, the E/T ratio for cogeneration is lower than 1, which indicates that the heat generation capacity is lower than it should be.

Given the targets set out in the National Energy and Climate Plan 2021-2030 as part of the roadmap towards decarbonisation in Portugal, which call for a higher share of electricity to be generated from renewable sources and more renewable sources in final consumption, it is very important to know what role cogeneration will have to play. While it seems evident that energy generation in cogeneration facilities is inefficient in the context of an electricity generation system in which a higher share of electricity is generated from renewable sources, it also seems obvious that there are certain subsectors that might have a more negative impact on that inefficiency, because they contribute towards a more diffuse installed capacity formed by smaller cogeneration units which may potentially be too large for generating electricity. On the other hand, it is estimated that 69% of the heating needs in the manufacturing sector are met by generation in cogeneration facilities, so there is very little margin to increase the penetration of cogeneration technology in this sector of economic activity. This solution is likely not to be economically viable for generating the remaining 31% of heat, either because of the size of the enterprises, the intermittent nature of the thermal needs in the process, the limited financial capacity of the enterprises, etc.

The use of biomass in cogeneration units is negligible outside the pulp, paper and board manufacturing subsector. It is important to understand the reasons why this is the case. There are some barriers that prevent the share of biomass in energy consumption for cogeneration from increasing. On the one hand, the main contributor towards the share of biomass, i.e. sulphite liquors, can only grow if there is an increase in the production capacity of the paper industry. On the other hand, the use of solid biomass, which accounts for 5.5% of the total energy consumption for cogeneration, is limited by the need for wood and forest residues to be collected and processed. The logistics chain also gets more complex and costly the larger the distance between the collection points and the consumer units. It is not just that the biomass gasification technology that produces syngas is still in the demo stage, but that the resulting gas would have to be transported in natural gas distribution networks in order to be used in decentralised cogeneration units. This would require a purification process that would make using it more costly. Competition from other markets for a scarce energy source like solid biomass is another factor that prevents this share of energy for cogeneration from increasing. Legislation was recently passed (Decree-Law 120/2019 and Ministerial Implementing Order 42/2019) to promote the installation of smaller decentralised biomass units, in an attempt to reverse this scenario.

The publication of the Roadmap and Action Plan for Hydrogen in Portugal put the spotlight on the generation and incorporation of renewable gases. In 2019, the amount of biomass used in [cogeneration] units was negligible, accounting for just 0.2% of the total energy consumption for cogeneration. It is now almost exclusively used by units located in waste water treatment plans, where it is mostly produced in sufficient volume for combustion in cogeneration facilities. It is possible for biogas to be injected into the natural gas infrastructure, but only after the mandatory quality requirements have been met. The Roadmap and Action Plan for Hydrogen in Portugal has brought hydrogen to the fore. Production is expected to increase over the next 10 years, particularly via the electrolysis of water using renewable electricity. This hydrogen will be incorporated into the natural gas distribution network, from where it could potentially be used to supply cogeneration units. Renewable gases can therefore be expected to account for a larger share of total energy consumption for cogeneration over the next 10 years.

It is estimated that the manufacturing industry sector consumed 1 686 272 toe of heat in 2019, mostly steam in the 200-500ºC temperature range. This sector will continue to consume heat, which will need to be generated as part of the process of decarbonising the Portuguese economy. For the heat fraction in the temperature range below 100ºC, technical solutions of the heat pump type are already available on the market. For temperature ranges below 200ºC, demo solutions may become available on the market in the coming years (Boer, 2020). This technology has the additional advantage that it can also make use of sources of waste heat and renewable electricity, which means it can be used for the intraday storage of electricity at times of day when excess renewable energy is being generated. For temperature ranges above 200 ºC, heat production in cogeneration appears to be the most viable solution from the technical perspective. In that regard, one hypothesis for generating heat and electricity more efficiently is to increase the scale of generation, specifically via centralised generation on industrial estates, which could be developed as part of the Renewable Energy Communities scheme under Decree-Law 162/2019. In a decarbonisation scenario, natural gas will be the energy vector for the transition of the cogeneration units. The gradual increases in renewable gases in the natural gas distribution network that are expected in the next decade will help achieve the goal of cogeneration with lower carbon intensity.

4. Potential for cogeneration and district heating grids

The detailed and comprehensive assessment of the potential for high-efficiency cogeneration and district heating was conducted in the three studies mentioned previously, which are attached to this document as Annexes:

Annex II - *District Heating and Cooling Potential in Portugal* (DGEG, 2021 a);

Annex III – *Cogeneration Outlook for Portugal* (DGEG, 2021 b);

Annex IV – *Waste Heat in Portugal, 2020 edition* (DGEG, 2021 c).

Although we will go on to provide brief summaries below; we would refer you to the original studies.

4.1. Potential to meet heating needs

See Chapter 4 of Annex II, cf. Sections 4.3 and 4.4., on the potential for district heating grids. Two scenarios were considered, a 'total comfort' scenario in which the lower temperature is kept constant in a comfort range, and a 'socioeconomic' scenario in which comfort is approached with more flexible strategies, which is considered to be more in keeping with Portugal's economic and cultural reality.

Maps depicting heating and cooling needs were used for the preliminary survey to identify candidate areas for district heating and cooling grids. Urban areas throughout Portugal were examined in detail using the HotMaps Toolbox. These candidate areas were then further delimited and refined to establish thresholds for the minimum energy demand to be met by a district heating grid. Lastly, an economic viability analysis was conducted to check if the distribution and transmission costs of a potential grid for the selected areas would be within the internationally accepted thresholds for viability. Based on these approaches, it was found that the potential for district heating grids based on cogeneration or even on centralised boilers is very low in Portugal.

As for grids based on harnessing waste heat, only three potentially viable cases were found: in the city of Amadora, a district heating grid could possibly be powered by a glassworks located in the urban area; in the city of Chaves, it might be possible to install a district heating grid powered by a geothermal heat source located nearby; the district heating grid that already exists in Parque das Nações, Lisbon, could also be powered by heat from a waste incineration facility east of Lisbon, if the current cogeneration system runs into economic viability problems when the public subsidy concession period comes to an end (special rate for injecting electricity into the national grid).

4.2. Potential to meet cooling needs

Chapter 5 of Annex II looks at the potential for district cooling grids. The same strategy as for heating was followed, but there was no economic viability analysis, because in the initial stage of identifying candidate areas with demand thresholds, none were found to be suitable. However, in practice there is the exception of the cooling grid already built in Parque das Nações, Lisbon, as mentioned above.

The main obstacles to the adoption of district heating and cooling grids were identified as, on the one hand, construction density being too low in inland areas with more extreme climate conditions; and on the other, the fact that there is a mild climate in the coastal areas where the most dense urban settlements are located. If this is the case for existing urban areas, it is all the more true in the case of new urban areas, as they will be built according to the *Nearly Zero Energy Building* standard. Given the requirements of the definition for Portugal (NZEB, 2019), this means that the very low heating and cooling needs of such buildings will soon be nearly zero in the majority of the country. It would therefore be pointless to install district heating grids. Chapter 6 of Annex II discusses other economic, sociocultural and practical barriers.

To sum up the quantitative results on energy efficiency set out in Annex II, district heating supplied by waste and geothermal heat could rise to almost 0.34 PJ (i.e., 96 GWh): 55 GWh in Parque das Nações, 31 GWh in Amadora and 10 GWh in Chaves).

Unlike in many European countries, the energy efficiency savings that could be achieved by adopting profitable district heating and cooling solutions are very modest.

4.3. Additional potential for high-efficiency cogeneration

See Annex II, cf. Section 2, pp. 5-20 for a comprehensive and detailed analysis of this matter. To sum up, the outlook for installed cogeneration is stable or negative, depending on the industrial subsector in question. It is negative for refineries, so no additional potential for cogeneration was identified. This is mostly due to the trend towards electrification and the fall in demand in some industrial subsectors, the lack of potential for district heating based on cogeneration and the reduction in activity by the refineries.

However, the medium to long-term outlook for industrial cogeneration is stable, as the subsector that most uses cogeneration, in terms of installed capacity and output, is the pulp and paper subsector by a wide margin (cf. Annex III). The outlook for this subsector is slightly favourable and it already accounts for over 60% of the biomass resources used (linked to the industrial processes themselves).

The current and future energy mix of fuels in cogeneration will continue to be dominated by biomass sources, following by grid gases. However, harnessing additional biomass for cogeneration seems different given the competition with other uses, such as the manufacture of advanced biofuels, biological hydrogen, biological methane and biogas, from power plants, and even cement manufacturing plants. There are also problems of economic unviability, due to the costs involved in collecting, chipping and transporting biomass from areas that are distant from such plants.

A conventional approach to the potential for cogeneration is however not believed to be enough in this current stage of accelerated energy transition. The outlook for cogeneration must be consistent with the national strategies for high-level planning on energy emissions. Both the Roadmap to Carbon Neutrality (RNC, 2019) and the National Energy and Climate Plan (NECP, 2020) focus on the electrification of end uses, a very high percentage of renewable sources in the electricity mix, the gradual phase-out of fossil fuels and the prevention of greenhouse gas emissions. Given these circumstances, Annex III shows that for the specific case of the Portuguese energy system, the primary energy savings from cogeneration based on fossil fuels are not as great as in the conventional outlook of the EED, and that a reduction in greenhouse gas emissions *is not* achieved by cogeneration based on fossil fuels. Moreover, no cogeneration system based on fossil fuels of this type can be classified as being high-efficiency. Therefore, the recommendation in the EED to conduct cost-benefit analyses on high-efficiency cogeneration is not relevant, as there are simply no systems of this kind that can be classified in that category.

Furthermore, the National Strategy for Hydrogen.(EN-H2, 2020) recently introduced policies and measures for the large-scale production of hydrogen and renewable synthetic gases, to be included in the mixture of gases circulating in the national gas grid, in ever-increasing doses until it is fully decarbonised. In this context, Annex III demonstrates that the use of renewable fuels of non-biological origins (RFNBOs) as input for cogeneration would lead not to primary energy being saved, but to primary energy being wasted.

On the basis of all these issues considered and using the energy emission models and scenarios developed by the DGEG to support public policies (DGEG, 2020 a, 2020 b), the conclusion is that by 2030-2035, cogeneration based on fossil fuels or on grid gas would start to be *detrimental* to the efficiency of the national energy system.

It is however important to bear in mind that most cogeneration is already based on biomass, and that another part uses fuels resulting from industrial processes (for example, non-combustible gases from chemical processes, various types of waste). Cogeneration using these inputs leads to primary energy savings in all scenarios and should continue to be promoted. In addition, in the context of large buildings and energy communities, certain opportunities for micro-cogeneration were identified in the analysis, particularly those using hydrogen fuel cell technologies. These are currently still niche applications but they may go on to play a significant role.

4.4. Additional potential for harnessing industrial waste heat

As regards harnessing industrial waste heat, Annex IV estimates that around 30% of the maximum theoretical potential could be classified as being technically viable (a more precise estimation would require surveys at local level).

As well as the potential being technically viable, there is also the issue of economic viability. So far, it is only possible to provide estimates based on the judgment of experts from their experience with assessments involving other types of energy sources. A success rate of 60% in harnessing the technically viable potential has therefore been allocated. It is also estimated that just 40% of economically viable situations can result in concrete projects. This is because there are barriers such as low investment capacity and because other energy efficiency measures are often more attractive - for example, changing fuels, installing regenerative burners or streamlining processes to improve the use of waste heat (for example, for the cement industry).

In view of all of these factors, the estimated feasible potential for uses involving waste heat is about 1% of the total energy demand in the industry.

This is not an insignificant value but it needs to be contrasted with other alternatives for energy efficiency. For example, replacing recovery burners with regenerative burners can boost efficiency by several percentage points, and streamlining processes can bring even greater efficiency. Therefore, if waste heat is to be used outside the facility where the heat is generated, substantial investments are required to recover, transport and distribute the excess heat, which means that in many circumstances this may not be the most cost-effective energy efficiency measure in the industry.

In any case, it may be an interesting option for some district heating systems, as discussed in Section 3 of Annex III and in Annex IV. It should also be noted that although the potential for making use of waste heat is small at national level, it may result in important contributions in the specific situations in which it is used.

5. Policies and measures for the 2030 horizon

Point (g) of Annex VIII to the EED specifies that after the potential for high-efficiency cogeneration and district heating grids is assessed, *where appropriate*, strategies, policies and measures covering a number of aspects should be proposed for adoption up to 2030. Of course the NECP already contains policies and measures to promote energy efficiency, including via cogeneration. However, both the National Strategy for Hydrogen (EN-H2) and this assessment have shown that the underlying conventional energy paradigm taken into consideration in the EED in 2012 will undergo such major changes by 2030 that it will be necessary to review the outlook in the NECP in even greater depth and reassess the existing support measures under Article 14 of the EED.

As regards point (i) on cogeneration, see the results of the strategic analysis on cogeneration set out in Section 3 of Annex III. The suitability and the role of cogeneration was examined from the point of view of the energy transition, and specifically for Portugal, considering the national energy emissions targets and plans for the medium and long term: the Roadmap to Carbon Neutrality 2050 (RNC, 2019), the National Energy and Climate Plan (NECP, 2020) and the National Strategy for Hydrogen (EN-H2, 2020).

One important conclusion reached is that cogeneration based on fossil fuels cannot be considered to be highly efficient from the perspective of Portugal, as it only leads to 10% savings in primary energy compared to the generation of heat and electricity separately, as explained in the abovementioned national plans and policies on energy emissions; this type of cogeneration also increases greenhouse gas emissions. In fact, this study shows that from 2030-2035 onwards, cogeneration based on fossil fuels, but also all cogeneration based on the mixture of fossil gases and renewable gases of biological and non-biological origin that will be circulating in the gas grid, will be detrimental for the efficiency of the Portuguese energy system.

There is therefore no point in discussing policies and measures to promote these types of cogeneration; the issue at hand is to prevent them from having a detrimental impact on the efficiency of the national energy system and delaying the reduction in greenhouse gas emissions. Even if this scenario will only come about from 2030-2035 onwards, these cogeneration facilities should start to be gradually phased out already, to avoid new investments being made in the same technologies, as this would have the effect of blocking the capacity for electricity and heat generation using methods that are incompatible with the national plans on energy emissions for many years. Annex III therefore describes and tests a scenario that is consistent with the gradual phase-out of undesirable cogeneration, showing a beneficial impact on the performance indicators and targets in the national plans for energy and emissions, essentially as a result of more biomass being used, thus lowering the need to import natural gas or manufacture renewable gases.

It is worth noting that the NECP already includes policies for removing tax exemptions on fossil fuels, the highlight being the VAT exemption from which they benefited when used to generate energy. However, cogeneration electricity based on fossil fuels is still being supported by subsidised remuneration. As discussed above, Portugal should only be interested in pursuing cogeneration based on biomass waste and possible by-products from industrial processes, such as waste gas (refineries, chemicals and plastics subsectors), industrial waste (rubber subsector) and black liquors (pulp and paper subsector), which are already being used on an extensive scale (see Section 2 of Annex III).

However, given that the availability of the abovementioned by-product energy sources is linked to activity within those subsectors, and that the outlook for same amounts to only modest variations in demand (either increases or decreases), it seems difficult for additional cogeneration to be developed using these energy sources which consist of by-products of the activity, as the existing capacity suffices to meet the expected variations in demand.

Therefore, the only way that remains to significantly increase the installed capacity in cogeneration appears to be the use of biomass. In fact, promoting the use of forest biomass has been pursued by Portuguese governments for over a decade, particularly as regards collecting and burning forest waste (ground cover biomass, forest thinning materials, etc.) with a view to reducing forest fires, which is a serious environmental problem in Portugal. In terms of strategic planning on energy, the NECP recently reinforced that public policies should follow that guidance. In terms of specific measures, Decree-Law No 64/2017 of 12 June 2017 already supported the involvement of municipalities, or of inter-municipal communities, in new power plants based on biomass; and Ministerial Implementing Order No 410/2019 of 27 December 2019 established the respective feed-in tariff. More recently, Decree-Law No 120/2019 of 22 August 2019 limited this support to the cases in which thermal energy is generated, with a view to encouraging new, smaller cogeneration units that can be more easily supplied with forest waste than the conventional biomass electricity generation plants. As regards buildings, cogeneration in general was promoted in Ministerial Implementing Order No 349-D/2013 of 2 December 2013, which laid down the thermal quality requirements for building envelopes and the efficiency of technical systems in new buildings and those that undergo in-depth renovation. Assessing the economic viability of cogeneration used to be mandatory in large commercial and services buildings, except when this was technically inviable. More recently, Ministerial Implementing Order [*Portaria*] No 42/2019 of 30 January 2019 limited this obligation only to cogeneration based on biomass.

As regards point (ii) on new district heating grids, the studies set out in Annex II and Annex III did not result in clear scenarios that would justify additional district heating and cooling infrastructure. There is just one exception of a potential case where waste heat could be harnessed by a grid in Amadora.

As regards point (iii) on encouraging new thermal electricity generation and industrial facilities generating waste heat in areas where this heat can be harnessed to meet existing or expected heating and cooling needs, we would like to make the following points: In light of the ambitious plans to increase the installed capacity with a view to generating renewable electricity and reducing emissions, i.e. the Roadmap to Carbon Neutrality, the National Energy and Climate Plan, and the National Strategy for Hydrogen, there are no plans for new thermal power plants, at least not in the next decade. The outlook for industry, subsector by subsector, does not seem to indicate an expected need for facilities generating waste heat in sufficient quantity to be economically viable for it to be harnessed, cf. Annex III and Annex IV.

As regards point (v) on the possibility of encouraging new residential districts to be located where they can benefit from waste heat; as discussed above, any new districts will be built according to the requirements that apply to Nearly Zero Energy Buildings, which in accordance with the definition implemented in Portugal means that they will have really very low heating (and cooling) needs, in fact close to zero in the areas where the overwhelming majority of buildings are located.

Returning to point (iv), on industrial facilities being located close to waste heat sources, this is indeed one possibility. However, it is important to note that in many situations it will not be possible (see Section 4 of Annex IV) and that the outlook for new industries is not favourable (see Section 3 of Annex IV), given that priority is given to using electricity rather than heat.

Finally, as regards point (v) and the intention of providing incentives for thermal electricity generation facilities, industrial facilities generating waste heat, waste incineration facilities and other energy generation facilities to be connected to district heating grids, only one potential scenario where this would be relevant was identified. To be more specific, it is the case of the district heating grid in Parque das Nações, Lisbon, which could be supplied by a waste incineration facility located nearby. This scenario is already known to be at the stage where its viability is being analysed.

6. Primary energy savings

As previously mentioned in Chapter 3 of this Report, and explained in Chapter 2 of Annex I, cf. Section 2.1 on electricity generation in Portugal, energy generation in cogeneration facilities is inefficient when renewable sources account for a share of over 19% of electricity generation.

Annex IV analyses the primary energy savings achieved by generating energy in cogeneration facilities.

Annex IV assesses the energy savings achieved through increased use of waste heat. To sum up, the technical and economic potential for energy savings that are viable through harnessing waste heat in the manufacturing industry is estimated to be 1% of the final energy demand, i.e. for 2020, some 2.1 PJ (575 GWh) in terms of primary energy. District heating supplied by waste heat could add around 0.3 PJ more (86 GWh: 31 GWh in Amadora and 55 GWh in Parque das Nações), Although there are currently no commitments from developers or specific public policy measures intended to guarantee these amounts, the NECP includes policies and measures with a view to achieving the obligations incumbent on countries under the EED for the 2030 horizon, which may lead to industries choosing to take action in order to harness that potential.

7. Public support

There are no existing or planned public support measures for heating and cooling systems. However, the publication of Decree-Law 101-D/2021 transposing Directive (EU) No 2018/844 (EPBD Directive) on the energy performance of buildings is expected to lead to a reduction in the thermal heating and cooling needs of buildings belonging to the residential and services sector, both new or substantially refurbished, given the thermal requirements imposed by the rules that apply to buildings at the design stage, for which the use of renewable and preferably local energy resources is required to meet any possible waste heating needs. Given that the harnessing of aerothermal and hydrothermal energy is considered for the purposes of calculating the share of renewable energies under Decree-Law 141/2010, it seems plausible that the use of waste heat sources such as those identified in Chapter 4 of Annex I, cf. Section 4.1, could be assessed, as long as the respective economic viability is ensured.

With the end of the reference tariffs applicable to electricity generation in cogeneration facilities under Decree-Law 23/2010, and the petroleum tax (ISP) penalty which applies to natural gas consumption to generate energy in cogeneration facilities, under Article 389 of the State Budget for 2021, it is expected that some smaller-sized cogeneration units scattered throughout the North Region of Portugal will be decommissioned as they may be too large for the installed capacity of the process.

8. Conclusions and Recommendations

Three main conclusions were reached as a result of the comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling systems set out in this document and in the studies attached to same as Annexes.

First of all, it has been confirmed that there is very little potential for district heating grids in Portugal. Using international criteria and even after adjustments to the reality in Portugal, only very few cases are found to be viable. Of course, heating and cooling grids may have their place in the energy panorama in future; but there is not enough demand, or sufficiently concentrated demand, to warrant conventional district grids. Moreover, for the cases found to be potentially viable, they are all based on harnessing geothermal heat or industrial waste heat, and not on cogeneration.

Secondly, the conventional outlook for industrial cogeneration is stable as a whole, without any additional potential, despite the existence of differences between the various subsectors. The pulp and paper subsector stands out as a positive case, with some potential for growth. The refineries sector stands out as a negative, given the impact of the energy transition.

Thirdly, a fundamental incompatibility was found between public policies such as the National Energy and Climate Plan and the National Strategy for Hydrogen, and cogeneration based on fossil fuels or grid gas even when partially from renewable sources. Energy analysis shows that in these cases, there are no primary energy savings in the medium term compared to the generation of heat and electricity separately and there is an increase in greenhouse gas emissions compared to the generation of heat and electricity separately using the methods promoted by the abovementioned public policy documents. While this effect is only expected from 2030-2035 onwards, it is inevitable to recommend the gradual phase-out of this type of facilities already, so as to avoid investment becoming blocked in undesirable technologies at national level. As well as phasing out support, which has already started in the case of fossil fuels used to generate energy, the recommendation is that access to subsidised remuneration should not be renewed for electricity injected into the national electricity grid and that facilities which use these technologies should not be granted licenses (or should not have their licenses renewed).

As a corollary to the previous paragraph, increases in cogeneration capacity will only be of interest if the energy inputs are biomass or by-products resulting from the industrial activity itself (e.g. black liquors, non-condensable chemical gases, residues of various types). In the latter case, no support measures are needed because cogeneration already makes complete sense in economic terms. Indeed, that is the case in Portugal. However, additional potential seems limited due to the stagnation or modest growth of industrial activity in the relevant subsectors, and the trend towards electrification being driven by public policies.

The remaining option is therefore biomass, a resource that public policies have already been promoting for use in cogeneration. However, there are issues that need to be examined in this regard: limits to economic viability; life cycle analyses, taking into account that there is energy expenditure in collecting, transporting and processing the materials; the additional availability of biomass, taking account of the demand for the same resources from other areas of the energy system, such as the manufacture of advanced biofuels, biological hydrogen, biological methane and biogas, and its use in electrical power plants and cement manufacturing plants. DGEG is already conducting studies into the availability of the resource and how to optimise biomass flows. However, this requires that a whole range of public policies would need to be reassessed on a streamlined basis in terms of their connection to biomass, such as those pertaining to biorefineries, transport and the generation of electricity and hydrogen.

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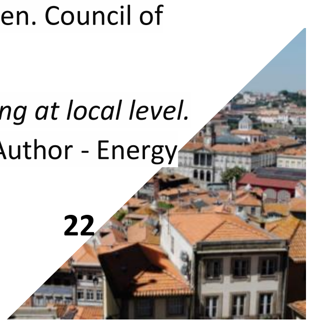

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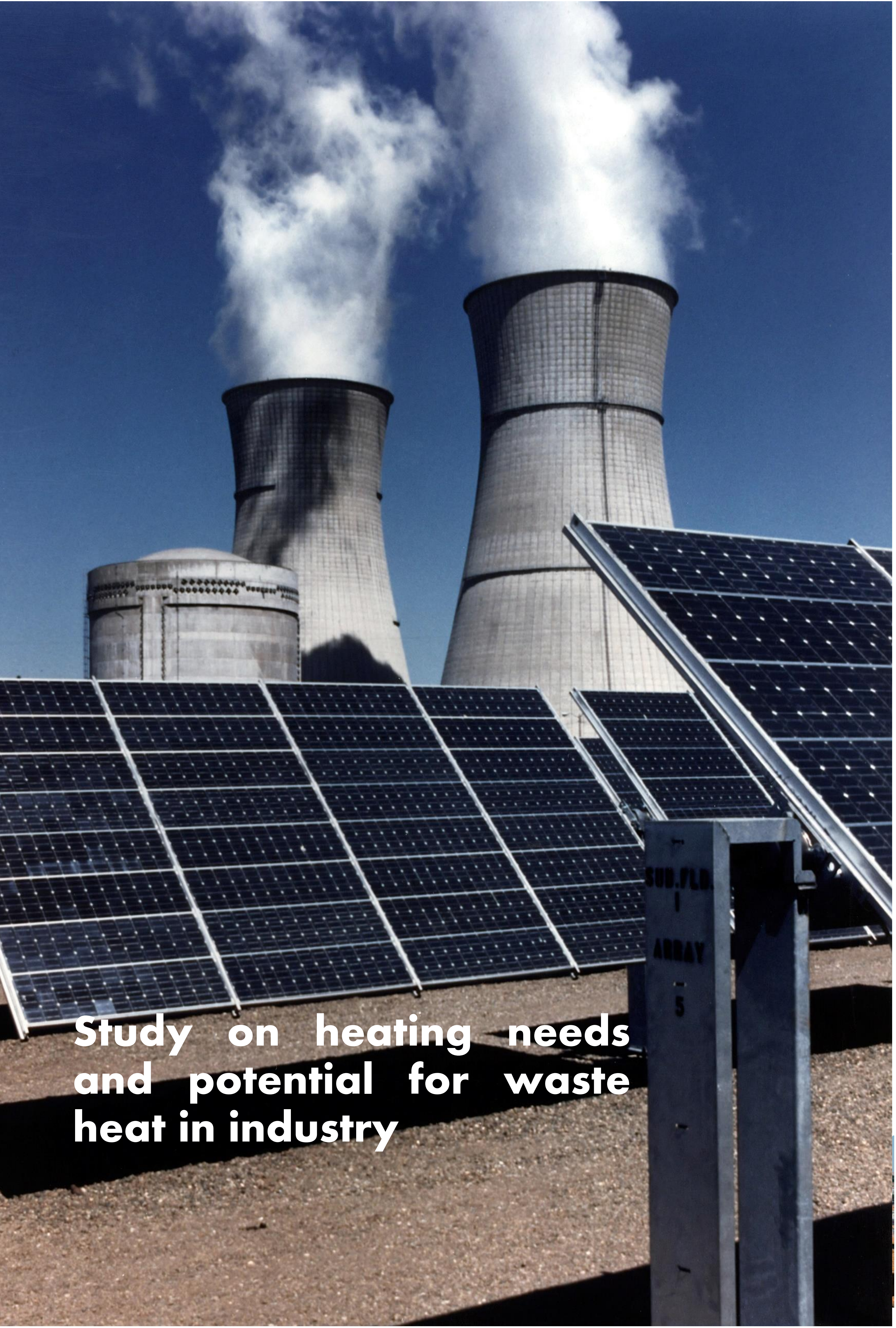
Annexes

Annex I – Study on heating needs and potential for waste heat in industry

Annex II – District Heating and Cooling Potential in Portugal

Annex III – Cogeneration Outlook for Portugal

Annex IV – Waste Heat in Portugal, 2020 edition



Study on heating needs and potential for waste heat in industry

Date

15 February 2021

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Table of contents

1. Introduction

This study uses a bottom-up approach to analyse the availability of industrial waste heat in Portugal and aims to identify facilities registered under the rules of the Intensive Energy Consumption Management System (SGCIE) that can supply waste heat as an energy source for industrial uses, as well as district heating and cooling.

This study is intended to be a useful contribution towards the obligations of Portugal[1] under Article 14(1) of Directive 2012/27/EU, known as the Energy Efficiency Directive (EED, 2012) (amended in 2018 by Directive 2018/2002/EU). The EED (Annex VIII thereof, in particular) specifies various items on which the Member States must report in relation to waste heat. Analysing the availability of waste heat will therefore be essential in meeting this requirement.

The first chapter analyses energy generation and consumption in mainland Portugal, comparing the electrical energy generated in cogeneration facilities and that which is generated via the national electricity generation system.

Subsequent chapters identify and provide details on the characteristics of dedicated facilities generating more than 20 GWh of electricity per year, incineration facilities and cogeneration units.

In addition, for facilities registered under the rules of the Intensive Energy Consumption Management System (SGCIE) with thermal requirements in excess of 20 GWh, a bottom-up approach was taken in mapping and analysing the availability of waste heat. For each of the facilities identified, the potential for this waste heat to be used in urban districts and/or other industrial facilities was analysed.

Finally, the waste heat points included in the report required under Article 14(1) of the EED (as specified in Annex VIII thereof) are also discussed.

[1]'Portugal' here means mainland Portugal; the autonomous regions of Madeira and the Azores are not covered by this study, as they have separate obligations in relation to EU Directives.

2. Electrical energy generation in mainland Portugal

This chapter aims to describe the electricity generation scenario in mainland Portugal, highlighting electricity generation in cogeneration units.

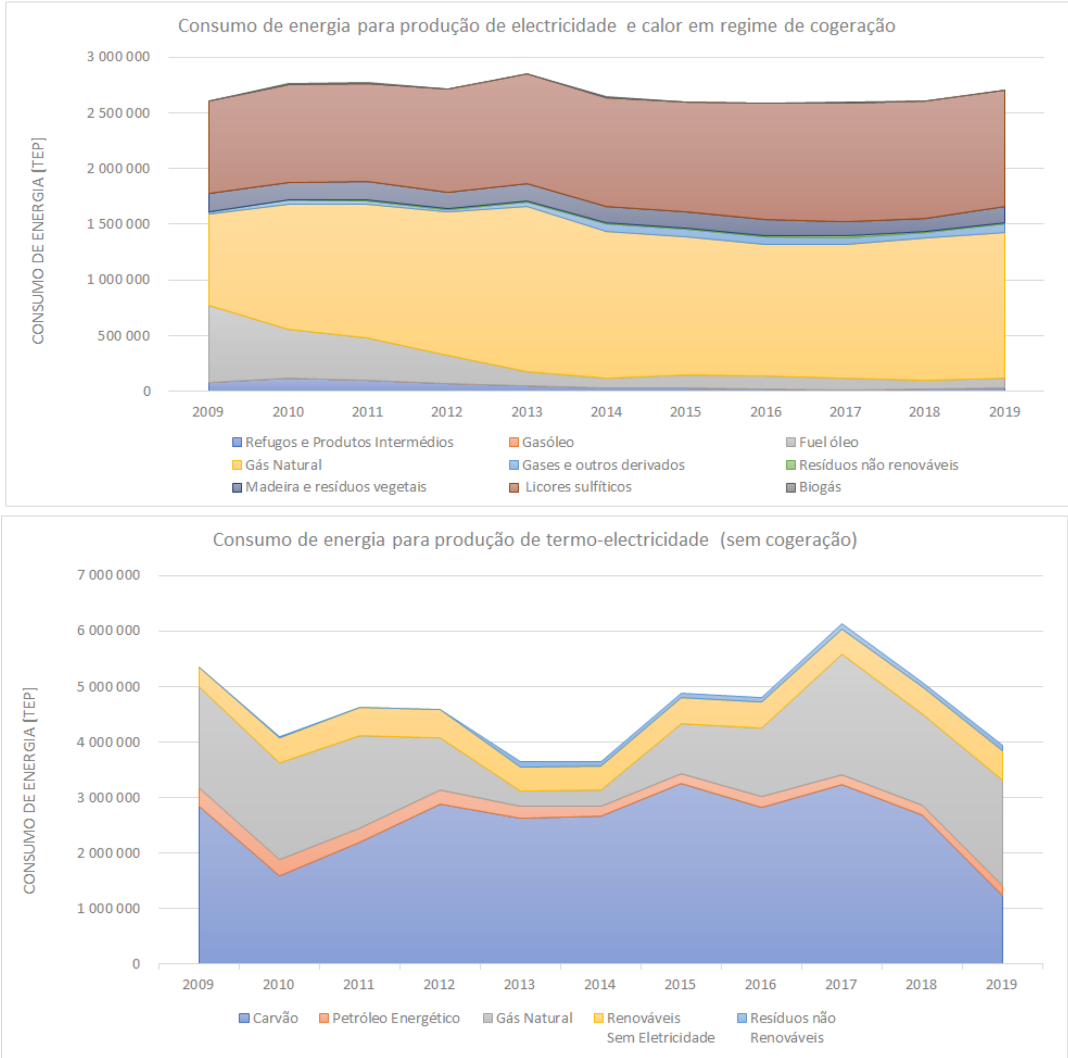
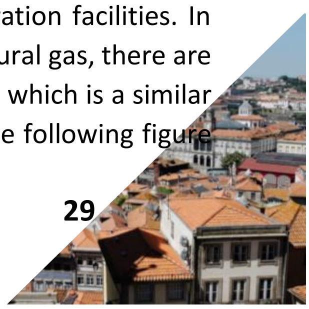


Figure 1-Primary energy consumption for energy generation in cogeneration facilities and the generation of thermal electricity (Directorate for Energy Planning and Statistics Services - DSPEE)

Natural gas has replaced coal as the fuel used in primary energy consumption to generate thermal electricity (without cogeneration). There has been a sharp drop in coal consumption from 2017 onwards, as a result of the staggered closures of the Pego and Sines coal-fired plants.

As far as cogeneration is concerned, the above figure shows that natural gas has been the predominant fuel consumed on a consistent basis, essentially since 2014, on a par with sulphite liquors, which are the main energy source obtained from biomass in generating energy in cogeneration facilities. Sulphite liquors are the main energy source used by the pulp and paper manufacturing subsector, accounting for some 66% of the total primary energy consumed by this subsector in generating energy in cogeneration facilities. In cogeneration, despite the sharp drop in fuel-oil consumption until 2014, in favour of natural gas, there are still cogeneration units in operation consuming 88 412 toe (3.3% of the total) of fuel-oil, which is a similar percentage to the cogeneration units consuming gases and other derivatives (2.9%). The following figure



shows a more detailed breakdown of primary energy consumption for electricity generation in cogeneration facilities.

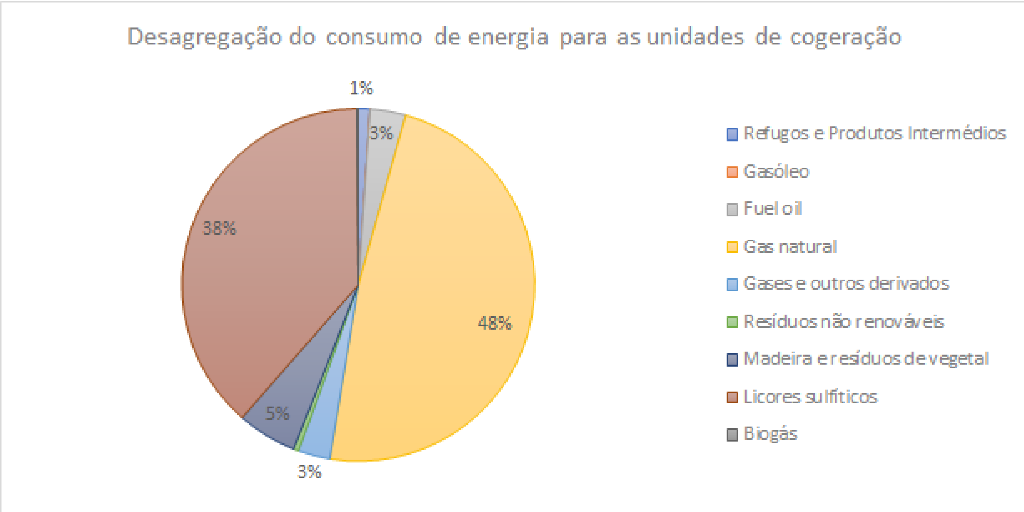


Figure 2-Breakdown of energy consumption for cogeneration units (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

In the above figure, biomass accounts for 44% of the total energy consumption for cogeneration units, and pulp, paper and board manufacturing is the subsector that is responsible for some 98% of the biomass consumed in cogeneration facilities. Of the total biomass consumed by this subsector, 89% comes from sulphite liquors, also referred to as black liquor, the main by-product of paper pulp manufacturing.

In the following figure, for energy generated in cogeneration facilities, the overall efficiencies of the thermal and electrical generation are calculated in accordance with the following formulae (Decree-Law No 23/2010 , as amended).

$$CHP\ H_{\eta} = \frac{Produção\ anual\ de\ calor}{Energia\ consumida\ na\ produção\ total\ de\ calor\ e\ electricidade\ em\ cogeração}$$

Equation 1- Thermal efficiency of the cogeneration process

$$CHP\ E_{\eta} = \frac{Produção\ anual\ de\ electricidade}{Energia\ consumida\ na\ produção\ total\ de\ calor\ e\ electricidade\ em\ cogeração}$$

Equation 2- Electrical efficiency of the cogeneration process

For the total energy consumption per generation unit at cogeneration facilities and the respective annual generation of heat and electricity, data from the Energy Balance Sheet for 2019 were taken into consideration (Directorate for Energy Planning and Statistics Services - DSPEE).

$$Ref\ H_{\eta} = Valor\ de\ referência\ da\ eficiência\ para\ a\ produção\ separada\ de\ calor$$

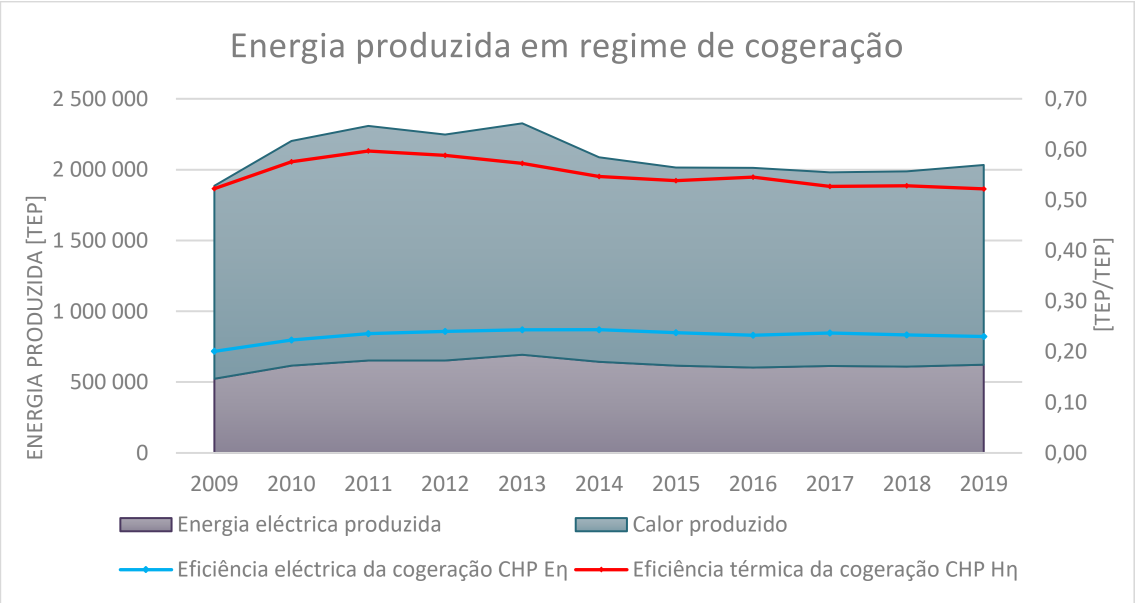
Equation 3- Efficiency reference value for separate heat generation

For the reference value Ref H_η the value considered was 0.9, in accordance with Order No 17313/2008.

$$Ref\ E_\eta = \frac{Produção\ anual\ de\ electricidade\ no\ SEN}{Energia\ consumida\ na\ produção\ de\ electricidade\ no\ SEN}$$

Equation 4- Efficiency reference value for separate electricity generation

To calculate the reference value Ref E_η the generation of thermal electricity and renewable electricity was considered, with the data for 2019 being obtained from the Energy Balance Sheet (Directorate for Energy Planning and Statistics Services - DSPEE). This calculation did not take losses in the electricity transmission and distribution grid into consideration.



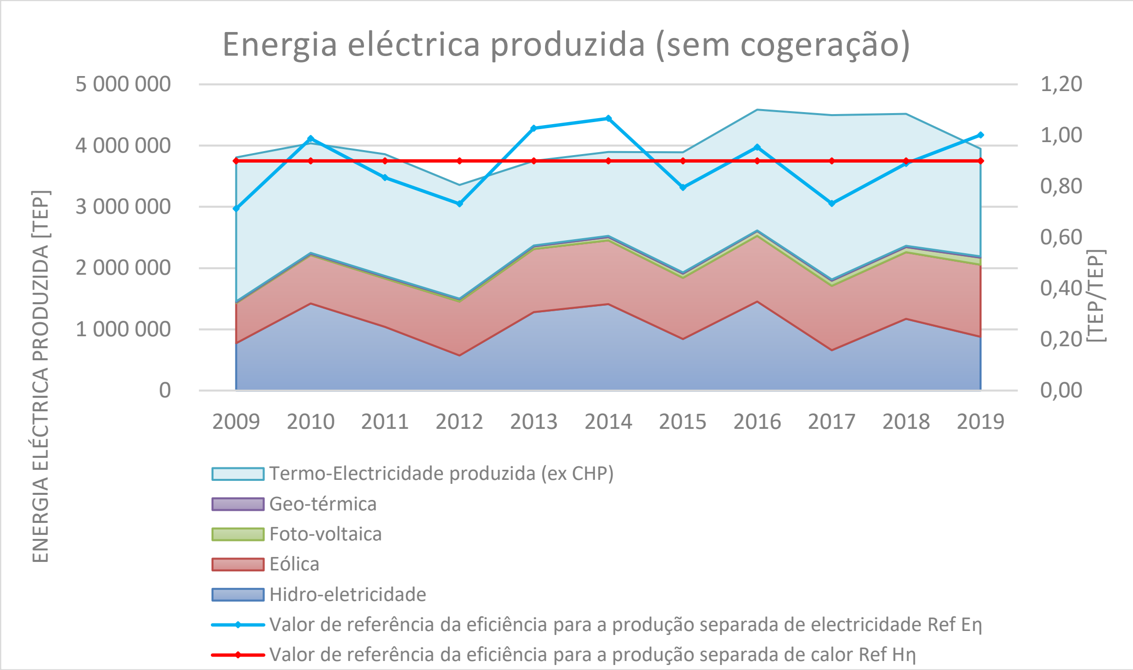


Figure 3- Energy generation in cogeneration facilities and total electrical energy generation without cogeneration (Directorate for Energy Planning and Statistics Services - DSPEE)

In 2019, the overall default electricity to heat generation ratio in cogeneration facilities was 0.44, with electricity generated in cogeneration units accounting for around 14% of the total electricity generated in Portugal.

As can be seen in Figure 3, the overall thermal efficiency of cogeneration has remained relatively constant, with an average efficiency rate of 0.55 in the last 10 years. This is in line with the trend in heat generation, as well as with the overall electrical efficiency which remained at an average of 0.23 between 2009 and 2019.

In energy generation in cogeneration facilities, the share due to heat is responsible for around 70% of the total energy output but this figure is more variable when compared to the electricity output, which reflects the higher indexing of heat consumption in generation. Heat generation peaked in the period 2011-2013 and then fell, perhaps in relation to the decline in economic activity in the same period and the fact that some cogeneration units were decommissioned from 2013 onwards (see Figure 5).

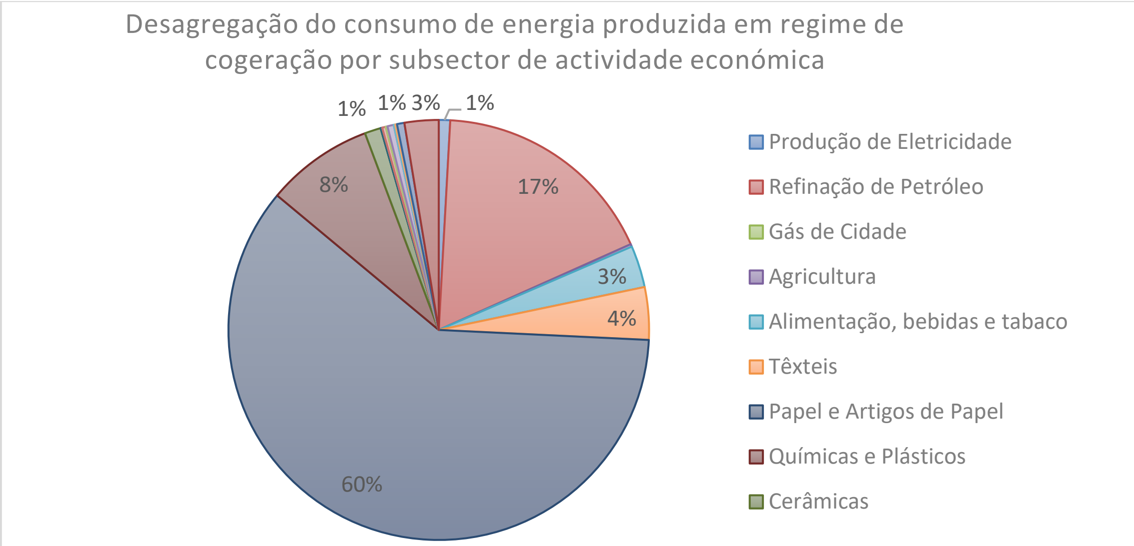


Figure 4-Breakdown of consumption of energy generated in cogeneration facilities according to sector of economic activity (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

The above figure shows that the subsector of pulp, paper and board manufacturing is the largest generator of energy (heat and electricity) in cogeneration facilities, followed by the subsector of oil refining, which is also the largest consumer of natural gas for this purpose, accounting for 33% of the total consumption of this gaseous fuel.

As regards electricity generation without cogeneration, the impact of good hydrological years in terms of overall electricity generation is clear, as well as the increase in the share of electricity generated by photovoltaic systems from 2017 onwards. To be more specific, there was a 25% jump in electricity generation by photovoltaic systems between 2018 and 2019 and it is to be expected that the share of electricity generated using photovoltaic systems will continue to rise in future as the number of interconnections with the national electricity system (*Sistema Eléctrico de Portugal* - SEN) is increased. In 2019, electricity generation from renewable sources accounted for 55% of the national electricity system. In 2017, which was the last hydrologically unfavourable year, renewable generation accounted for 40% of the national electricity system. The seasonal nature of electricity generation from renewable sources underlines the importance of energy being saved on a seasonal basis to overcome this variability.

The overall electrical efficiency in generating the electricity, not including the cogeneration facilities, is much more variable in comparison to generation in cogeneration facilities, as a result of the variability in the generation of renewable electricity and hydroelectric output in particular. Overall electrical efficiency was at its lowest in the hydrologically unfavourable years, i.e. 2009, 2012, 2015 and 2017. Despite this, the overall electrical efficiency (0.89 for the period 2009 to 2019) is higher than the average overall electrical efficiency in cogeneration facilities.

2.1. *Existing cogeneration plants*

The following figure shows how the number of cogeneration units and their installed capacity have evolved.

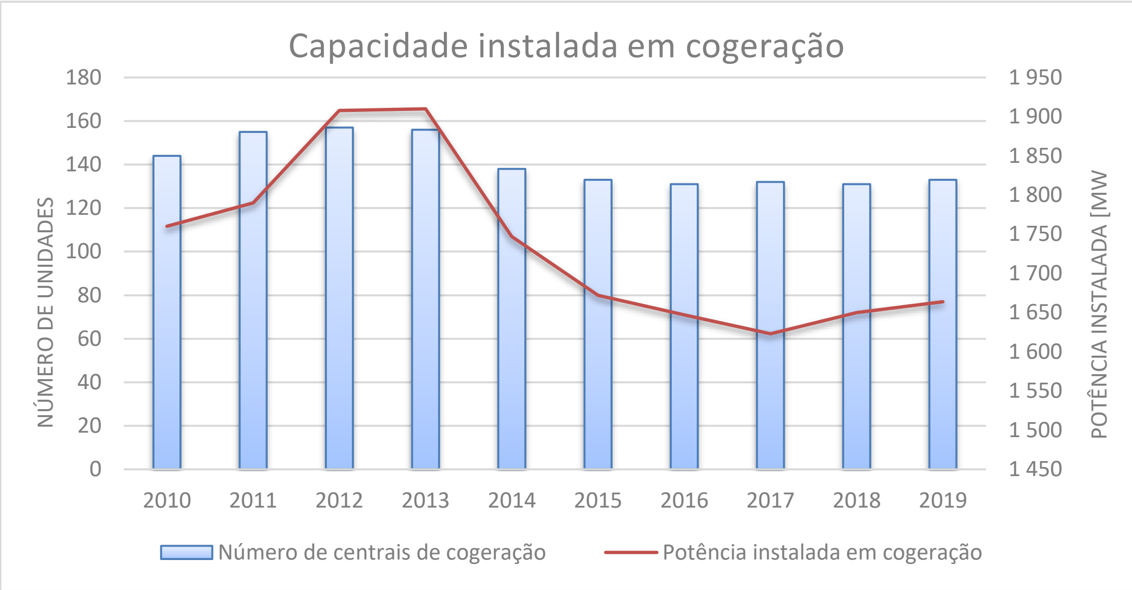


Figure 5-Number of facilities and total installed capacity for generation in cogeneration facilities (DSPEE, 2019)

The above figure shows that from 2013 onwards there was a 17% fall in the number of cogeneration facilities in operation, which led to the same drop in the installed capacity.

Of all the cogeneration units in operation in 2019, 18 had an installed capacity of more than 25 MW and half of those belonged to the pulp, paper and board manufacturing sector.

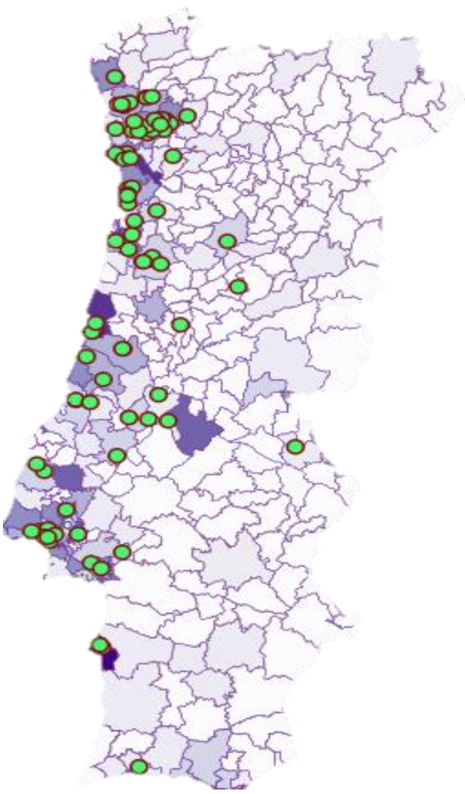


Figure 6-Geographical location of cogeneration units

As can be seen in the above figure, the cogeneration units are located along the West coast, with 45% concentrated in the North region of Portugal, accounting for 28% of installed electrical capacity. The Alentejo region, on the other hand, with just 6% of cogeneration units, represents 21% of installed electrical capacity. These figures, together with the fact that 32% of cogeneration units belong to the textiles, clothing and footwear manufacturing subsector (11% of installed capacity and just 4% of the energy generated), indicate that the installed capacity for cogeneration will be more scattered in the North region, as the industrial units are smaller in size. The pulp, paper and board manufacturing subsector is on the other end of the spectrum, with just 11% of the number of cogeneration units, corresponding to 42% of the total installed capacity for cogeneration units and generating around 60% of the total energy generated in cogeneration facilities in the year 2019.

The following table shows a more detailed breakdown of the cogeneration units per region, in accordance with the NUTS II classification.

Table 1-Distribution of number of plants, respective power and energy generated per region (Directorate for Energy Planning and Statistics Services - DSPEE, 2018)

NUTS II regions	Number of plants		Electrical power (MW)		Energy generated (GWh)
North Region	58	45%	542	28%	2 223
Lisbon Region	24	18%	352	18%	1 481
Central Region	38	29%	625	33%	2 100
Alentejo	9	7%	395	21%	1 082
Algarve	1	1%	2	0%	NA

In the following figure, the primary energy consumed for the separate generation of heat and electrical energy was obtained by dividing the energy generated in cogeneration facilities by the efficiency references for the generation of heat and electricity (Equation 3, Equation 4 and Figure 3).

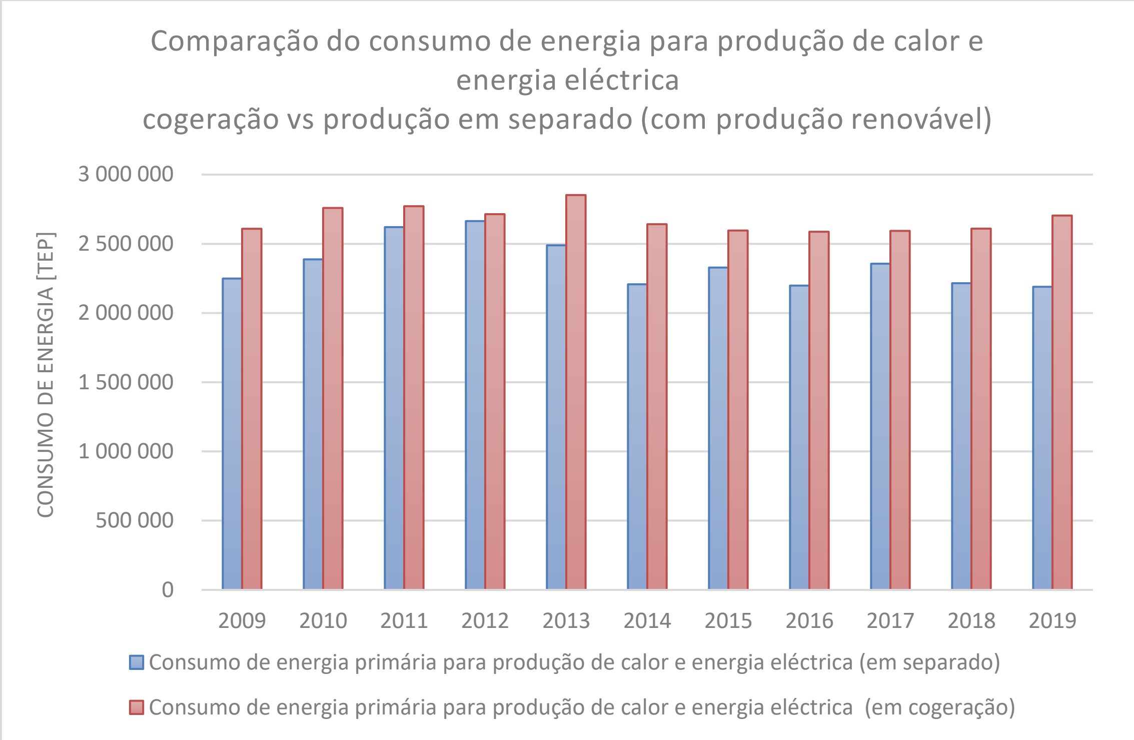


Figure 7- Total heat and electrical energy generation in cogeneration facilities and separately (including renewable output).

The above figure shows that in the period 2009-2019, the consumption of primary energy for the separate generation of heat and electricity was always lower than generation in cogeneration facilities.

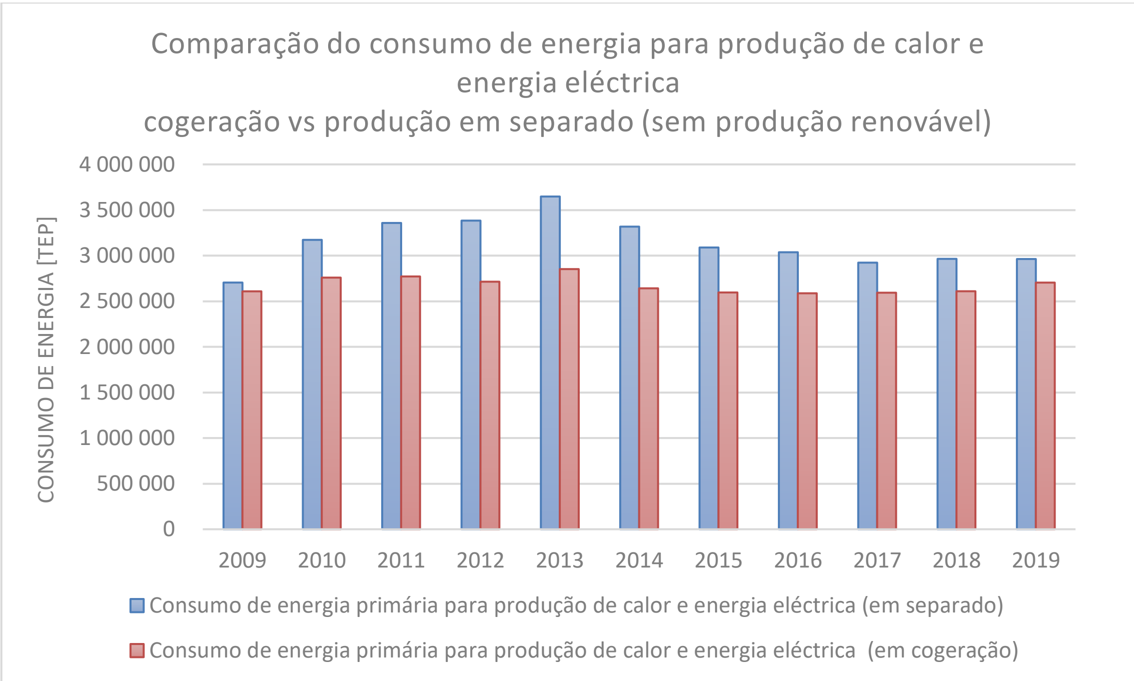
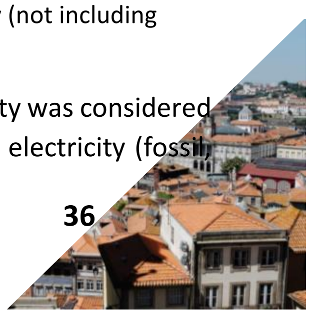


Figure 8- Total heat and electrical energy generation in cogeneration facilities and separately (not including renewable output).

To calculate the hypothetical scenario featured in the above figure, only thermal electricity was considered for the numerator in Equation 4 and only the energy needed to generate that thermal electricity (fossil,



biomass or non-renewable waste) was considered for the denominator. In other words, in this hypothetical scenario, the reference for generating electricity separately does not consider electricity generated from renewable sources (wind, hydro, solar and geothermal). In this hypothetical scenario, the generation of energy in cogeneration facilities would lead to overall energy savings of around 13 Mtoe in the 11 years under analysis. In accordance with a simulation carried out by the author of this study, for Portugal as a whole, energy generation in cogeneration facilities no longer results in energy savings when by comparison with separate generation, the share of electricity generated from renewable sources is higher than 19%. As stated previously, the minimum share of renewable energy occurred in 2017, when 40% of the electricity generated in the Portuguese electricity system was renewable.

The data obtained only allowed for an analysis of the efficiency of generating energy in cogeneration facilities for the country as a whole. It was not possible to carry out a detailed calculation of the efficiency of each of the cogeneration plants in accordance with Annex II to the EED, because there is no breakdown available with information on energy generation or the other data needed to respond to point (f) of Annex II to the EED.

2.2. Waste incineration plants and electricity generation plants with a total annual output of more than 20 GWh.

This chapter and the following figures map and provide details of the characteristics of the dedicated thermoelectric power plants and waste incineration plants with a total energy generation output of more than 20 GWh.

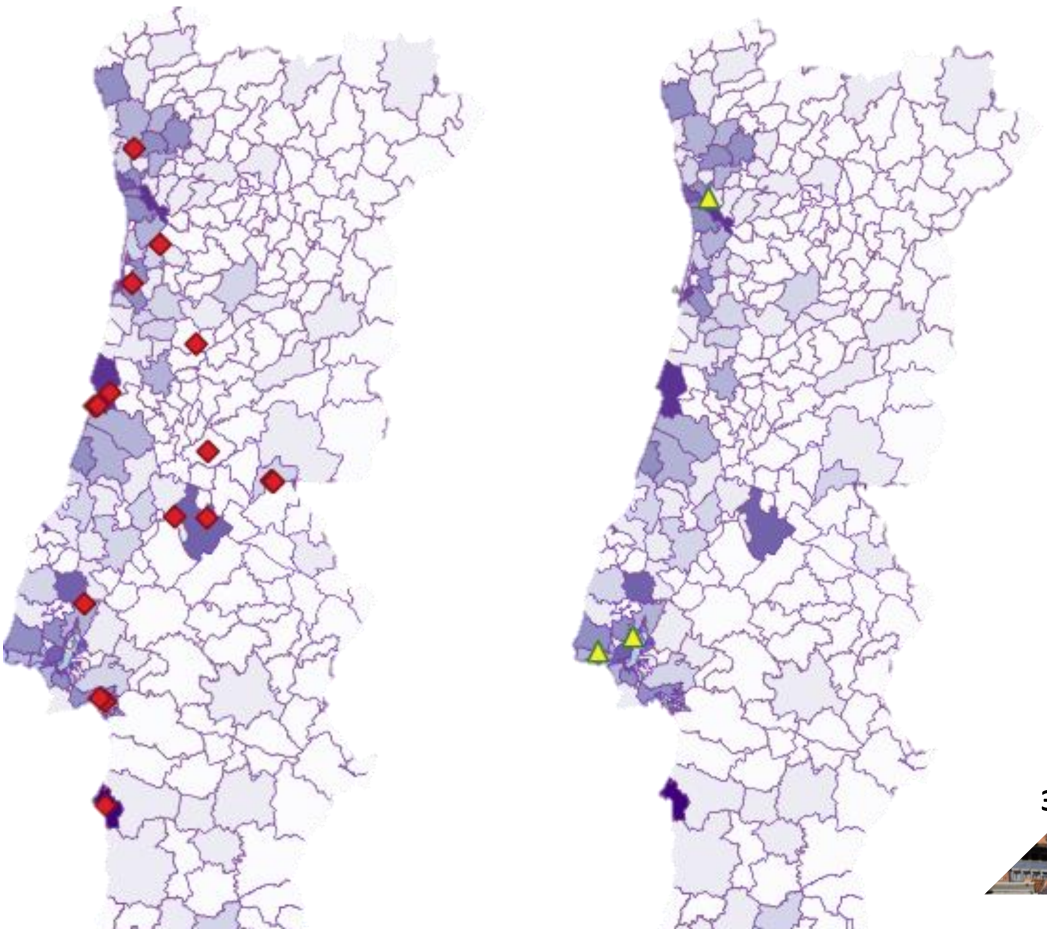


Figure 10- Geographical location of dedicated thermal power plants with an output of over 20 GWh on the map for total energy consumption (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

Figure 9- Geographical location of waste incineration plants on the map for total energy consumption (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

There are 18 dedicated thermoelectric power plants in mainland Portugal with a total installed capacity of 6 113 MW. The following table displays the breakdown according to NUTS II regions.

Table 2-Distribution of installed capacity figures at dedicated thermal plants per region (Directorate for Energy Planning and Statistics Services - DSPEE, 2018)

NUTS II regions	Installed capacity (MW)
Northern Region	1 109
Central Region	3 677
Lisbon Region	69
Alentejo	1 259

There are 3 incinerator plants In the Greater Porto and Greater Lisbon regions, with a total installed capacity of 77 MW.

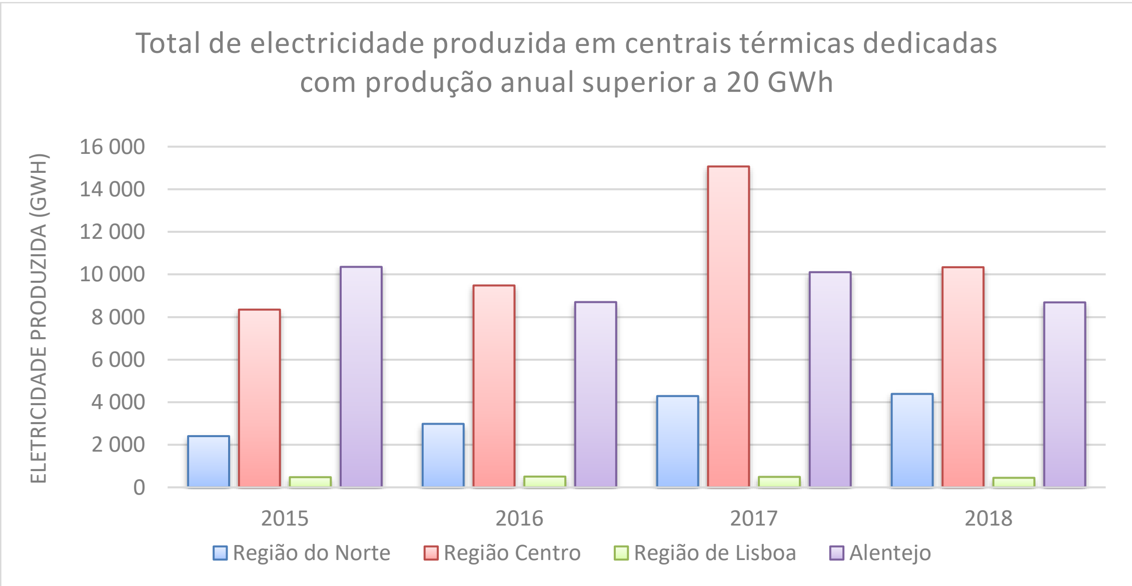


Figure 11- Total electricity generated at dedicated thermal power plants with an annual output of more than 20 GWh (Directorate for Energy Planning and Statistics Services - DSPEE, 2018).

In 2018, the dedicated thermal power plants located in mainland Portugal generated 23.9 TWh of electricity (5 129 255 toe), while incinerator plants generated 578 GWh (124 270 toe).

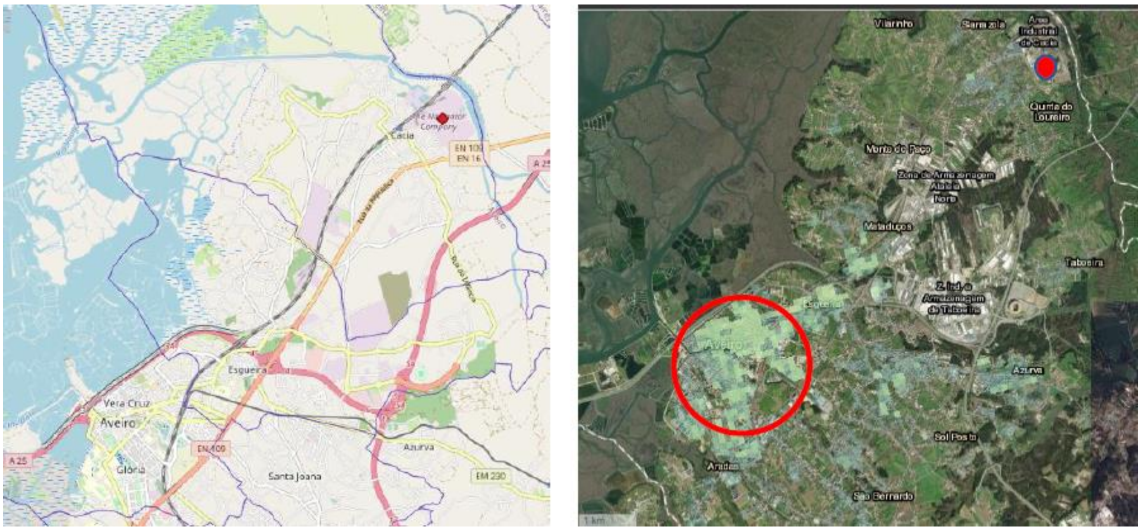


Figure 12- Location of thermal power plants and potential consumers of the respective waste heat

In the above figure, 1 thermal power plant is located 7 km from Aveiro, a city with a low average heating density (<200MWh/ha).

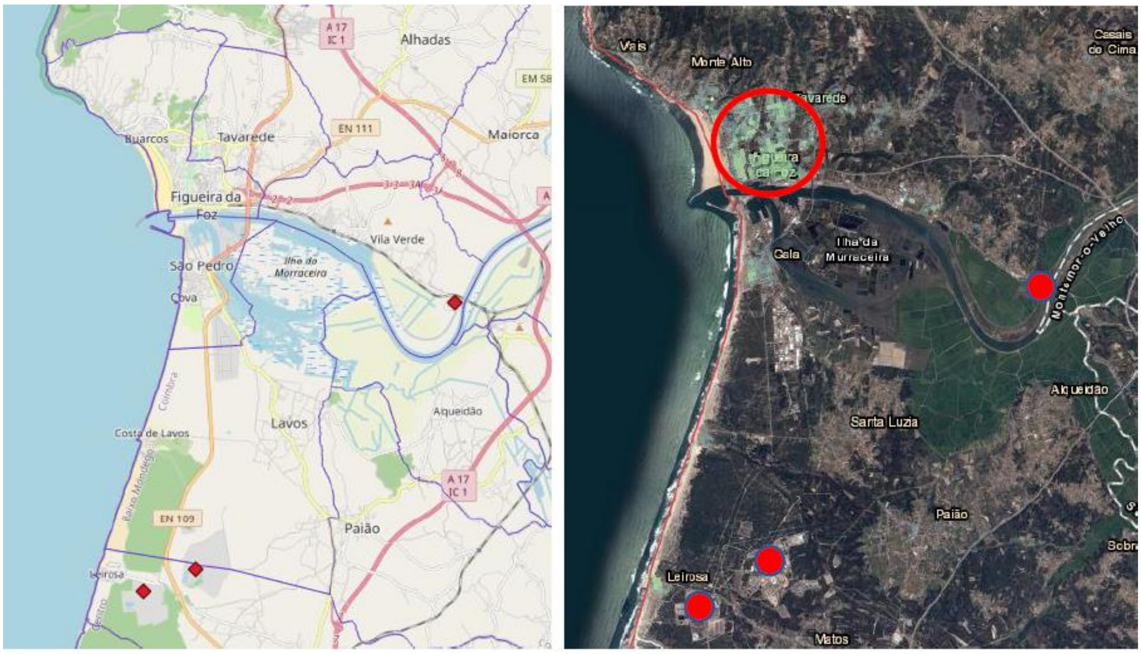


Figure 13- Location of thermal power plants and potential consumers of the respective waste heat

In the above figure, 3 thermal power plants are located a maximum of 10 km from Figueira da Foz, a city with a low average heating density (<100MWh/ha).

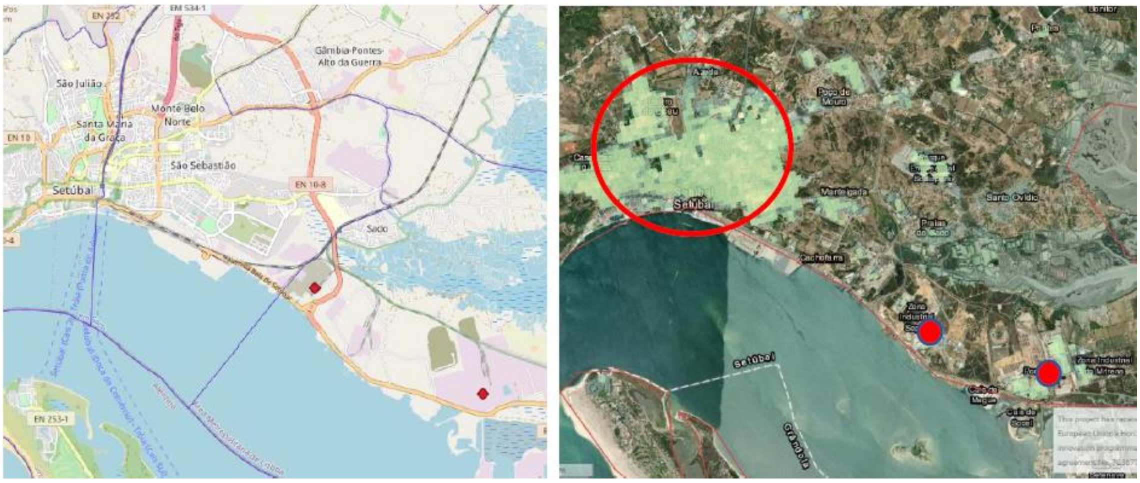


Figure 14- Location of thermal power plants and potential consumers of the respective waste heat

In the above figure, 2 thermal power plants are located a maximum of 7 km from Setúbal, a city with a low average heating density (<300MWh/ha).

The potential for waste heat at incinerator plants is analysed in Chapter 4.6 of the study ‘Waste Heat in Portugal – 2020 Edition’ (DGEG, 2021 c).

3. Final energy consumption in mainland Portugal

The figure below shows the trend in final energy consumption in mainland Portugal for all sectors of activity, including the residential sector, but not including the energy generation subsector.

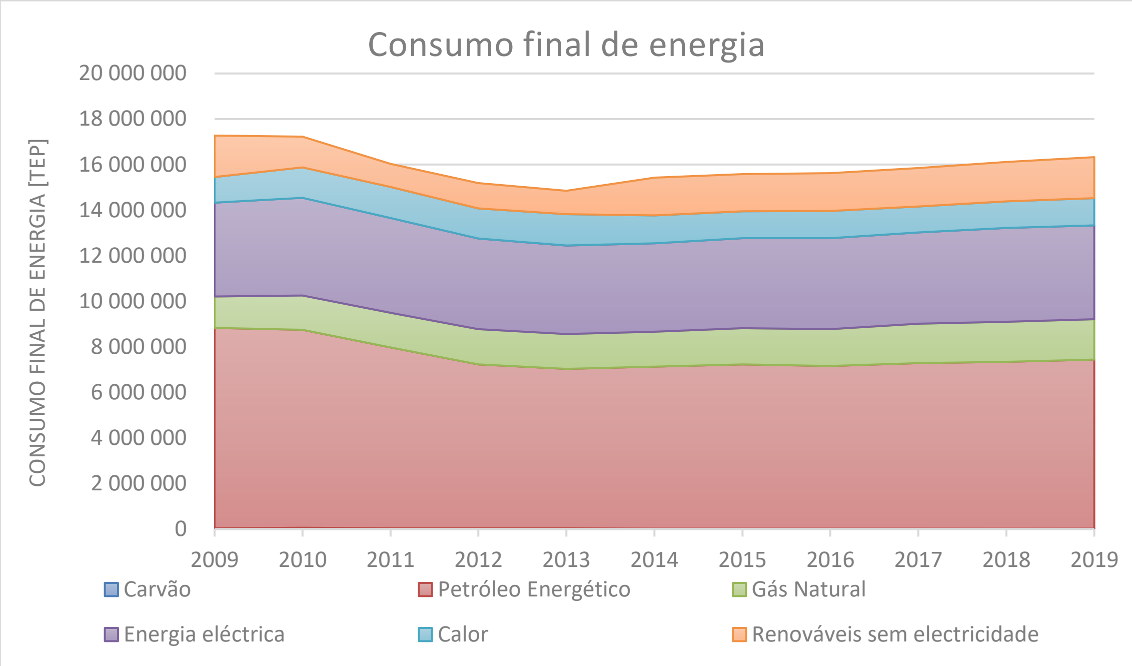


Figure 15-Final energy consumption (DSPEE)

The above figure shows that final energy consumption fell by 6% in the period 2009 to 2019, which is still an improvement on the 16% drop in energy consumption recorded between 2010 and 2013, which will have been linked to the economic crisis the country went through at that time. Given that the economic recovery in the period after 2013 raised GDP levels above the levels seen prior to the economic crisis (INE, 2020), it is legitimate to infer that this economic recovery will have been achieved at the expense of the economy having a lower energy intensity.

All sectors of economic activity felt the impact of the economic crisis that affected the country in the 2010-2013 period (see Figure 15 and Figure 16), but the drop in consumption in the transport sector will have been what most affected the overall final energy consumption, given this sector's importance in the Portuguese economy (see Figure 19). In the 2010-2013 period, the biggest drop (24%) was in the consumption of oil for energy, compared to a 19% drop in the consumption of oil for energy in the total period analysed. Once again, this was due to the fall in the consumption of this oil by-product by the transport sector (see Figure 16).

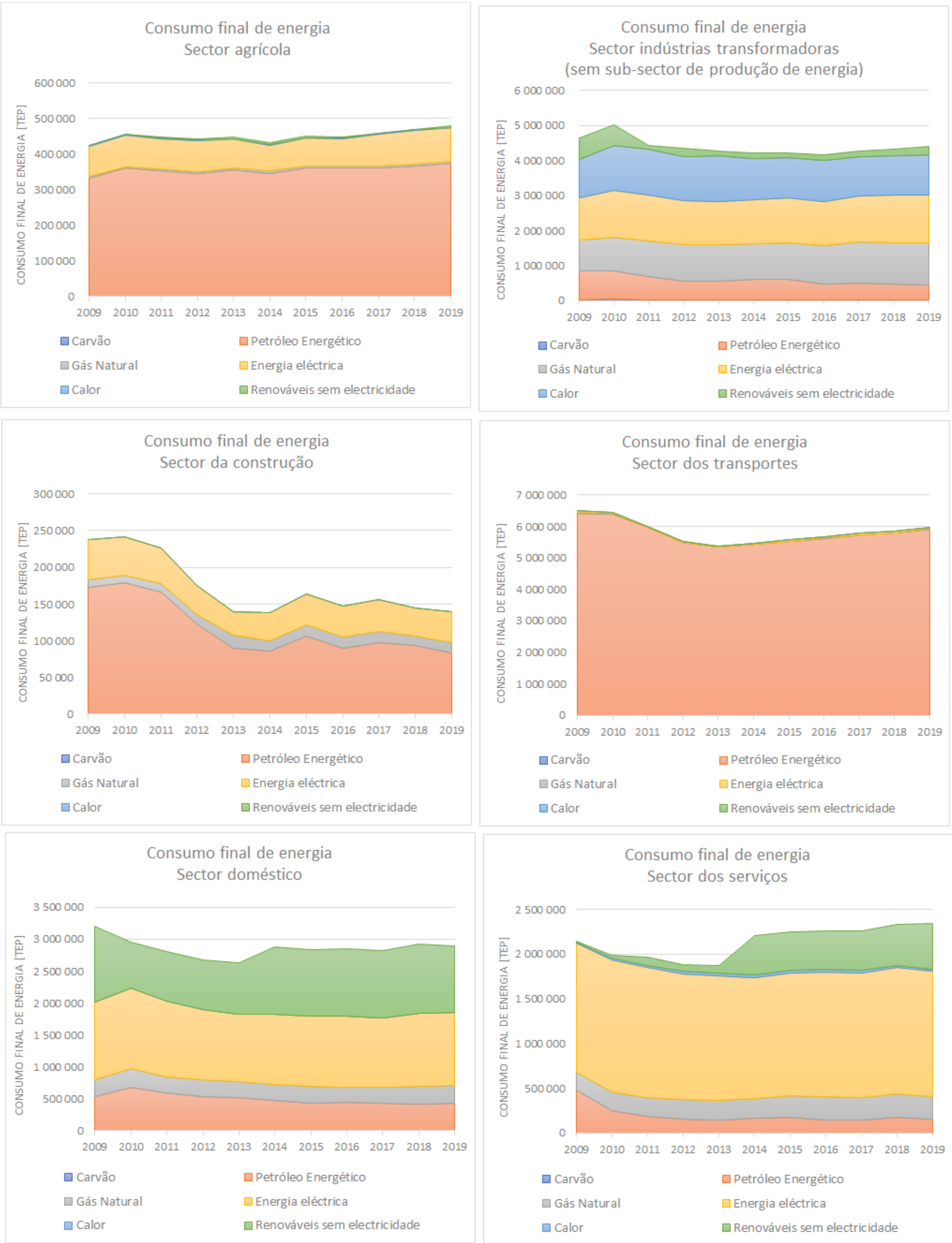


Figure 16-Final energy consumption per economic activity sector (not including the energy generation subsector) since 2009 (DSPEE)

The manufacturing sector has a more diversified energy mix that is less dependent on derivatives of oil for energy; consumption of heat generated in cogeneration facilities accounts for around 28% of the total energy consumed by this sector, or 1 1159 019 toe. Despite it not being possible to count the rest of the heat consumed by the manufacturing industry, if we assume that the total fossil energy consumed by this sector is converted into thermal energy, applying a conversion factor of 0.9, the conclusion is that heat generated in cogeneration facilities will meet around 69% of total thermal needs. The residential sector also has a diversified energy mix, with renewable energies (not including electricity) accounting for around 36% of total consumption. In both the residential and services sectors, the substantial increase in renewable energies (not including electricity) between 2013 and 2014 is because heat pumps were included as renewable resources in the National Energy Balance Sheet. The sectors of agriculture and transport, followed by the construction sector, are almost entirely dependent on oil derivatives for energy.

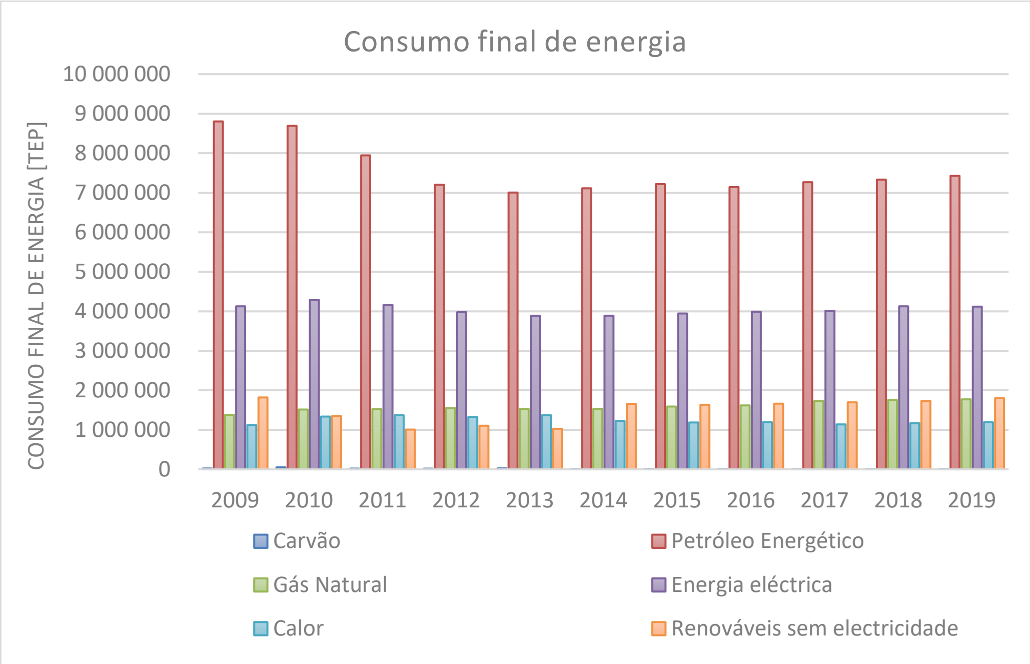


Figure 17- Breakdown of final energy consumption (not including the energy generation subsector) in the period 2012 to 2019 (Directorate for Energy Planning and Statistics Services - DSPEE)

There was a 78% drop in coal consumption for non-energy purposes in the period 2012 to 2019. This drop occurred in the chemicals and plastics manufacturing subsector. Coal consumption only accounts for about 0.1% of the total energy consumed in Portugal (not including the energy generation subsector). In the same period, there was an increase of about 39% in the consumption of renewable energies (not including electricity). As explained previously, this is because heat pumps were included as renewable resources in the National Energy Balance Sheet. There was a drop of about 11% in heat consumption, mostly due to the lower consumption in the manufacturing sector, which accounts for 96% of the total heat consumption.

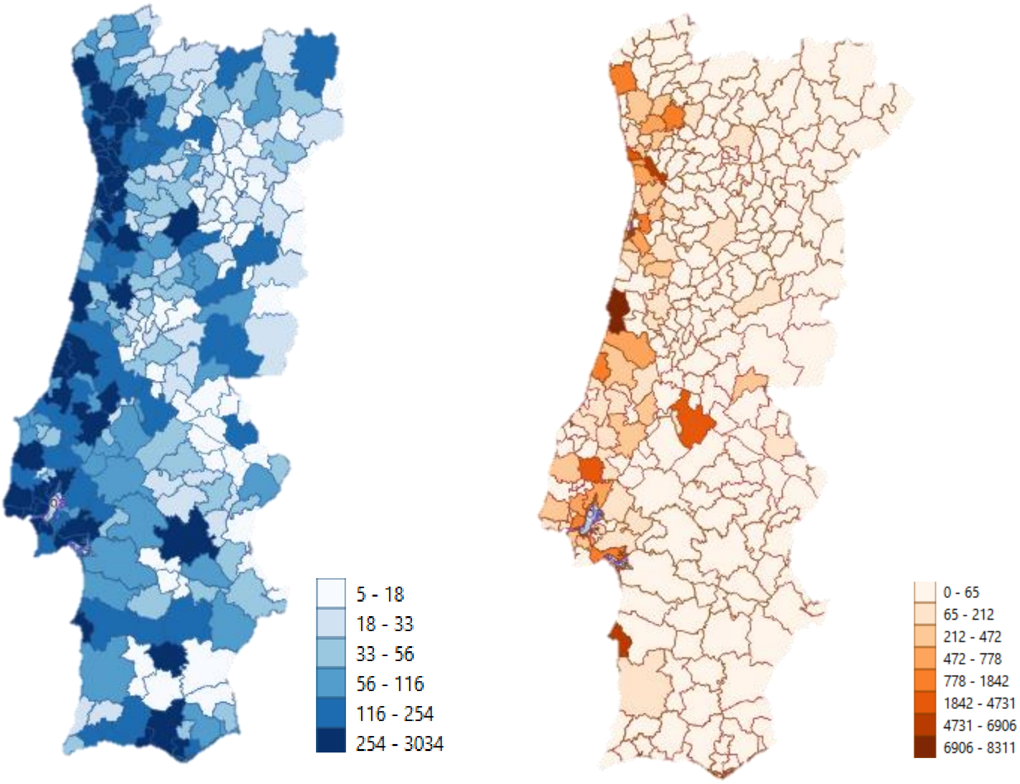


Figure 18-Distribution of natural gas and electricity consumption according to municipality (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

Energy consumption is higher on the West coast. This is particularly evident for natural gas consumption, as there are still many inland municipalities that are not connected to the natural gas distribution grid. There are some natural gas consumption clusters in municipalities located inland, which are due to large energy consumers, such as thermoelectric power plants (municipality of Abrantes). The same can be said for electricity, as inland municipalities such as Évora, Viseu and Castro Verde stand out for their electricity consumption due to their industrial estates (Évora and Viseu) and/or large mining operations (Castro Verde).

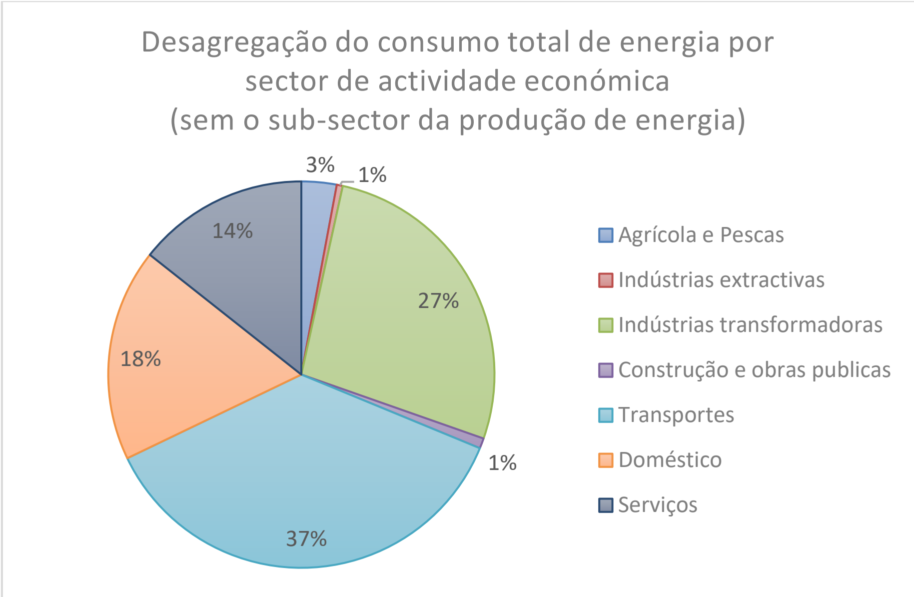


Figure 19- Breakdown of total energy consumption according to sector of economic activity

(not including the energy generation subsector)

(Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

The transport sector accounts for the highest share in the total energy consumption, with 37% of the total energy consumed in 2019. It is followed by the manufacturing industry and the residential sector.

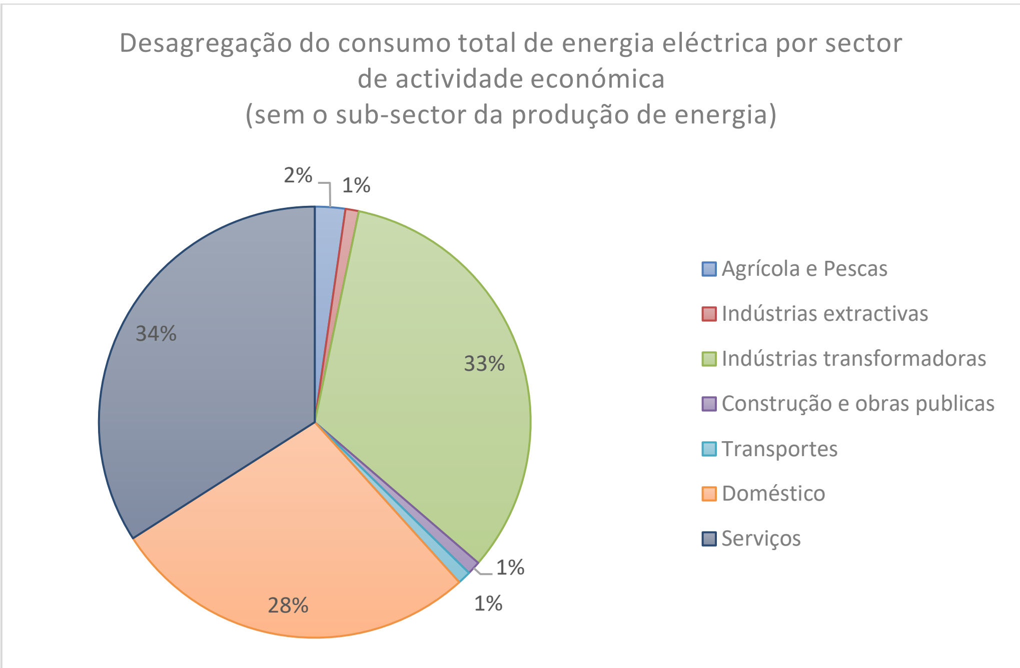


Figure 20- Breakdown of total electrical energy consumption according to sector of economic activity
(not including the energy generation subsector)
(Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

The services sector is responsible for 34% of the total electricity consumption, followed by the manufacturing sector (33% of consumption) and the residential sector, which accounts for 28% of total electricity consumption.

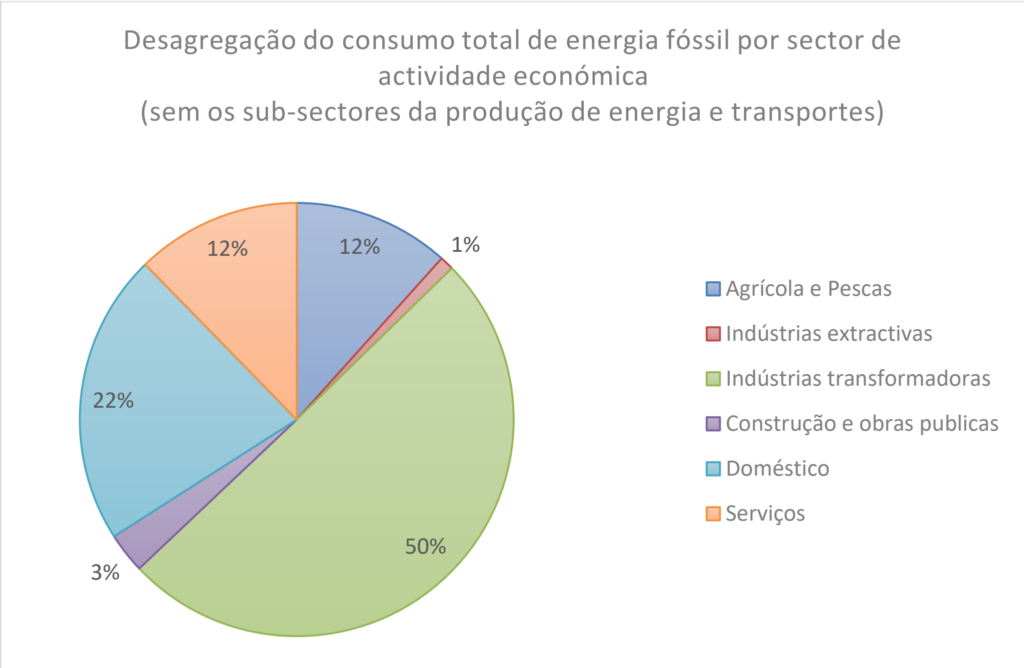


Figure 21- Breakdown of total fossil energy consumption according to sector of economic activity (not including the energy generation and transport subsectors) (Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

As can be seen in the above figure, if the consumption by the transport sector is not included, the manufacturing sector accounted for half of the fossil energy consumed in 2019.

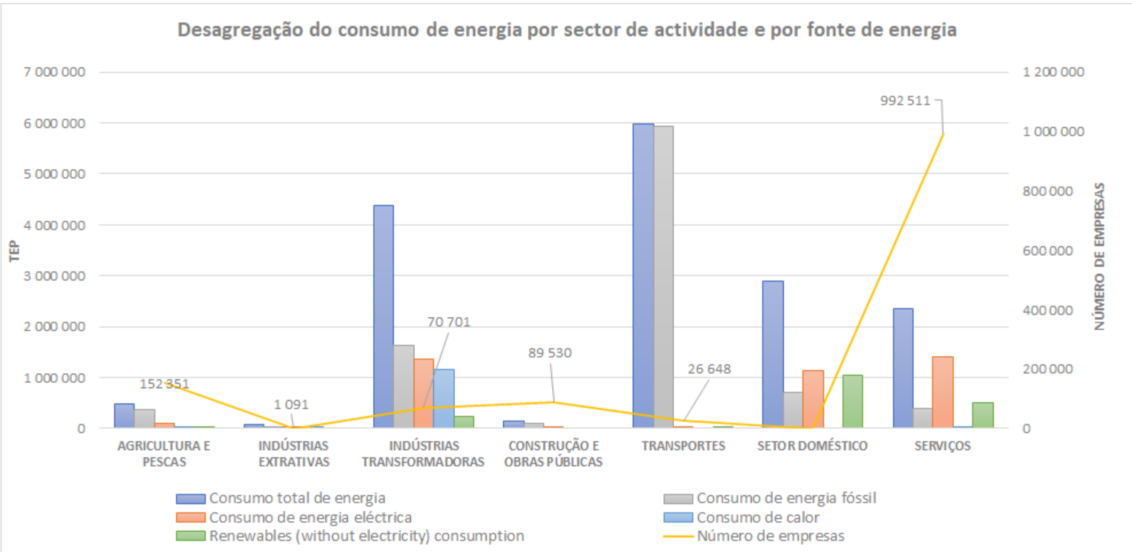


Figure 22- Breakdown of energy consumption according to sector of activity

(Directorate for Energy Planning and Statistics Services - DSPEE, 2019) and total number of enterprises

(National Institute for Statistics - INE, 2018)

The above figure shows that transport sector companies account for the highest energy intensity (energy consumption by number of enterprises), followed by the manufacturing sector, which is the largest absolute energy consumer after the transport sector. The residential sector accounted for about 59% of total renewable energy (not including electricity) consumed in 2019.

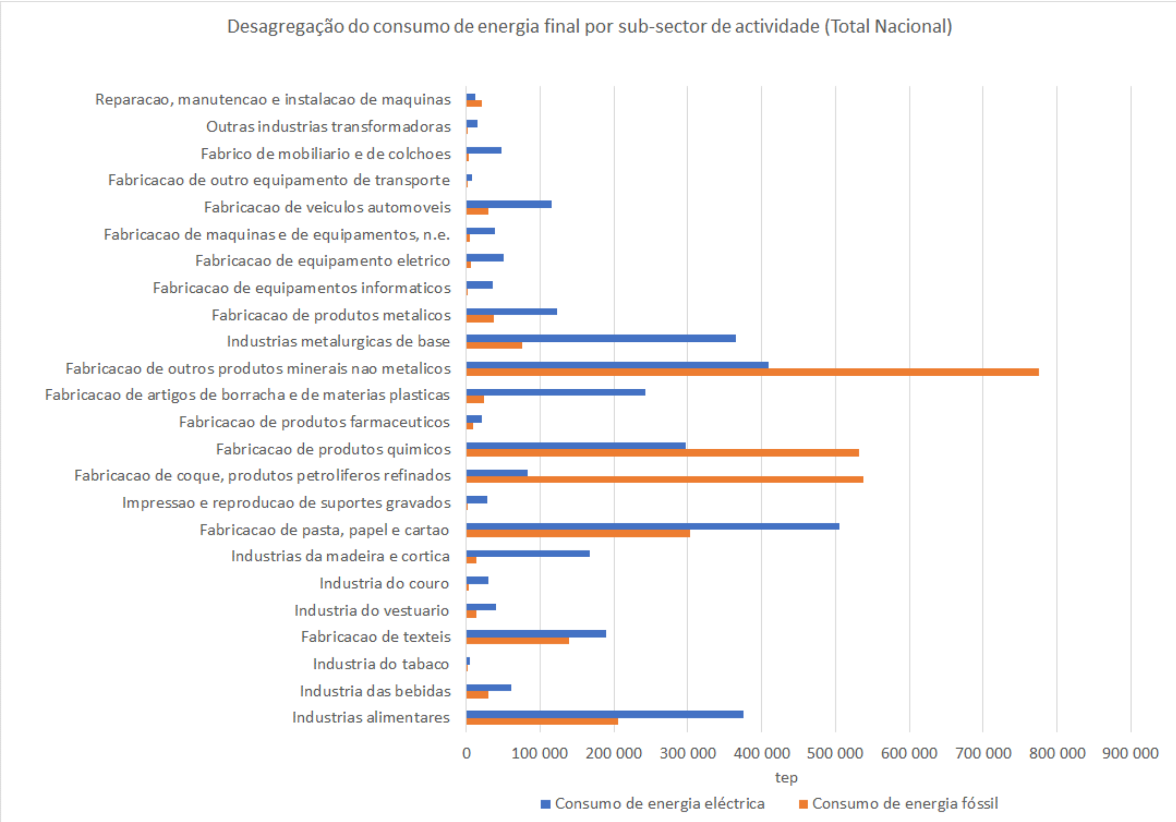


Figure 23- Breakdown of total final energy consumption according to sector of economic activity

(Directorate for Energy Planning and Statistics Services - DSPEE, 2019)

Manufacturing of other non-metallic mineral products, chemicals and other refined petroleum products are the subsectors that consume the most fossil energy, which can lead us to believe that these will be the subsectors where the highest process heat needs can be found. This analysis does not take biomass consumption (which will also be used for conversion into thermal industry) by other manufacturing subsectors into account.

4. Industrial zones with a total annual heating and cooling consumption of more than 20 GWh

The rules of the Intensive Energy Consumption Management System (SGCIE), which has been in place since the early 1980s and was reviewed in 2008 when Decree-Law 71/2008 was published, apply to facilities with annual energy consumption above 500 toe. These facilities must be registered on the SGCIE portal, complete mandatory energy audits and submit energy consumption streamlining plans (Portuguese acronym: PREn) setting out the measures being taken to optimise energy consumption. Every two years, compliance with implementing the measures is assessed with partial reports and by monitoring indicators reported to the DGEG via the SGCIE portal. This means that there is a database available on the energy consumption of 1 289 enterprises (0.1% of all Portuguese enterprises), which account for about 9% of total energy consumption. Of these enterprises registered in the SCGIE, 1 094 belong to the manufacturing sector, representing 1.7% of the total number of Portuguese enterprises in that sector and 25% of the total energy consumption in the manufacturing sector.

For this bottom-up approach, 544 energy audit reports submitted via the SGCIE portal by facilities located along the West coast were analysed. There was a particular focus on the Porto and Lisbon regions, as 132 facilities with process heating needs and 74 facilities with process cooling needs were identified. Thermal needs for processes at facilities are directly obtained from energy audit reports or calculated by multiplying the energy consumed for thermal generation by the efficiency of the thermal energy generator, in accordance with information obtained from the energy audit report. Where process heat generation was calculated due to efficiency not being set out in the energy audit report, a thermal conversion efficiency rate of 0.9 was considered, in accordance with Order 17313/2008. Where process heat was calculated due to the efficiency of the cold water generator not being set out in the energy audit report, an EER of 2 was considered.

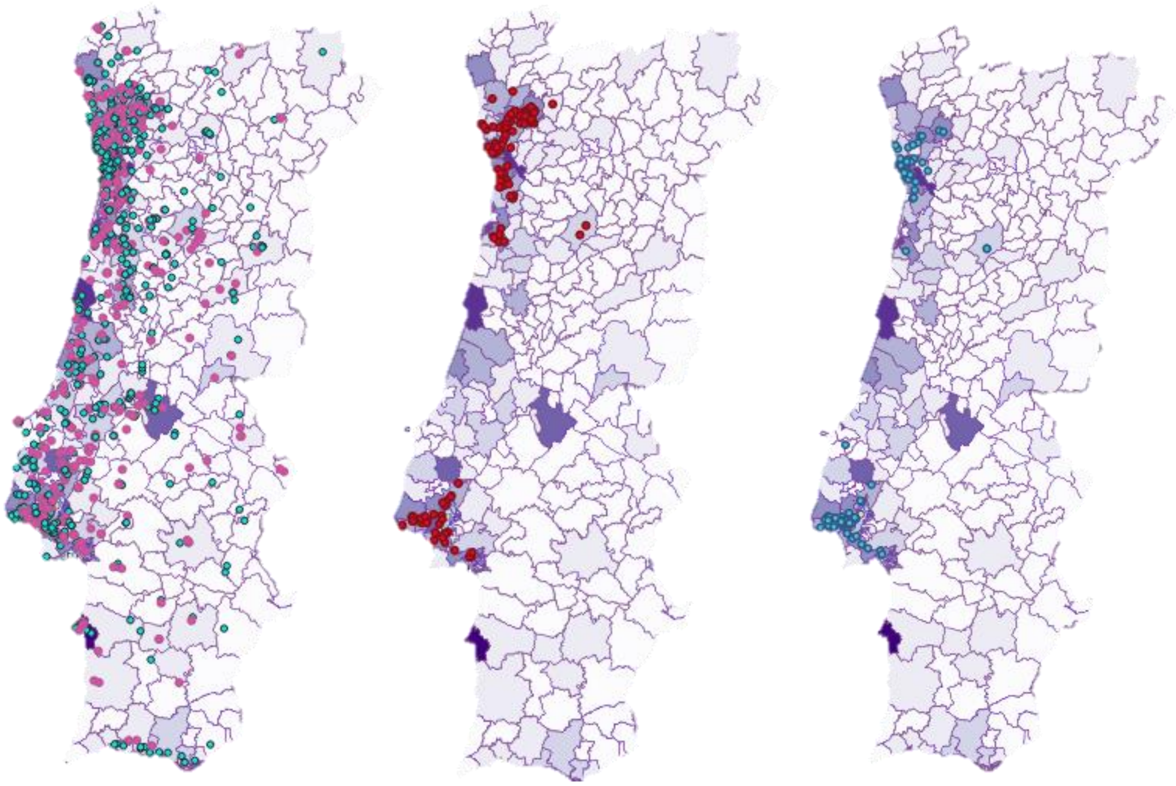


Figure 24- Geographical location of all SGCIE facilities and of the latter, the ones that need process heating or cooling (selected facilities along the West coast) shown on the map for total energy consumption ((Directorate for Energy Planning and Statistics Services - DSPEE, 2019).

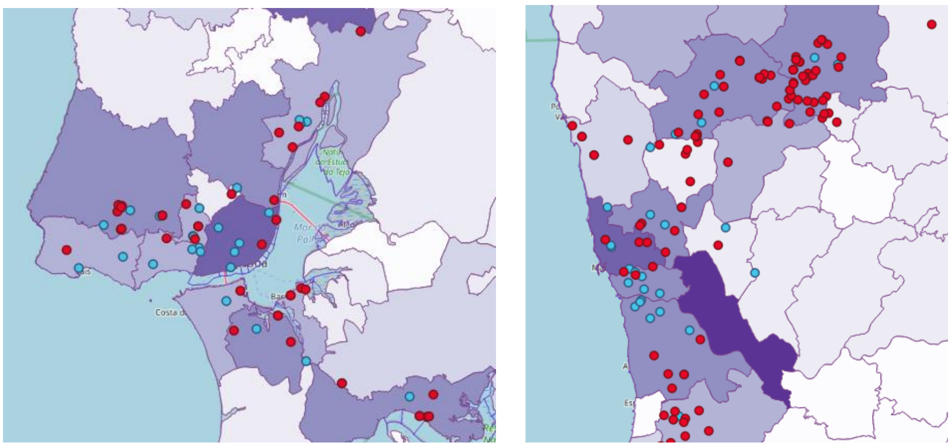


Figure 25- Geographical location of heating and cooling demand for SGCIE facilities in the regions of Porto, Lisbon and Vale do Tejo.

The following figures show how the demand for process heating and cooling is distributed according to municipalities and industrial estates.

The total quantity of heat required by the 132 SGCIE facilities analysed in this study is 2.6 TWh/year distributed among 22 municipalities.

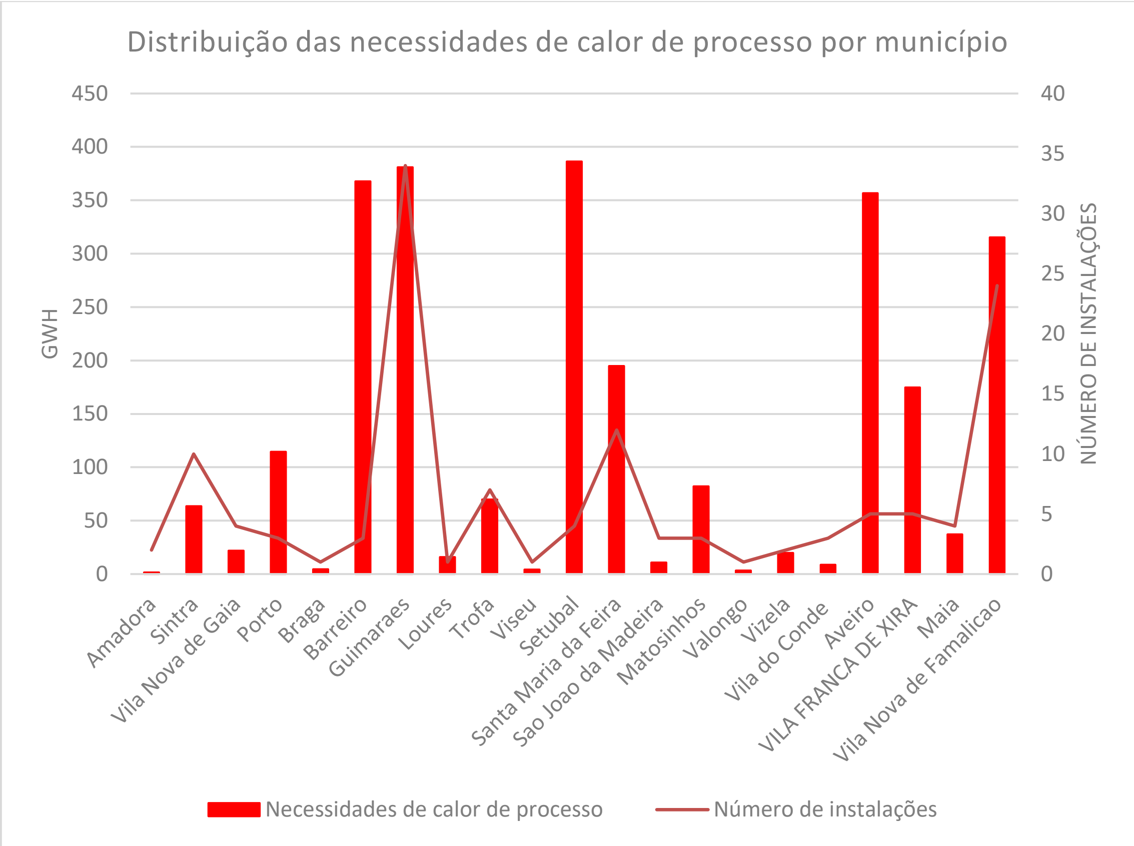


Figure 26- Distribution per municipality of process heating needs at Intensive Energy Consumption Management System (SGCIE) plants

The above figure shows that process heating needs are more concentrated in the municipalities of Porto, Barreiro, Aveiro, Setúbal and Vila Franca de Xira, as these municipalities have larger facilities, i.e. pulp, paper and board manufacturing facilities located in Aveiro and Setúbal. On the other hand, process heating needs are less concentrated in the municipalities of Guimarães and Vila Nova de Famalicão. This is because of the type of manufacturing subsectors in those municipalities, i.e. the textiles and clothing industry, which accounts for about 88% of the facilities with process heating needs in these two municipalities.

Of the 132 facilities mentioned above, 19 (of which 15 are located in the North region) generate process heat using cogeneration units, representing a total of 1.5 TWh/year of steam or hot water. There are 32 SGCIE facilities with process thermal needs above 10 GWh/year, representing a total of 855 GWh/year in thermal needs, which do not have cogeneration systems installed.

Of the total of 2.6 TWh/year of process heat required by the SGCIE facilities, 1.5 TWh/year are from industrial estates, which are distributed as shown in the following figure.

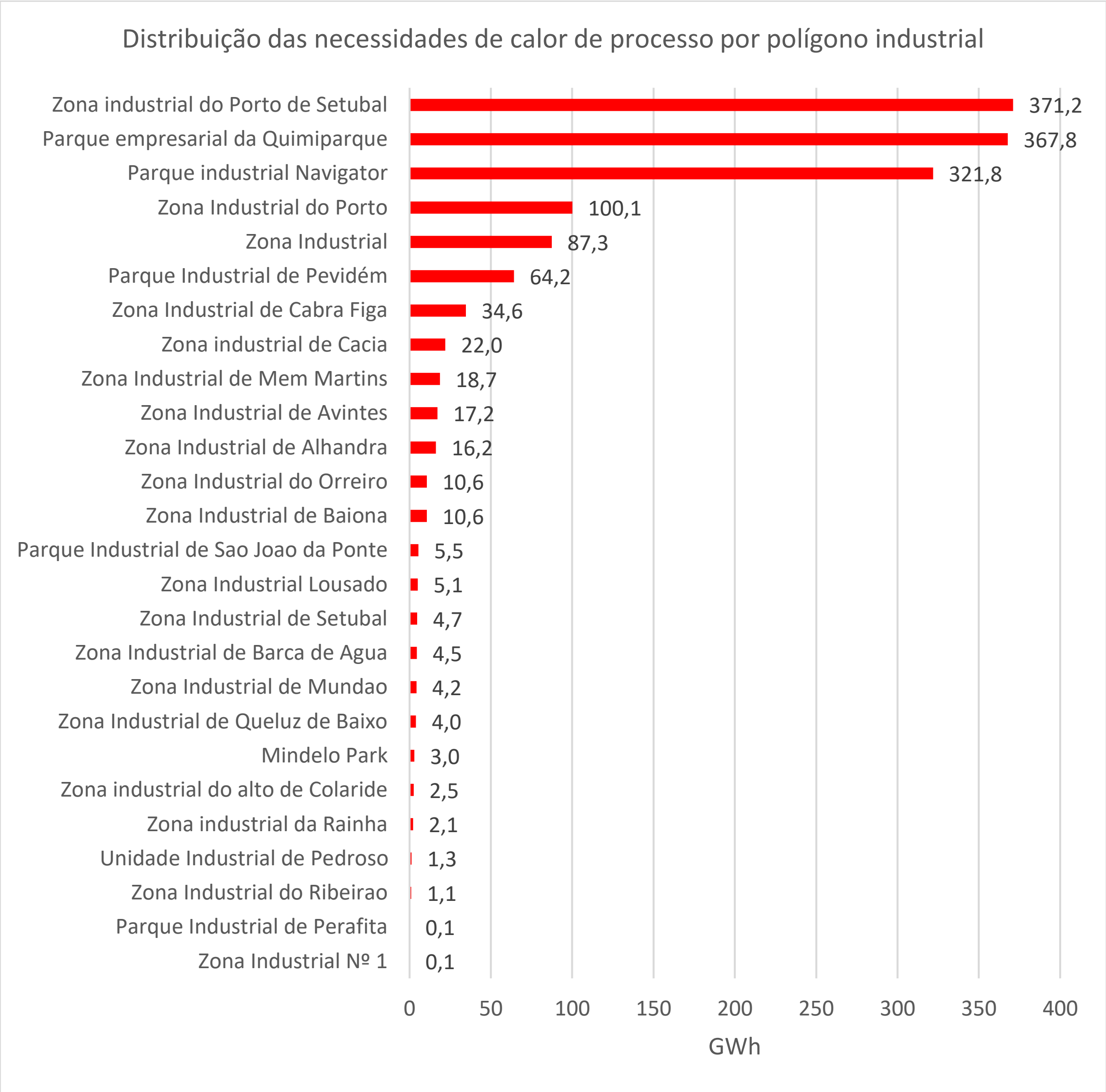


Figure 27- Distribution per municipality of process heating needs at Intensive Energy Consumption Management System (SGCIE) plants

In the above figure, 'Industrial zone' means unorganised clusters of facilities, all located in the North Region. About 64% of SGCIE facilities requiring process heat are in operation outside industrial estates. Almost 90% of these facilities in operation outside industrial estates are in the North Region.

Figures 26 and 27 show that the heating needs in the North Region, which account for around 47% of the total heating needs of the SGCIE facilities identified in this study, are from smaller units that are more scattered, operating either on an isolated basis or in unorganised clusters of facilities belonging to the textiles and clothing subsectors. It is in these two manufacturing subsectors in the North Region that almost 45% of all the cogeneration plants installed in Portugal are located, accounting for around 28% of the installed capacity for cogeneration, as stated previously in this study (Waste heat in Portugal 2020 (DEIR Studies 005, 2021), Table 1).

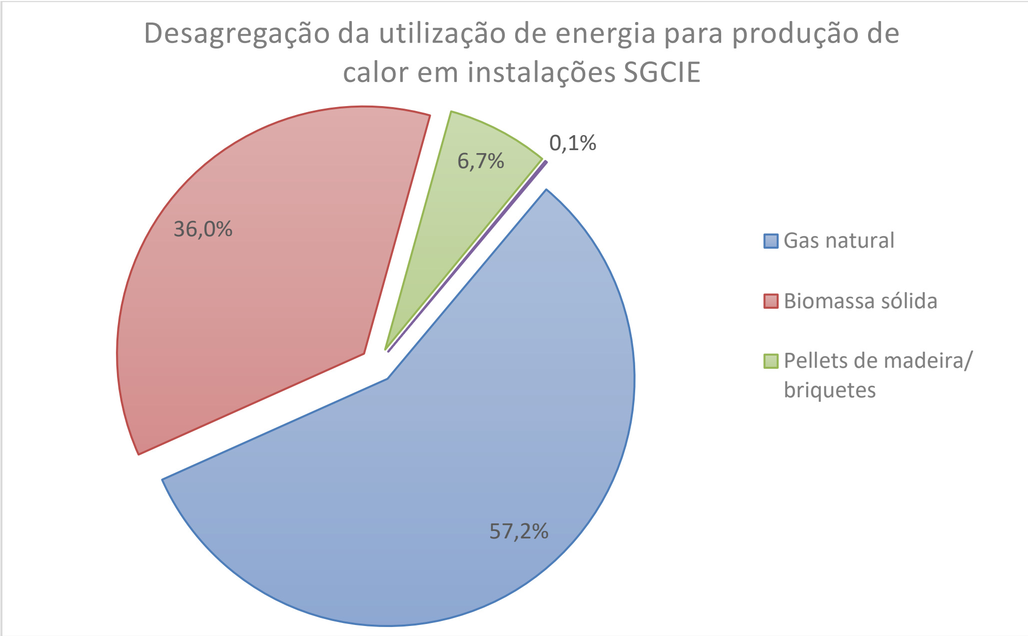


Figure 28- Breakdown of energy used to generate heat at Intensive Energy Consumption Management System (SGCIE) plants

As can be seen in the above figure, around 43% of the energy used to generate heat at SGCIE facilities comes from biomass.

The following paragraphs will briefly describe the process cooling needs pinpointed in the SGCIE facilities identified in this study. The total quantity of cold required by the 74 SGCIE facilities is 339 GWh/year distributed among 24 municipalities.

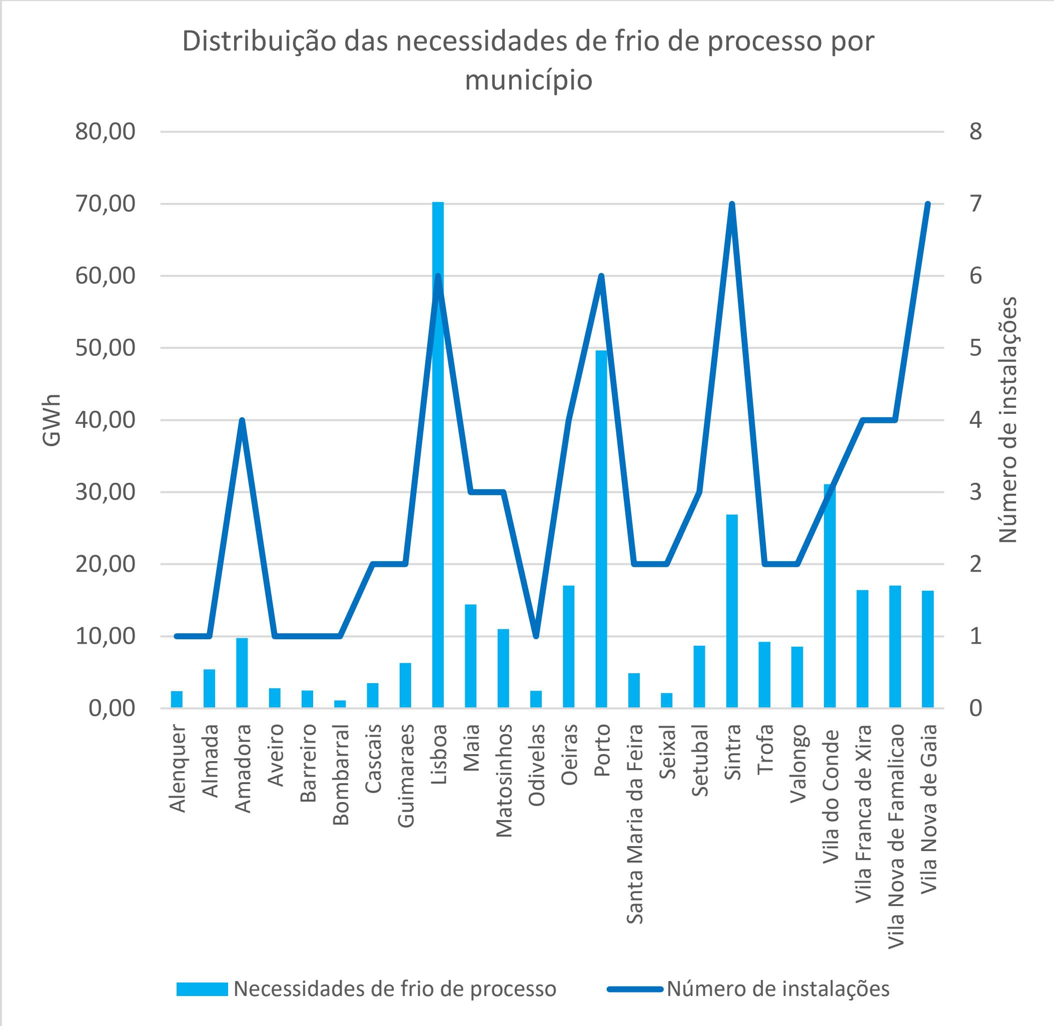


Figure 29- Distribution per municipality of process cooling needs at Intensive Energy Consumption Management System (SGCIE) plants

With the exception of Lisbon and Porto, the above figure shows that the demand for cooling is very scattered. Of the total number of facilities, 37 are supermarkets and shopping centres, 10 are data centres located in Lisbon and Porto and 8 are refrigerated warehouses.

Of the 339 GWh/year in cooling needs required by SGCIE-registered facilities, 68 GWh/year come from facilities in industrial estates, distributed as shown in the following figure:

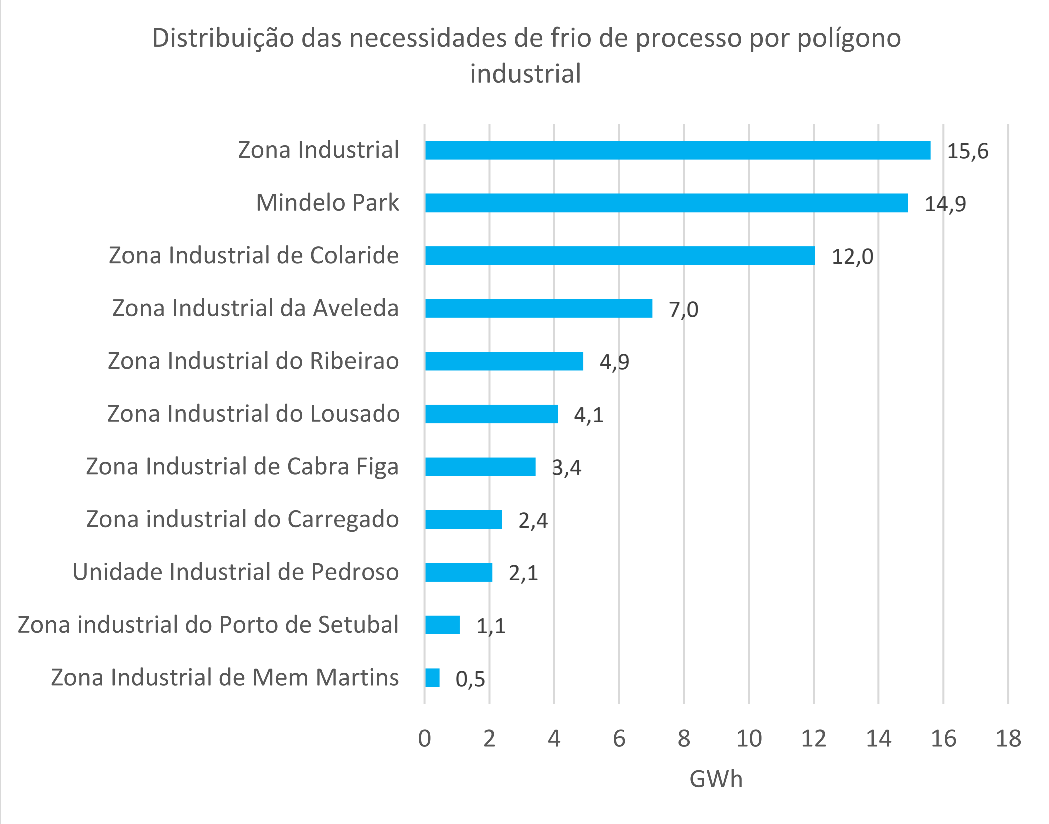


Figure 30- Distribution per municipality of process cooling needs at Intensive Energy Consumption Management System (SGCIE) plants

In the above figure, 'Industrial zone' means an unorganised cluster of facilities. The majority of cold needs are not located in industrial estates because they are services buildings located in cities (shopping centres, supermarkets, data centres).

4.1. Case studies

In accordance with the Renewable Energy Directive (Directive(EU) 2018/2001),

'Waste heat and cold': means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;

Waste heat can be recovered to meet the internal needs of an enterprise, or to directly meet heating needs, or to meet cooling needs by using absorption chillers. Waste heat can also be distributed via thermal grids to users in the residential or services sectors in the vicinity and/or used to generate energy, particularly in self-consumption mode, to replace electricity acquired from the grid. In hierarchical terms, the priority should be for the heat to be recovered at internal level, insofar as this is technically and economically viable, in accordance with the principle of energy efficiency.

If there is potential to establish a link between sources of waste heat and district heating and cooling grids, the following technical challenges may arise (Schmidt, 2020):

- Incompatibility in terms of timing

This refers to an incompatibility that may arise between the hourly/daily and/or seasonal availability of waste heat and the heating needs of the district heating and cooling grid, also known as intermittence.

- Incompatibility in terms of location

The district heating and cooling grid may not be geographically close to the waste heat source and/or may not have the necessary transmission capacity to absorb the waste heat. To be more specific, large-scale industries are often located outside urban settlements, which is where the majority of potential consumers will be located.

- Incompatibility in terms of quality

As the temperature level of waste heat sources is lower than the temperature level of district heating grids, it is impossible to supply the grid directly. In addition, some waste heat sources may be relatively small in volume and/or be in the form of steam, be based on radiation or convection and/or contain pollutants. Waste heat sources may also be intermittent, i.e. only operate at maximum load for a limited number of hours.

Generally speaking, waste heat can be classified as being conventional and non-conventional (Schmidt, 2020).

The first category includes industries with a high energy intensity, belonging to industry subsectors where waste heat is generally available, easy to identify and in a high temperature range. For these types of heat source, there is experience available on the recovery and use of waste heat available in many countries, with scope for improvements and the opportunity for the practice to become more widespread.

The second category of waste heat includes data centres, as well as HVAC systems in buildings (e.g. offices, hospitals, supermarkets, shopping centres).

i) Conventional sources of waste heat

In the following case studies, SGCIE facilities - either on their own or part of industrial estates - with process heating needs of more than 20 GWh/year were considered. In order to be included in the case studies, the facility with process heating needs must have potential 'clients' for the respective waste heat in the surrounding area. In the following case studies, the breakdown of waste heat according to temperature range was estimated using the methodology already set out in this report (see Waste heat in Portugal 2020 (DEIR Studies 005, 2021), Table 1). For reasons of anonymity, the identification details of the facilities were omitted.

Case study H.1

Figure 31- Intensive Energy Consumption Management System (SGCIE) plants in Pevidém Industrial Estate and potential waste heat consumers in vicinity

In the above figure, the 6 plants consume 88 GWh/year of process heat. In the surrounding area, which covers around 150 ha, there is a neighbourhood with a low population density. Two of these plants have 2 cogeneration plants fired by natural gas, which produce 27 GWh/year of heat.

Table 3- Waste heat from process at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha.yr)
Pevidém Industrial Estate	88	25.5	2 (natural gas)	150	**Residential:** 27 **Non-residential:** 69

The following figure displays an estimated waste heat distribution for a range of temperatures.

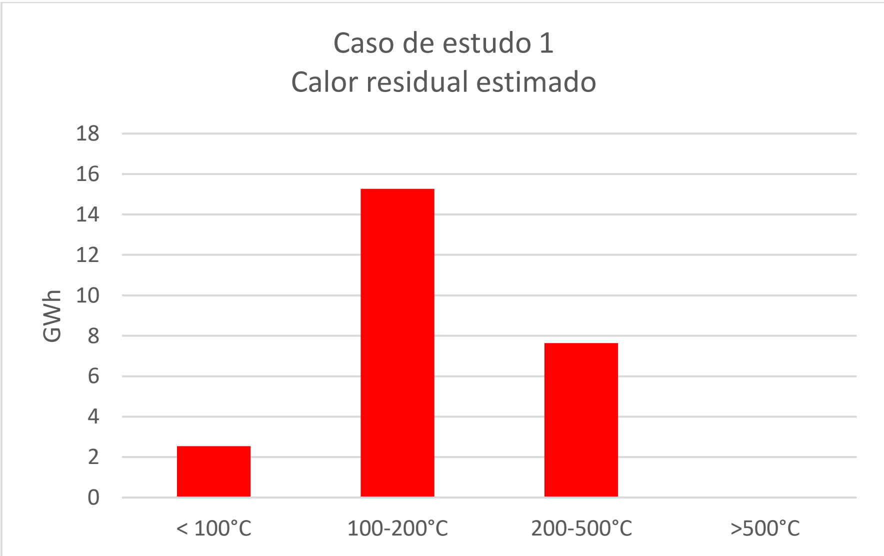
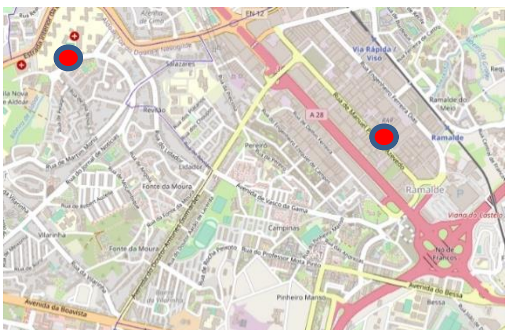


Figure 32- Estimated waste heat for case study 1

Case study H.2



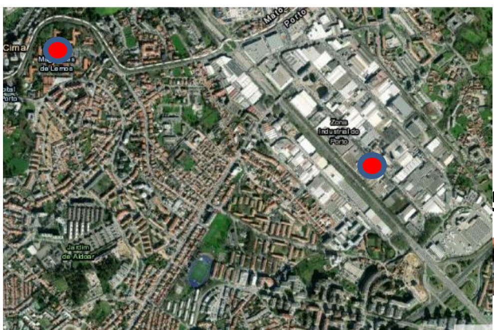


Figure 33-Intensive Energy Consumption Management System (SGCIE) plants in Porto Industrial Zone and potential waste heat consumers in vicinity

In the Porto Industrial Zone, there are two plants which consume 106 GWh/year of process heat. In the surrounding area, there are 3 hospitals (Hospital da Prelada, Hospital de Magalhães Lemos and Hospital Pedro Hispano), a university ((University of Porto-School of Management), a shopping centre (NorteShopping) and a neighbourhood with a high population density. These facilities are located in an area covering about 400 ha. One of them has a cogeneration unit in operation (natural gas) with an installed capacity of 5.4 MWe.

Table 4- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	**Process heat needs (GWh/year)**	**Estimated waste heat (GWh/year)**	**Cogeneration units available**	**Area (ha)**	**Average heating density MWh/(ha.yr)**
Porto Industrial Zone	106	10	5.4 MWe (natural gas)	400	**Residential:** 95 **Non-residential:** 114

The following figure displays an estimated waste heat distribution for a range of temperatures.

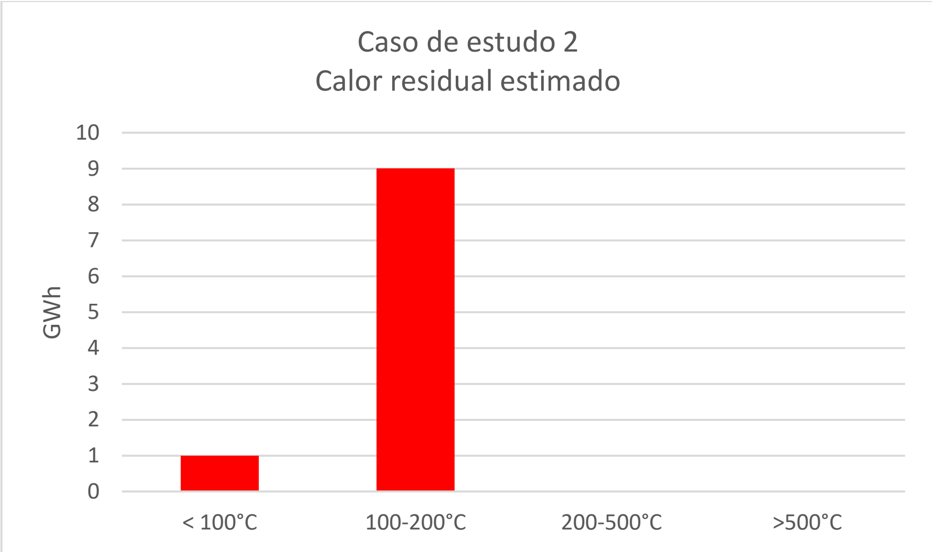


Figure 34- Estimated waste heat for case study 2

Case study H.3

Figure 35- Intensive Energy Consumption Management System (SGCIE) plants in Mem Martins Industrial Zone and potential waste heat consumers in vicinity

In the Mem Martins Industrial Zone, there are 4 plants which consume 19 GWh/year of process heat. In the surrounding area, there is a hospital, Hospital da CUF Mem-Martins, a shopping centre and a neighbourhood (São Carlos) with a high population density. These facilities are located in an area covering about 150 ha. None of these facilities has an operating cogeneration plant.

Table 5- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	**Process heat needs (GWh/year)**	**Estimated waste heat (GWh/year)**	**Cogeneration units available**	**Area (ha)**	**Average heating density MWh/(ha.yr)**
Mem Martins Industrial Zone	19	2.2	--	150	**Residential:** 125 **Non-residential:** 131

The following figure displays an estimated waste heat distribution for a range of temperatures.

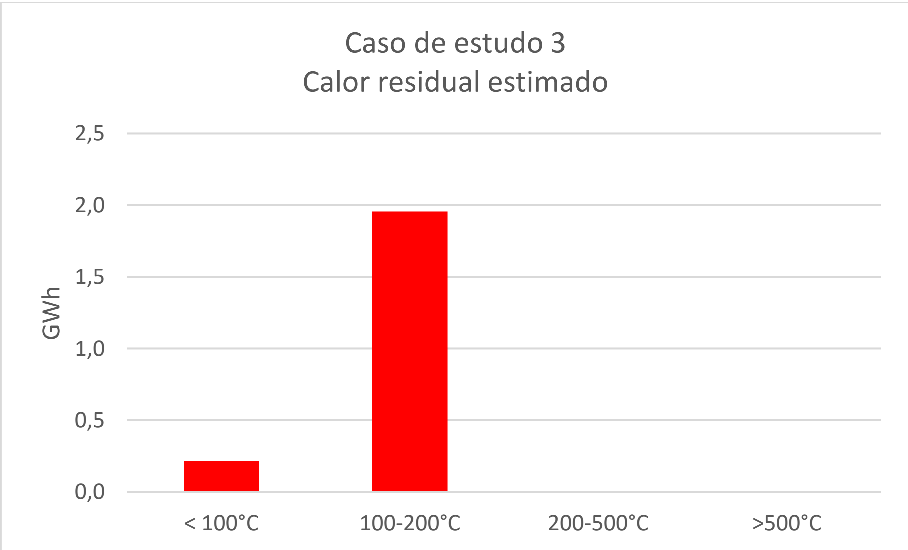


Figure 36- Estimated waste heat for case study 3

Case study H.4

Figure 37- Intensive Energy Consumption Management System (SGCIE) plants in Cabra Figa Industrial Zone and potential waste heat consumers in vicinity

In the Cabra Figa Industrial Zone, there are 4 plants which consume 34 GWh/year of process heat. In the surrounding area, there is a health centre, 3 neighbourhoods (Bairro da Tabaqueira, Cabra Figa and Varge Mondar) with medium/ low population density. These facilities are located in an area covering about 170 ha. None of these facilities has an operating cogeneration plant.

Table 6- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha.yr)
Cabra Figa Industrial Zone	34	4.0	--	170	**Residential:** 19 **Non-residential:** 48

The following figure displays an estimated waste heat distribution for a range of temperatures.

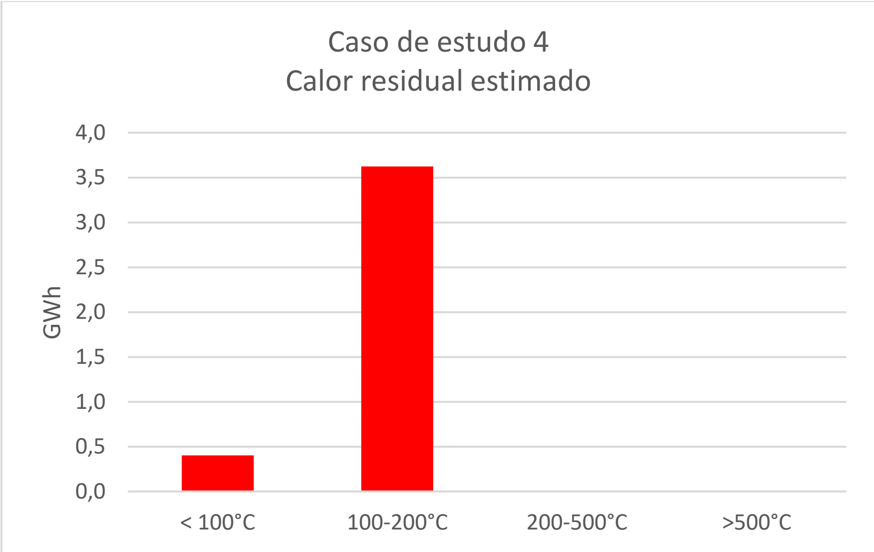


Figure 38- Estimated waste heat for case study

Case study H.5

Figure 39- Intensive Energy Consumption Management System (SGCIE) plants in Quimiparque Industrial Zone and potential waste heat consumers in vicinity

In the Quimiparque Industrial Zone, there are 4 plants which consume 368 GWh/year of process heat. In the surrounding area there is a neighbourhood with medium/high population density (Lavradio and Alto do Seixalinho). Two of these facilities have cogeneration units installed, one with an installed capacity of 24 MWe (natural gas). The installed capacity of the other one, which runs on natural gas/ biogas, was not available.

Table 7- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha.yr)
Quimiparque business park	368	33	**#1:** 24 MWe (natural gas) **#2:** capacity not disclosed (biogas)	450	**Residential:** 160 **Non-residential:** 39

The following figure displays an estimated waste heat distribution for a range of temperatures.

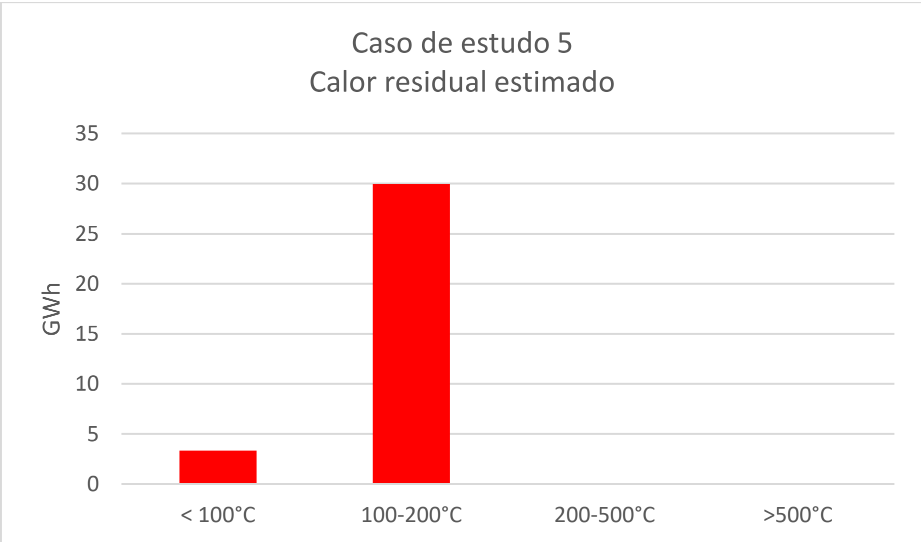
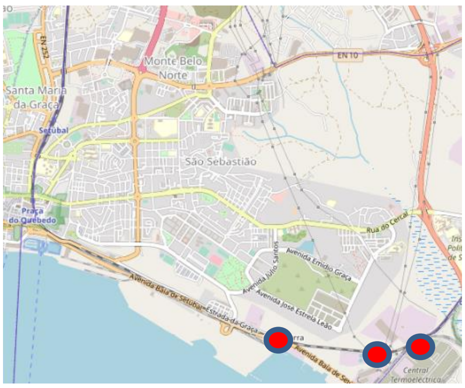


Figure 40- Estimated waste heat for case study 5

Case study H.6



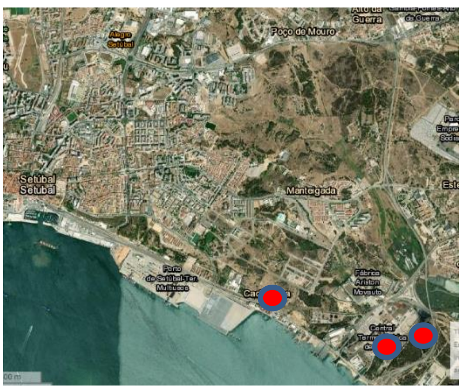


Figure 41- Intensive Energy Consumption Management System (SGCIE) plants in Porto Industrial Zone and potential waste heat consumers in vicinity

In the Setúbal Industrial Zone, there are 3 plants which consume 375 GWh/year of process heat. In the surrounding area there is a neighbourhood with medium/high population density (São Sebastião, in Setúbal) and a university (*Instituto Politécnico de Setúbal* and student halls of residence). One of these plants has a cogeneration unit with an installed capacity of 125 MWe. Another also has a cogeneration unit but its installed capacity is not known.

Table 8- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha/yr)
Setubal Port industrial zone	372	34	**#1** 12 MWe (biomass) **#2:** capacity not disclosed (biogas)	400	**Residential:** 180 **Non-residential:** 61

The following figure displays an estimated waste heat distribution for a range of temperatures.

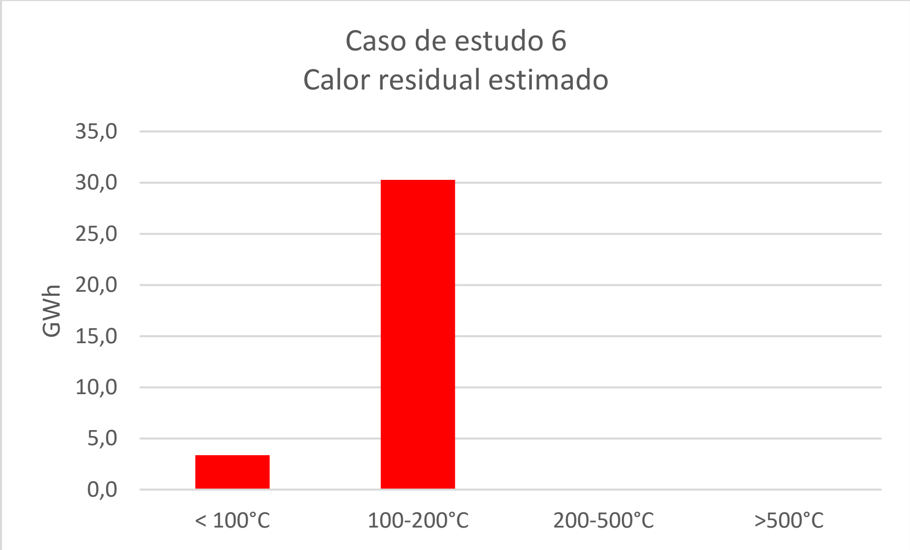


Figure 42- Estimated waste heat for case study 6

Case study H.7

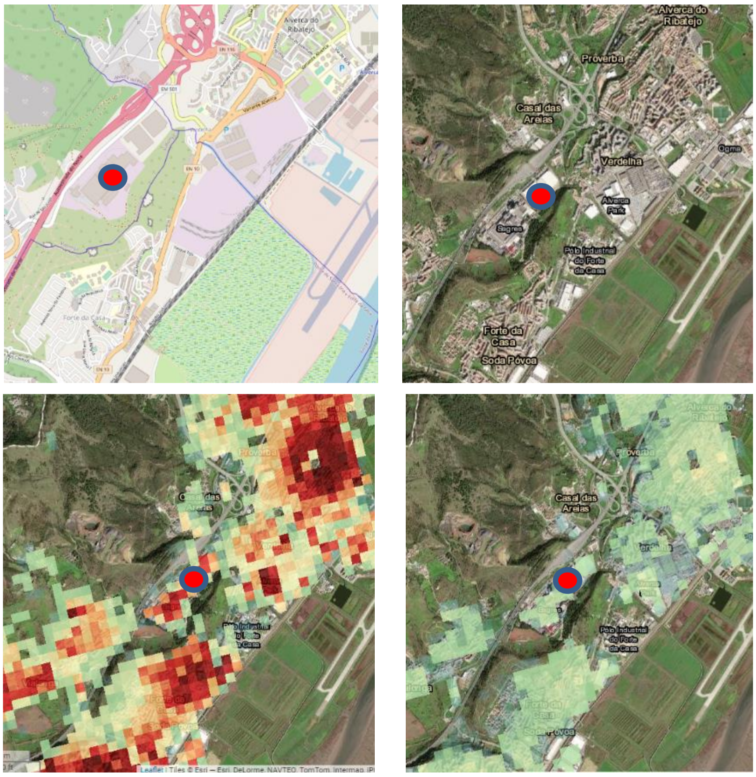


Figure 43- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity

The plant in the previous figure is not located in an industrial estate but it consumes 139 GWh/year of process heat. In the surrounding area, which covers some 450 ha, there is a neighbourhood with medium/high population density (Forte da Casa and Alverca do Ribatejo). This plant has a cogeneration unit with an installed capacity of 7.5 MWe.

Table 9- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha.yr)
--	139	19.4	7.5 MWe (natural gas)	450	**Residential:** 176 **Non-residential:** 81

The following figure displays an estimated waste heat distribution for a range of temperatures.

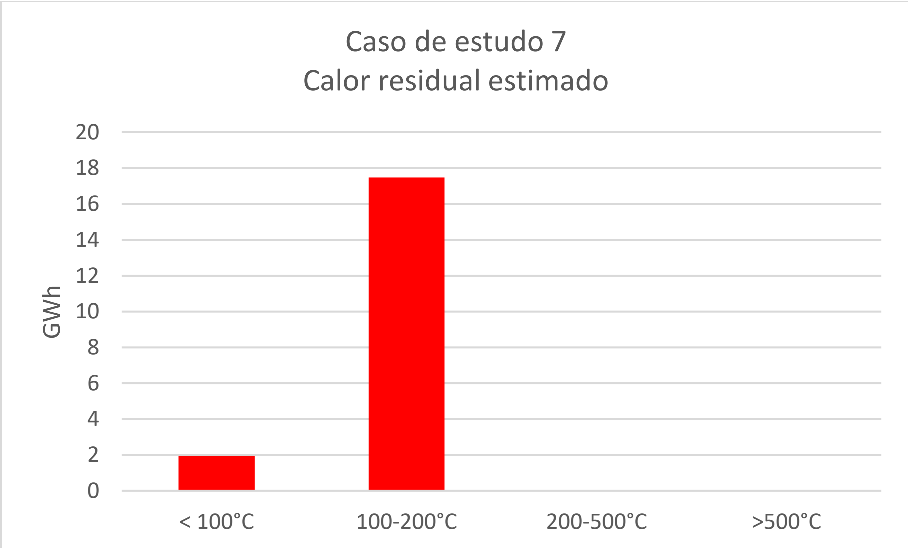


Figure 44- Estimated waste heat for case study 7

Case study H.8

Figure 45- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity

The plant in the previous figure is not located in an industrial estate but it consumes 15.8 GWh/year of process heat. In the surrounding area there are two neighbourhoods with medium/high population density (Forte da Casa and Santa Iria da Azoia). The plant does not have any cogeneration unit in operation.

Table 10- Waste heat from processes at Intensive Energy Consumption Management System (SGCIE) plant(s)

Industrial estate	Process heat needs (GWh/year)	Estimated waste heat (GWh/year)	Cogeneration units available	Area (ha)	Average heating density MWh/(ha/yr)
--	15.8	1.42	--	360	**Residential:** 127 **Non-residential:** 50

The following figure displays an estimated waste heat distribution for a range of temperatures.

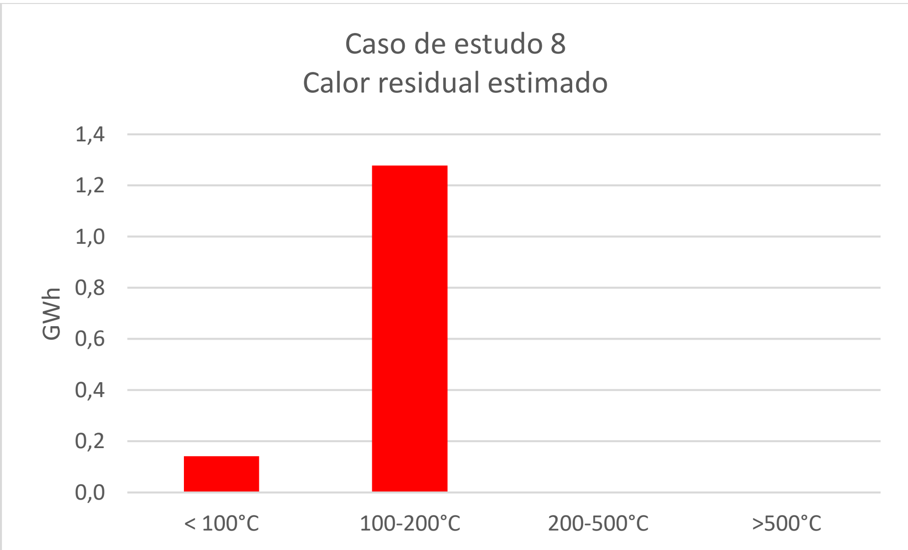
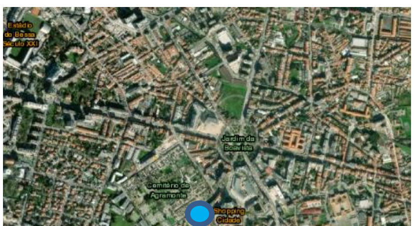


Figure 46- Estimated waste heat for case study 8

ii) Non-conventional sources of waste heat

Four SGCIE facilities (services buildings) with annual process cooling needs of over 20 GWh were identified. These facilities are located in settlements with a high population density. Two of them produce cold water using trigeneration units, supported by compression chillers. The other two produce cold water using compression chillers.

Case study C.1



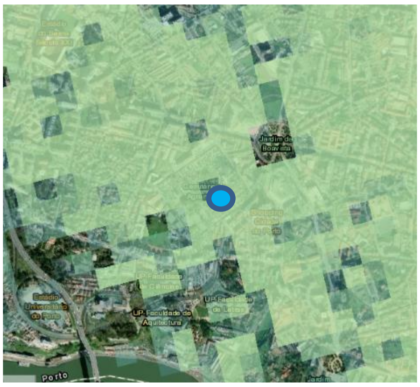


Figure 47- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity.

The plant indicated in the above figure consumes 39 GWh/year of cold water, which is produced by compression chillers with an installed capacity of 1.8 MWt. This facility is located in the vicinity of a university (Faculty of Arts, *Universidade do Porto*), a shopping centre (Shopping Cidade do Porto) and a neighbourhood (Bairro do Bom Sucesso and Cedofeita) with average heating density needs of 120 MWh/ha year.

Case study C.2

Figure 48- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity.

In the above figure, the two facilities consume 27 GWh/year of cold. One of these facilities produces cold water using a trigeneration unit supplemented by compression chiller units. In the vicinity of these facilities, covering an area of 70 ha, there are various services buildings (the Higher School of Technology and Management of Viseu, a senior citizens' home, *Hospital CUF Viseu* and *Centro Hospitalar Tondela-Viseu*), as well as a neighbourhood with average heating density needs of 140 MWh/ha per year.

Case study C.3

Figure 49- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity

In the above figure, one facility (services building) consumes 30 GWh/year of cold, produced in compression chiller units with an installed capacity of 9.2 MWt. The facility is located in the Lisbon district of Avenidas Novas, which has an area of less than 100 ha, a high population density and an average heating density of 370 MWh/ha.year. It is located in the vicinity of other services buildings, such as hotels and the Lisbon Prison.

Case study C.4

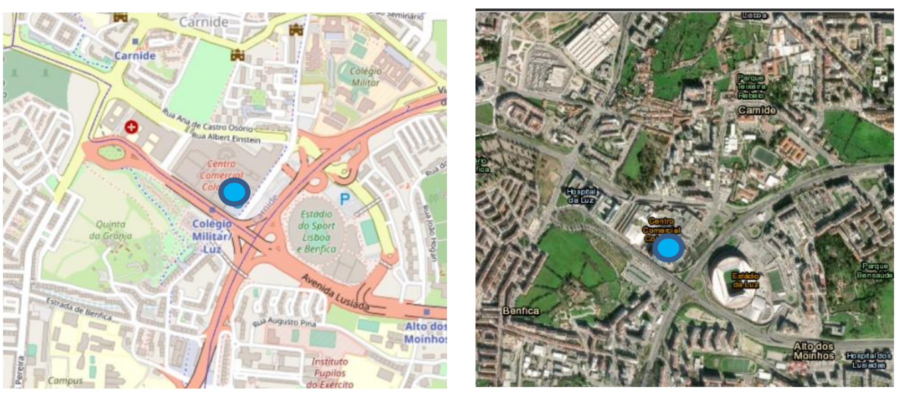


Figure 50- Intensive Energy Consumption Management System (SGCIE) plant and potential waste heat consumers in vicinity

In the above figure, one facility (services building) consumes 23 GWh/year of cold, which is produced using a trigeneration unit supplemented by compression chiller units. The facility is located in the Lisbon district of São Domingos de Benfica, which has an area of less than 120 ha, a high population density and an average heating density of 280 MWh/ha.year. It is located in the vicinity of other services buildings, such as the Hospital da Luz and the Military College.

5. Existing and planned district heating and cooling infrastructure

There is just one instance of district heating and cooling infrastructure in operation in Portugal, located in the Lisbon district of Parque das Nações. This infrastructure has been in operation since 1997 and it is equipped with a turbo-alternator set consisting of a TUMA Turbomach gas turbine and an ABB alternator with a rated electrical capacity of 4.7 MWe. The steam produced is used to run two double-effect absorption chillers with lithium bromide and the hot water is produced using two concentric tube heat exchangers and one plate exchanger. The thermal power plant also has four compression chillers and an auxiliary steam boiler with a rated thermal capacity of 15 MWt.

The thermal energy generated at the power plant is distributed to 150 buildings and 4 000 customers spread over an area of 330 hectares (average heating density of 174 MWh/ha per year), using a distribution grid measuring 21 km and consisting of four tubes for two primary water circuits (hot water and cold water). The main parts of the grid, i.e. the transmission tubes, are installed in technical vaults built of reinforced concrete. Despite the higher investment compared to a conventional solution, the technical gallery option is for the most part offset by the simplicity of access when the tubes need maintenance or repairs. The rest of the distribution grid is buried underground.

The energy transfer substations, which are located in the buildings that avail of this public service, are equipped with compact plate heat exchangers. These units act as the interface between the primary grid of the urban heating and cooling infrastructure and the secondary circuit for the customers' water. The number of exchangers depends on the thermal capacity installed at each delivery point. Some substations have three or more heat exchangers in the cold water circuit. As well as the exchangers, the substations also have systems to control the temperature and flow. They are also equipped with energy meters.

In 2017, this district heating and cooling infrastructure sold 65 GWh of cold water and 40 GWh of hot water. According to the Activities Report and Accounts of the operator of this district heating and cooling infrastructure for 2015, revenues amounted to EUR13 million, which corresponds to an average tariff of EUR124/MWh. A reference tariff of EUR90-95/MWh is applied to the electricity generated in the cogeneration unit, under the terms of Decree-Law 23/2010, which will cease to apply in February 2023. In addition, following the publication of the State Budget for 2021, a rising penalty will be applied to the petroleum tax (ISP) levied on natural gas consumed in cogeneration facilities, which will penalise cogeneration units supplied by fossil-fuel energy, such as the unit described above.

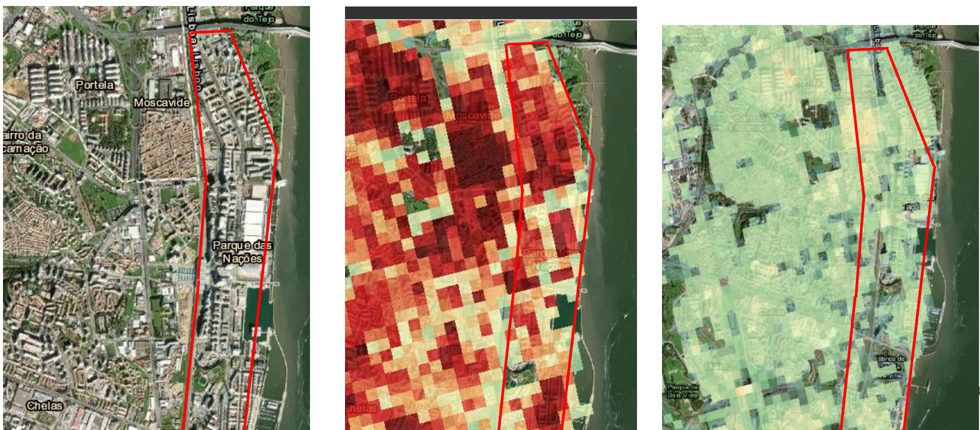


Figure 51- Overview of the area covered by the district heating and cooling infrastructure.

According to the operator of the district heating and cooling infrastructure, investments in the region of EUR 85 million have been made since the project was launched in 1997.

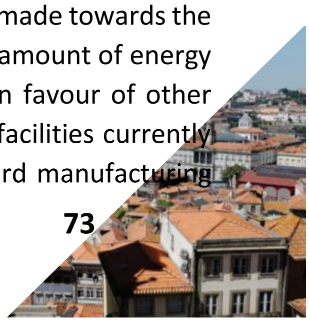
6. Conclusions

The bottom-up analysis carried out in this study was possible thanks to the database built over the years as a result of a rule that has been in force since 2008, whereby industrial facilities whose annual energy consumption is higher than 500 toe are obliged to carry out regular energy audits and implement measures intended to streamline the use of energy and monitor and regularly report on indicators proving how the efficiency of their facilities is evolving.

12 facilities or industrial estates with heating needs in the region of 20 GWh/year or more were identified. For the eight facilities with conventional waste heat sources it was possible to estimate that around 84% of the waste heat, corresponding to 108 GWh/year are in the temperature range of 100-200 ºC. However, none of those eight facilities are located in areas with average heating density needs of over 318 MWh/year, which is threshold for district heating and cooling infrastructure to be considered economically viable (District Heating and Cooling Potential in Portugal (DEIR Studies 003, 2021) page 23). Moreover, these facilities are located in areas where the residential stock is old and of a low standard of thermal quality. There are also additional barriers to the economic viability of district heating and cooling infrastructure, some of which have already been identified (District Heating and Cooling Potential in Portugal (DEIR Studies 003, 2021), page 40), such as the need for continued improvements in the internal use of waste heat, the low investment capacity, the lack of familiarity of facility managers with the value of waste heat, possible regulatory barriers and the perceived loss of control by facility managers over the heat generated for the facility and how that loss of control might affect the production process at the facility. One example of how evident these barriers are is when the same industrial estates are found to have two cogeneration units belonging to different facilities (case studies H.1, H-5 and H-6). However, they are also evident in the fact that a single industrial estate (case study H.3) has several facilities with process heat needs that could benefit from sharing a thermal generation plant, which could potentially be more efficient than using smaller decentralised thermal power plants. Therefore, once the internal improvements on using process heat have been exhausted, it would be advisable for facilities belonging to the same industrial estate to look for possible synergies with adjacent facilities. This could potentially be incentivised by regulatory frameworks, such as Decree-Law 162/2019 regulating Renewable Energy Communities.

Of the four facilities with non-conventional waste heat sources analysed in the case studies, two produce their cold water using compression chillers and the other two (which have trigeneration units installed) supplement the water production process with compression chillers. The temperature of the heat dissipated in the compression chillers will be lower than 70ºC, so if it is assumed that all of the energy efficiency measures have been implemented internally, any solution to use the waste heat from these facilities in district heating and cooling infrastructure would involve the use of heat pumps (for the heating station) and possibly absorption chillers (for the cooling station), given that absorption chillers typically require 65-80ºC for adsorption technology (Schmidt, 2020). Heat pumps can use waste heat sources at low temperatures (below 45ºC) in the district heating grid, minimising heat losses. Given that they work when renewable energy generation is high, these systems can also facilitate the integration of renewable energy in electricity distribution grids. The four facilities identified in these case studies on non-conventional sources of waste heat are located in urban areas with high population density. The average heating densities in case studies C.3 and C.4 are close to the 318 MWh/ha per year threshold used for the purposes of determining the economic viability of a district heating and cooling grid.

As the penetration of electrical energy from renewable sources increases and progress is made towards the decarbonisation targets set out in the National Energy and Climate Plan 2021-2030, the amount of energy generated in cogeneration facilities supplied by fossil energy is expected to change, in favour of other solutions using mostly gases of renewable origin. 44% of the energy for cogeneration facilities currently comes from biomass, although 98% of this consumption is in the pulp, paper and board manufacturing



sector. This share is expected to increase, particularly the share of renewable gases, which is negligible today.

Portugal has a mild climate, particularly on the West coast, where the sources of waste heat are located. Therefore any urban infrastructure intended to use waste heat in a district setting will have to take account not only of district heating but also cooling. This means that absorption chillers and/or compression chillers will possibly need to be installed, which will raise the cost of the investment, as well as meaning the infrastructure will be used for more of the year.

There is just one instance of district heating and cooling infrastructure in Portugal. Although it serves a neighbourhood with an average heating density that is lower than the threshold for economic viability, it was originally designed for the purpose of supplying cold water and hot water to a new set of buildings with distinctive thermal characteristics. This scenario is therefore not easily extrapolated to other areas of the country. The Alta de Lisboa new-build housing development in Lumiar district has an average heating density of 340 MWh/ha per year. Its zoning plan could have included a viability study for heating and cooling infrastructure. Although this neighbourhood does not have any nearby source of waste heat, the municipal zoning plan could have provided for buildings with potential waste heat sources, such as those mentioned in case studies C.3 and C.4. However, in future, as new thermal requirements applicable to buildings come into force as Directive (EU) 2018/844 on the energy performance of buildings (EPBD) is transposed, it is expected that new buildings will have nearly zero thermal needs for heating and cooling, which will reduce the viability of any possible heating and cooling infrastructure.

For this bottom-up approach to yield a more accurate image, the number of facilities included in the Intensive Energy Consumption Management System (SGCIE) will have to be increased. This is expected to happen as these rules are reviewed in future. A future edition of this report would also benefit from the geo-referencing of other potential sources of waste heat, such as cooling towers, evaporative condensers and cooling systems in cogeneration units, in accordance with Article 5 of Law 52/2018 on preventing and controlling Legionnaires' Disease.

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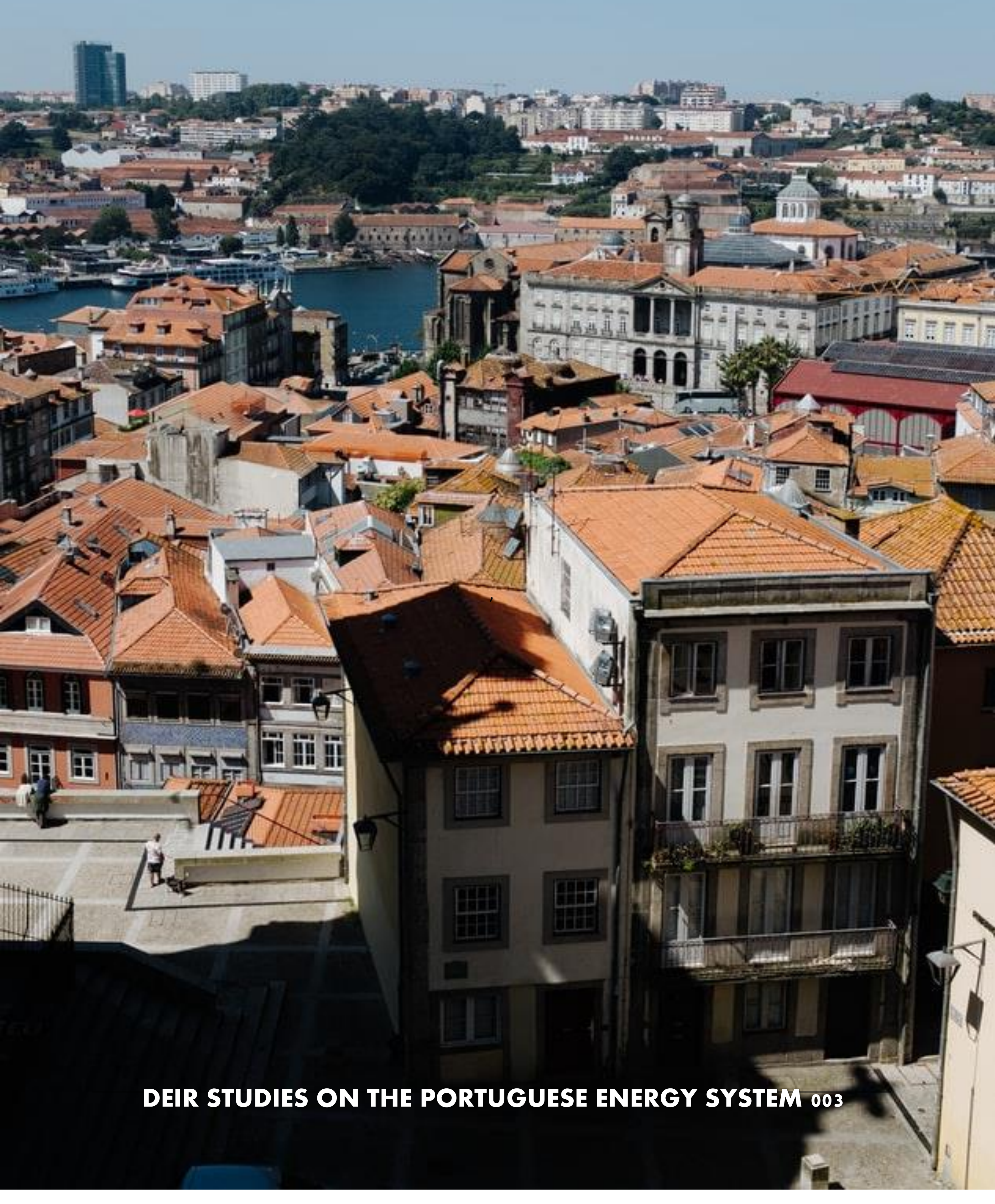
Assessment of District Heating and Cooling Potential in Portugal



DEIR STUDIES ON THE PORTUGUESE ENERGY SYSTEM 003

Date

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Index

Executive Summary

A new assessment was made of the potential of district heating and cooling systems in Portugal, taking advantage of GIS-based tools that very recently become available. Improving on previous studies, it was possible to account better for climate and building stock characteristics, to perform more exhaustive and detailed surveys of the territory, to obtain more accurate estimations of heat distribution costs – with large consequences for economic viability assessments – and to identify specific opportunities for using low-cost heat (viz. natural geothermal and waste heat).

Besides the practical interest for promoters and investors as well as for energy planning at municipality level, this work also contributes to the reporting obligations of Portugal under the Article 14(1) of the Directive 2012/27/EU, known as Energy Efficiency Directive.

Two scenarios were considered, a "full comfort" scenario where there the indoor temperature is maintained constantly in a comfort band, and a "socioeconomic" scenario that deals with comfort with more flexible strategies and it is considered more adherent to the economic and cultural reality of Portugal.

Preliminary identification of candidate areas for district heating and cooling was done using heating and cooling needs' maps, surveying the urban areas of the entire territory. Next, the delimitation of candidate areas was refined setting thresholds for the minimum energy demand to be satisfied by a district heating or cooling network. For the case of heating, an economic viability analysis was then performed, examining if the district heating grid distribution and transmission costs for the areas selected were within internationally accepted viability thresholds.

Using this approach, the potential for district heating and cooling in Portugal was found to be very low or close to null.

The major obstacles to the adoption of district heating and cooling were identified as a construction density too low at interior zones with more climatic extremes, and in contrast a mild climate at coastal zones with denser urban areas. Additional economic, sociocultural, and practical barriers were identified. It was concluded that, unlike for most other EU countries, for Portugal there is not a case for substantial energy efficiency savings through the adoption of district heating and cooling solutions. In this case the Energy Efficiency Directive does not require the country to adopt policies and measures to foster district heating and cooling.

Nevertheless, some opportunities for district heating were found for a few specific situations where nearby geothermal or industrial waste heat sources are available (Chaves, Amadora, Parque das Nações). Also, it was investigated, and seems possible although not strictly economically viable *per se*, to adopt district heating in historical and tourist neighbourhoods so as to reduce the impact in the urban landscape of intrusive heating and cooling solutions such as HVAC devices.

It is remarked that, although the best international wisdom available was applied in the study, technologies and its costs are constantly improving. It is likely that in the near future, some types of renewable heat sources can become a solution to power district heating and especially district cooling, making these options viable even under large energy distribution costs.

Plus, there is the perception that although conventional district heating and cooling may be a niche solution only, small scale networks could be a solution for many more situations, this fitting neatly with the new concepts of micro-grids and energy communities.

1. Introduction

This study is a new assessment of the potential of district heating and cooling systems (DHC) in mainland Portugal, relying heavily on GIS-based tools that very recently become available, namely the HoTMAPS Toolbox product of the Horizon 2020 Project "HoTMAPS", hereafter referred simply as "Toolbox".

The main objective of this Project (HoTMAPS, 2016) was the preparation of an open source heating and cooling mapping and planning toolbox, pre-loaded with default data for EU28 at national and local level. These targets users of these data and tool were public authorities (like DGEG) that seek to identify, analyse, model and map resources and solutions to supply energy needs within their territory of responsibility. The Project started in October 2016 and lasted four years, meaning that the final, validated toolbox, has only become available shortly before the time of writing.

The Toolbox was developed together with seven European pilot areas that have been successfully testing it, to develop their heating and cooling strategies: Aalborg (Denmark), Bistrita (Romania), Frankfurt (Germany), Geneva (Switzerland), Kerry County (Ireland), Milton Keynes (UK) and San Sebastián (Spain).

A typical screenshot of the Toolbox is provided in Figure *1*. It is described in detail at the publications of the Project (HoTMAPS, 2019), but hereafter a brief overview is provided.

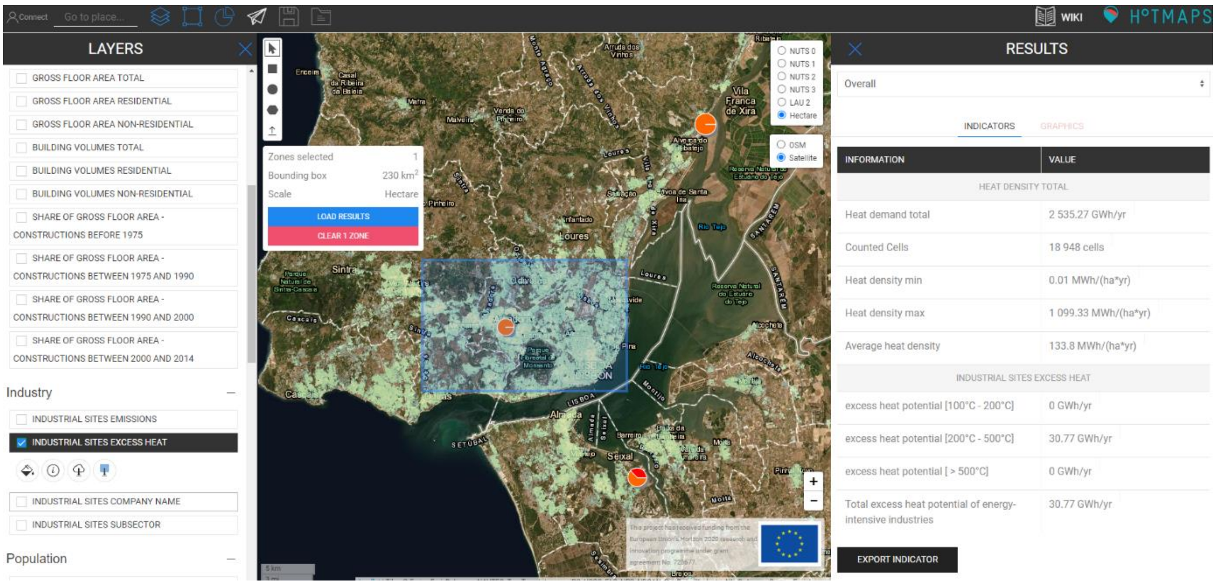


Figure 1 - Screenshot of the HoTMAPS toolbox in a typical situation of data analysis.

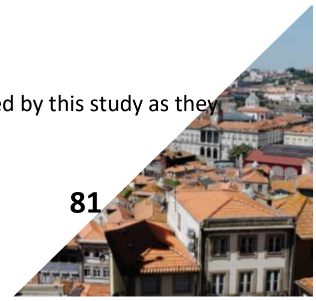
In practice the Toolbox is accessed via an online GIS (HoTMAPS, 2020). The GIS is loaded with data sets (layers) with resolution from NUTS 0 (country) to LAU 2 ("freguesia" in Portugal) and even down to hectare (1 ha = 0,01 km²). Default data is available for the entire EU28 and Switzerland. The information provided includes: building stock, including details of residential / non-residential, period of construction, floor areas and volumes; space heating, cooling and domestic hot water demand; climate context, including temperature, heating and cooling degree-days; main industrial sites; excess heat availability by temperature range for energy intensive industrial processes; data and potential of several renewable energy sources; hourly load profiles; and technical and economic characteristics of several technologies for heat production. Close analysis of the data revealed that some of the information is outdated: some industrial sites are by now deactivated, such as ammonia and steel fabrication facilities. Because the construction periods of the Toolbox – before 1975, 1975-1990, 1991-2000 and after 2000 – are not well aligned with the stages of Portuguese thermal regulations for buildings – 1990; 2006; 2013; 2020. Indeed post-2007 and especially post-2014 buildings are much more efficient than those built under previous regulations, which means that the data is very likely overestimated. However, it is remarked that the Toolbox has features that can compensate these problems, including allowing additions to the database, scaling of the heat demand, and energy savings factors. The values for appropriate scaling can be estimated with a calculation module of the Toolbox itself.

The Toolbox also contains a set of calculation modules: heat density; detection of district heating potential according to demand thresholds; economic assessment of district heating viability; demand projection; heat load profiles; excess heat transport potential; proposed layout of district heating transport and distribution networks, and district heating dispatch considering several cogeneration and renewable heat supply options. The calculation modules support numerous user-defined parameters, such as energy thresholds, energy prices, financial assumptions, trends, etc., that allow a sophisticated analysis of district heating (DH) technical and economic potential. The tools for district cooling (DH) are not so sophisticated, nevertheless very useful.

With this Toolbox the assessment of DHC potential can be perfected, in particular at the following aspects: performing more exhaustive and detailed surveys of the territory than before; estimation of DHC distribution costs, with consequences for economic viability assessments; identifying opportunities for using very low-cost heat (e.g. natural geothermal and waste heat).

It is expected that this work will be of practical interest for DHC promoters and investors as well as for energy planning at municipality level. This work is also conceived as a contribution to the reporting obligations of Portugal[2] under the Article 14(1) of the Directive 2012/27/EU, known as Energy Efficiency Directive (EED, 2012), amended in 2018 by Directive 2018/2002/EU, as part of the 'Clean energy for all Europeans package': contributions of this study are summarized at Annex I.

[2] Meaning mainland Portugal; the autonomous regions of Madeira Islands and Azores Islands are not covered by this study as they handle their own obligations with respect to EU Directives.

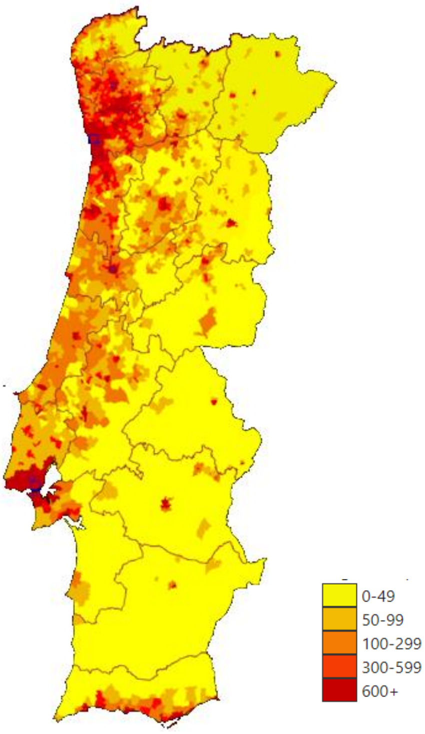


2. Data

2.1. Building stock

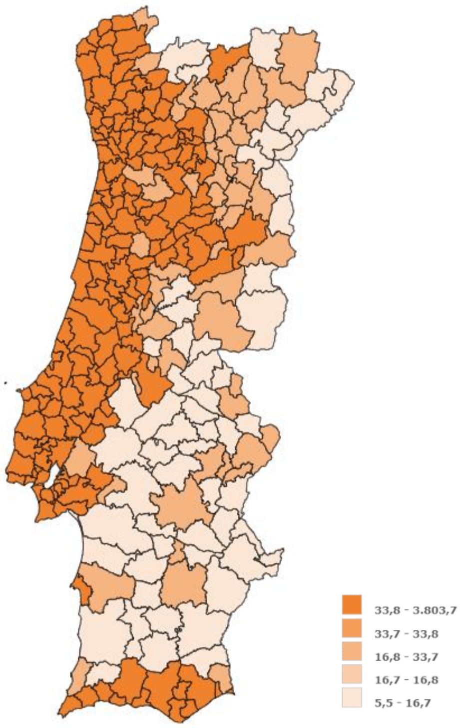
Hereafter we provide an overview of the features of the mainland Portugal building stock that are more relevant for the objectives of this study. As can be appreciated in Figure 2, the population distribution in is rather inhomogeneous (INE, 2012). It concentrates mostly along the western coast, roughly between latitudes 41.9 °N (border with Spain) to 38.5 °N (Setúbal region), and along the southern Coast, roughly between longitudes 8.7 °W and 7.5 °W (touristic zone of the Algarve region). There are major metropolitanean areas centered at the two largest cities, Lisbon and Porto. Then, apart from some middle size cities, the rest of the country has a low population density.

Naturally, the distribution of buildings displays a similar pattern, see Figure 3 for the case of residential buildings. Much more detailed data and analysis that support this point are provided by Statistics Portugal (INE, 2019).



Source: based on 2011 Census [5]

Figure 2 - Population density in Portugal, by LAU 2 (persons/km²).



Source: [6] based on 2011 Census [5]

Figure 3 – Residential buildings' density in Portugal, by municipality (dwellings/km²).

For assessing distrit heating and cooling (HC) potential, data at the municipality level or even LAU 2 level ("freguesia") is not enough, the spatial resolution must be higher. This is achieved in HoTMAPS via image processing of the territory. The Toolbox provides not only building floor areas but also building volumes, which is an even better type of input data to estimate HC needs. An example of these data is provided in

Figure 4 for the mid-size city of Évora. Data for residential and non-residential buildings is provided – this is a very important feature, since dwellings require mostly heating, whereas services buildings in general require much more cooling than heating.

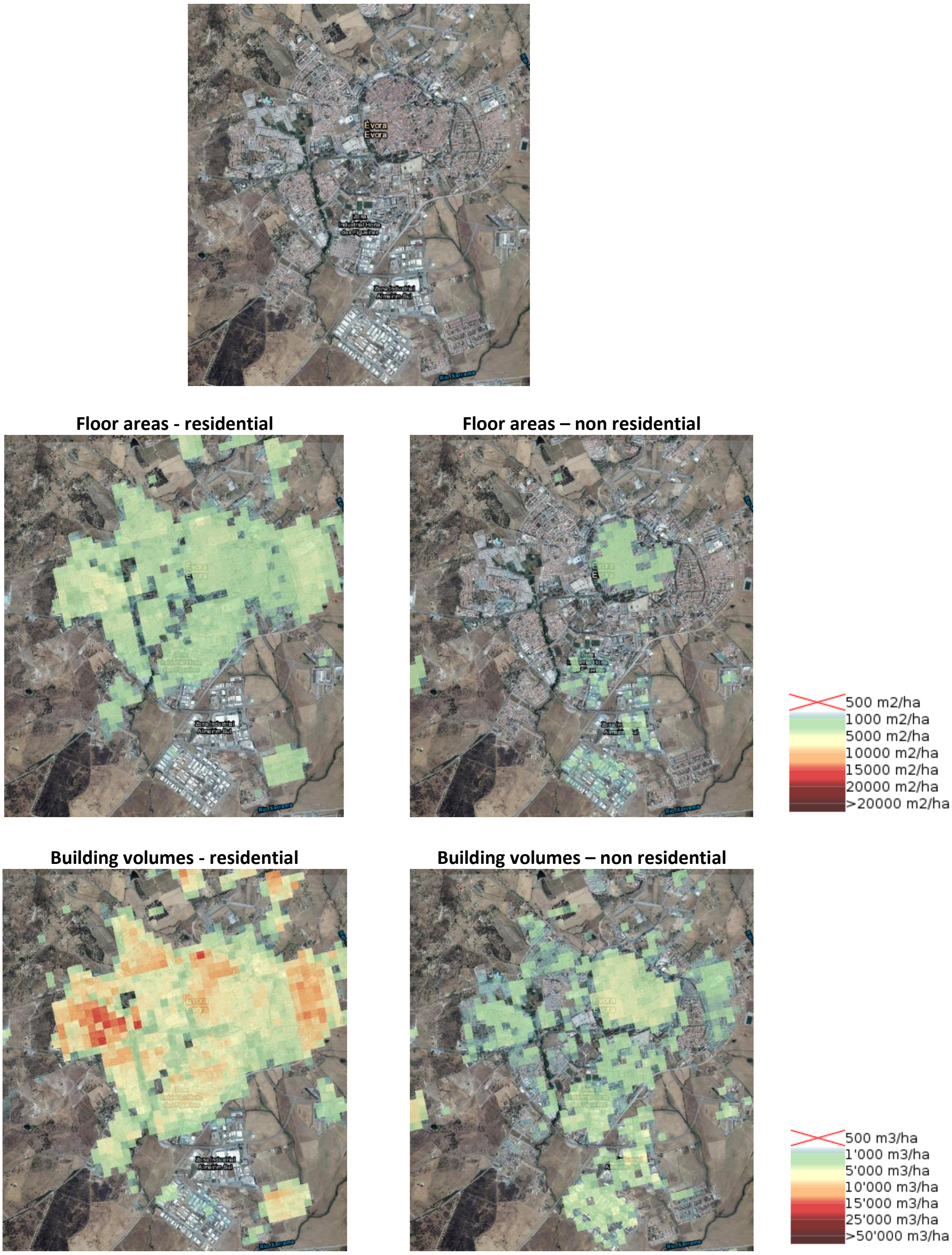


Figure 4 – Case study of assignment of building floor area and volumes, city of Évora.

The construction period is also provided, see Figure 6, again for the case of the city of Évora.

It can be appreciated that indeed a basically correct distinction is made between: older buildings at the historical core, built before 1975; a first spur of construction of new residences after 1975, bordering the historical nucleous, still with almost no thermal requirements; a second spur of construction of suburban dwellings up to 2000, further away from the centre,already under some requirements for insulation set by the 1990 building code; and a third expansion phase featuring new suburbs as well as large commercial and industrial buildings areas, built partially under the more strict 2006 building code, but even before that, already using better practices regarding thermal efficiency.

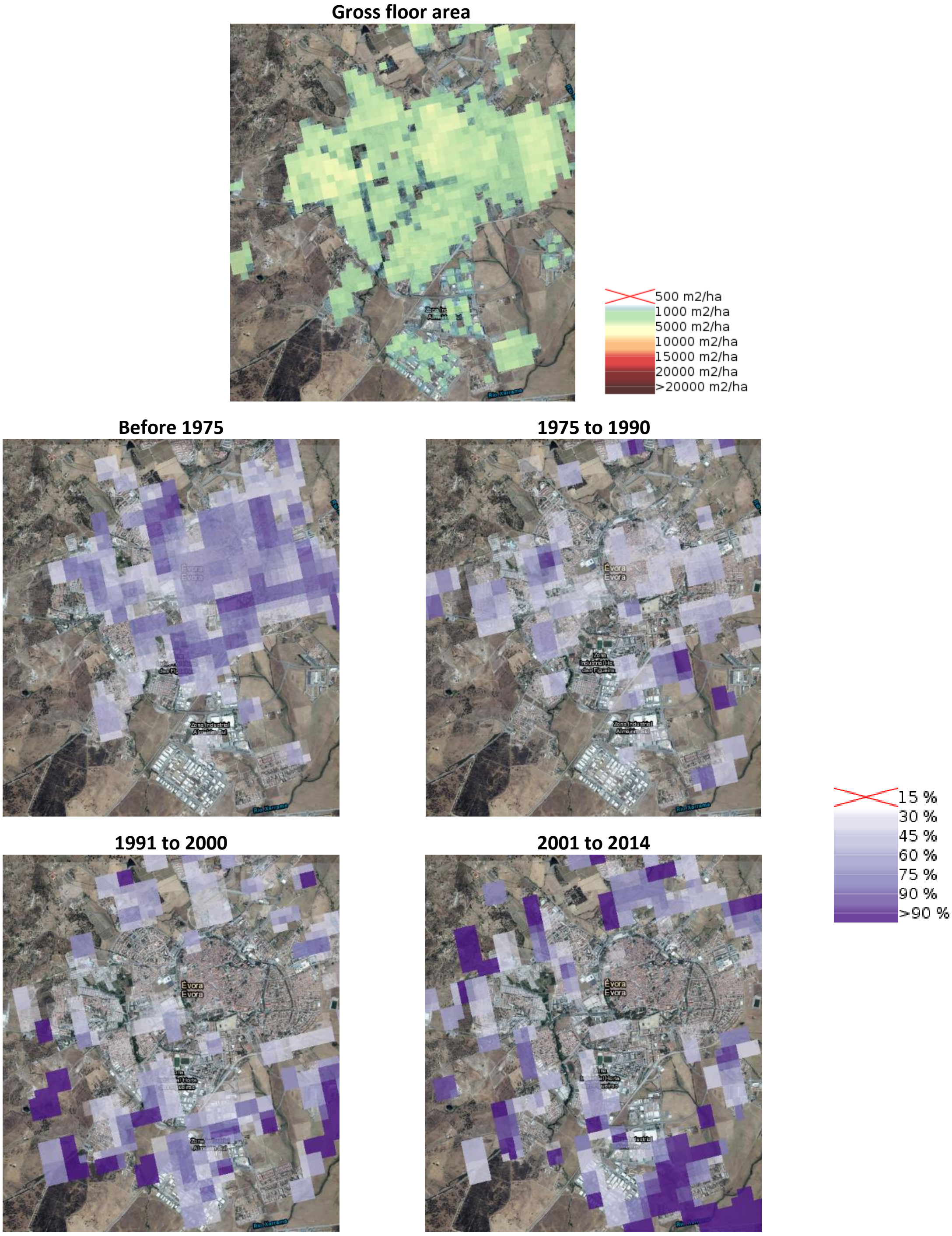


Figure 5 – Case study of assignment of shares of construction period to gross floor areas, city of Évora.

Regarding DH and DC potentials, it is especially important to analyse the most densely built areas. Figure 6 shows the estimated building volumes for these zones; for the especially interesting case of Lisbon metropolitan area, the data separated by residential and non-residential type can be analysed at Figure 7.

Lisbon Metropolitan area **Porto Metropolitan area**

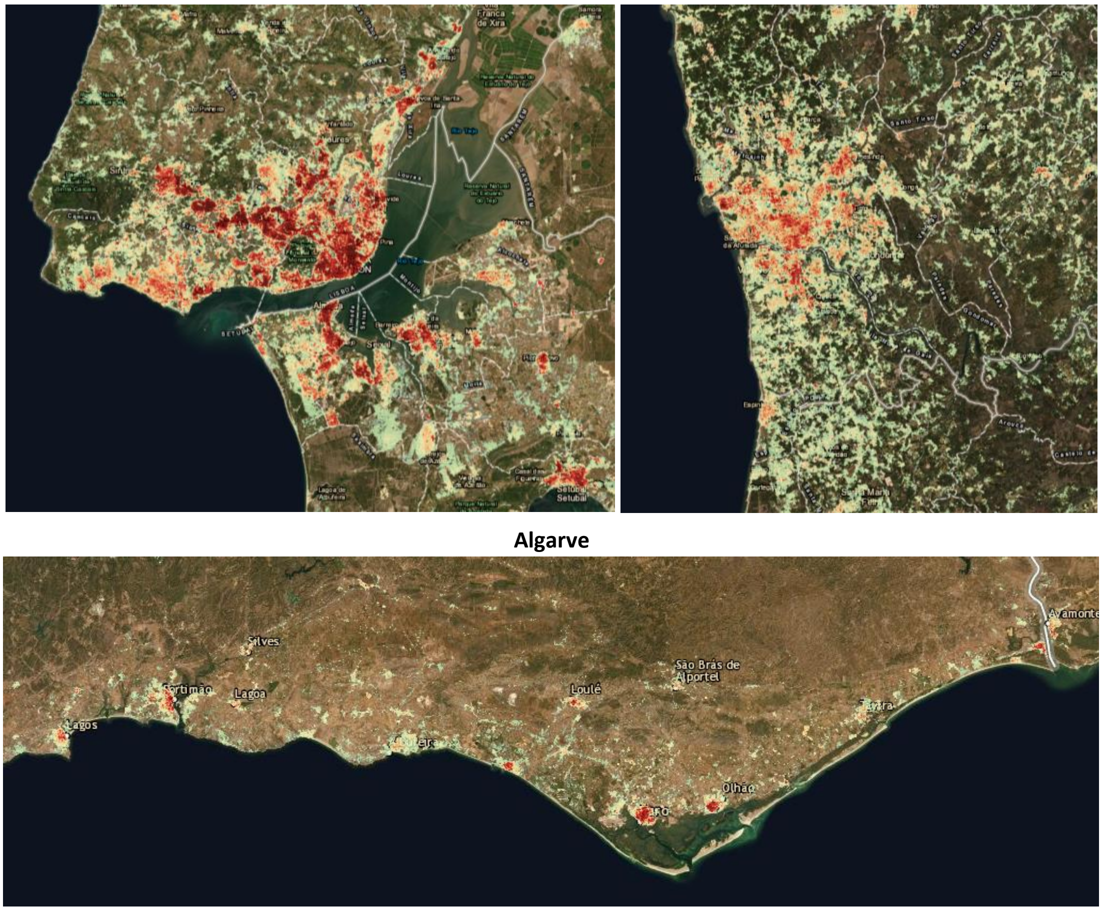


Figure 6 - Building volumes for the three zones with the highest density of construction.

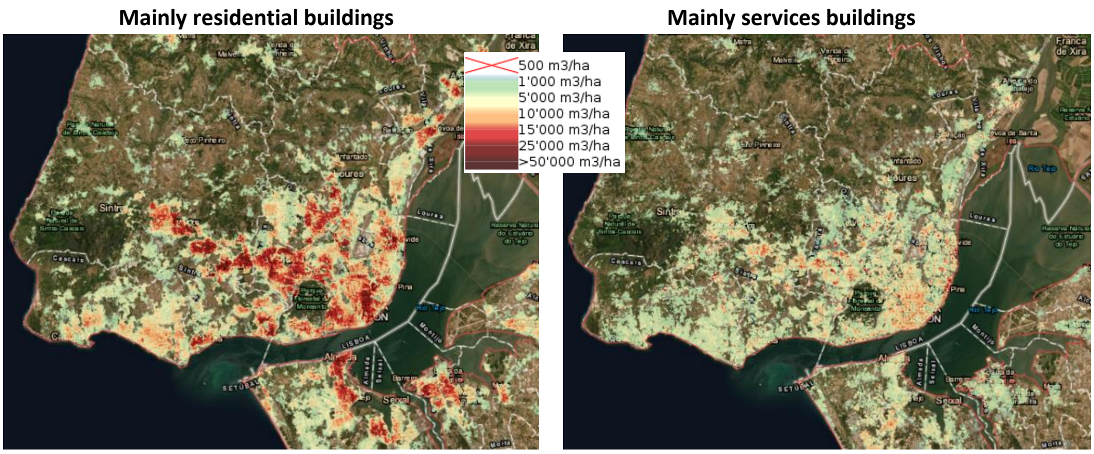


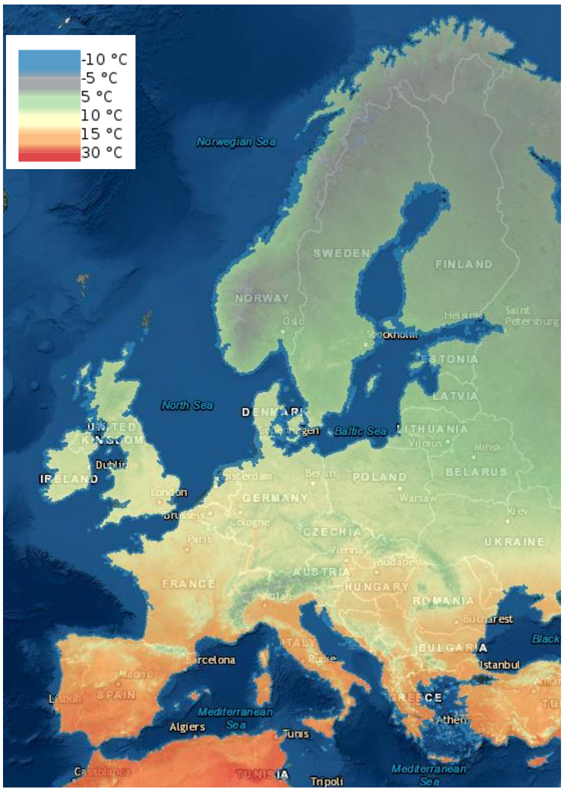
Figure 7 - Building volumes by type, Lisbon zone.

It is remarked that the last construction period provided ends in 2014, which is about when a new building code was published (SCE, 2013). Thus from 2014 up to now, new buildings have quite high energy efficiency standards; residences in particular require only occasional heating and almost no cooling, for the areas depicted.

As it will be discussed later on, a correction can be made for this effect, as well as for taking into account renovated and demolished buildings.

2.2. *Climate*

The climate of mainland Portugal is mild in comparison with average EU conditions. Figure 8 displays the average annual temperature, ranging from 10.9 °C to 21.9 °C. The mainland territorial average is 17.2 °C, the highest at mainland EU, at country level. It is especially remarkable that it displays less seasonal and geographical extremes than other countries, including neighbouring Spain as well as than countries considered to also have a Mediterranean climate, such as Italy and Greece. At country level, only the island states of Malta and Cyprus have higher average temperatures and lower extremes.



Source: HoTMAPS toolbox.

Figure 8 - Average annual temperature in Europe.

The yearly accumulated heating degreed days (HDD) and cooling degree days (CDD) are a proxy for heating and cooling needs of buildings. Further, they can be used for a statistically adequate computation of these needs in combination with the built volumes, periof of construction and type of building. The degree days data are depicted in Figure 9.

Heating **Cooling**

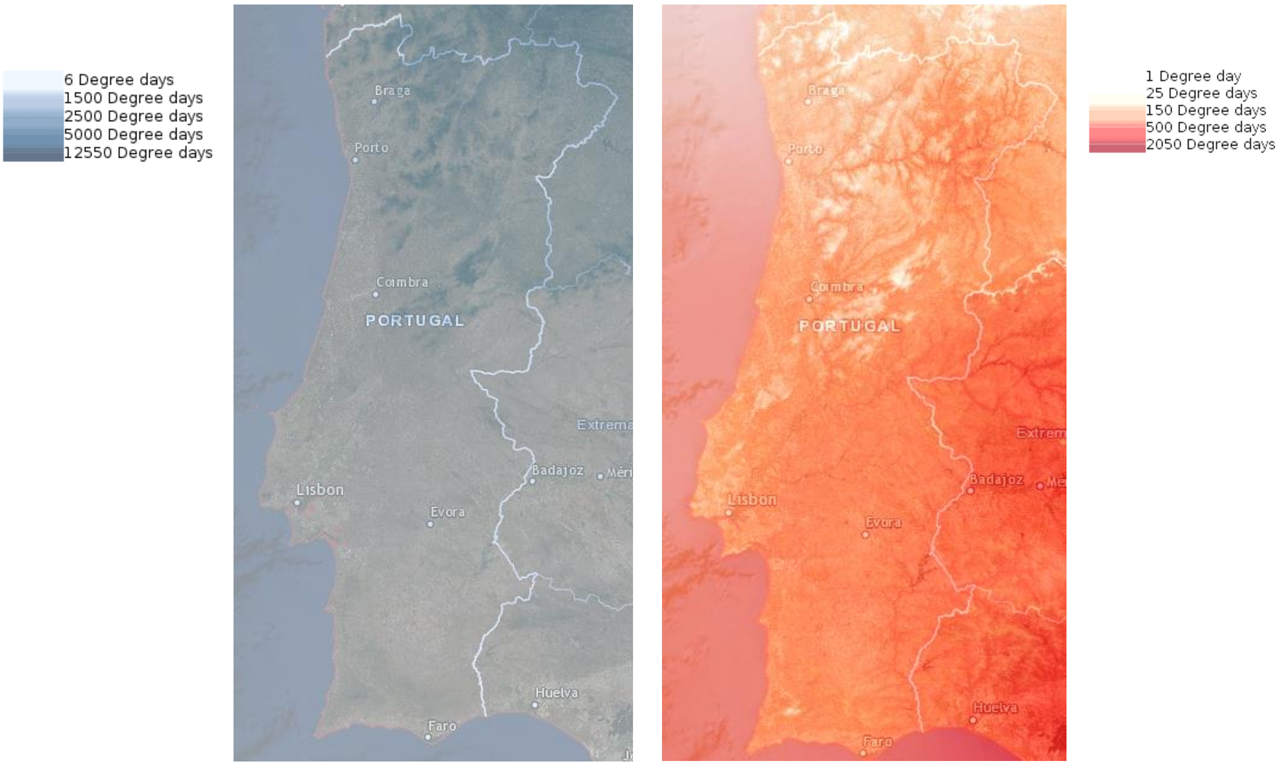


Figure 9 - Heating and cooling degree days.

The HDD range from 436 °C to 3413 °C, with an average of 1340 °C. Inspection of Figure 9 shows that the highest HDD relate to the mountainous zones of the interior centre and of the northwest, therefore those with a more continental climate.

Regarding cooling needs, the CDD range from 2 °C to 431 °C, with an average of 170 °C. The highest CDD appear mostly at southwest zones, especially those closer to the border with Spain. In a large part because of the mitigating effect of the ocean, the coastal zones of highest population and building densities have low CDD.

In summary, the climate is generally mild, and even more so at the coastal areas that have highest building density and thus relevance to a search for district heating and cooling potential.

2.3. Heating needs

Based on the previously discussed data, the HoTMAPS toolbox provides estimates of HC needs of the building stock, around 2014. Figure 10 shows some sample data for the city of Setúbal (ca. 90 000 inhabitants) and the surrounding industrial and commercial areas. It is confirmed that the various residential and non-residential areas in most cases are well identified at the data provided by the Toolbox. However, close analysis shows that the Toolbox often assigns heating and cooling needs to industrial buildings and wharehouses, which are in fact not climatized except maybe for small offices inside the facilities.

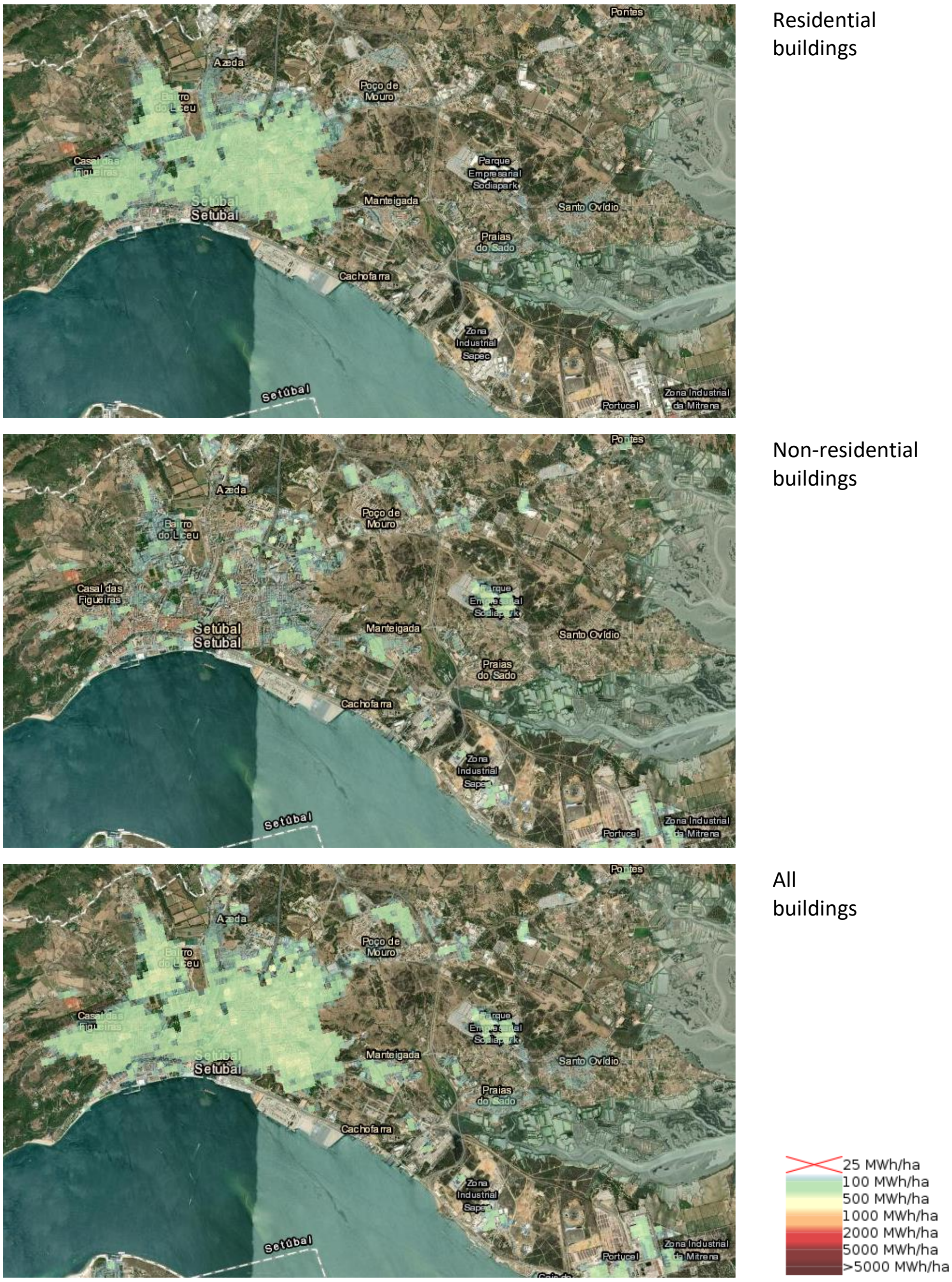


Figure 10 – Sample maps of heating needs - zone of Setúbal.

2.4. Cooling needs

Figure 11 shows cooling needs for the same area depicted in Figure 10. In this case there is only data available in the HoTMAPS toolbox for total cooling needs. Nonetheless, a detailed analysis of the images at hectare resolution revealed that there was a good identification of scattered services buildings with large cooling needs, as well as a good attribution of different levels of cooling needs to older and to more recent residential districts.

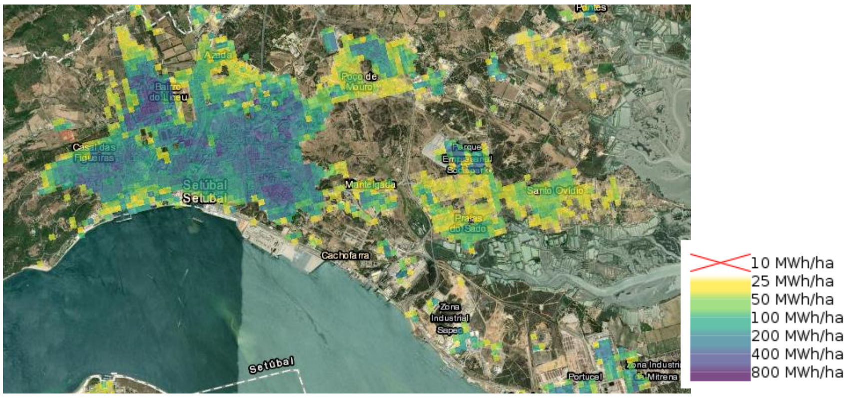


Figure 11 - Sample map of cooling needs - zone of Setúbal.

2.5. Projection of heating and cooling needs for 2021-2040

The HoTMAPS data is provided for 2014, therefore an adjustment should be made for the period of analysis of the DHC potential, 2021-2040. For heating needs, this can be performed using a calculation module of the Toolbox; unfortunately, not so for cooling needs, but a simplified methodology will be proposed.

Following a preliminary analysis of the heating needs' maps, the NUTS II area of Lisbon and Tagus Valley seemed the most promising for district heating, therefore it is presented as a case study. The heat needs map for this region is depicted in Figure 12.

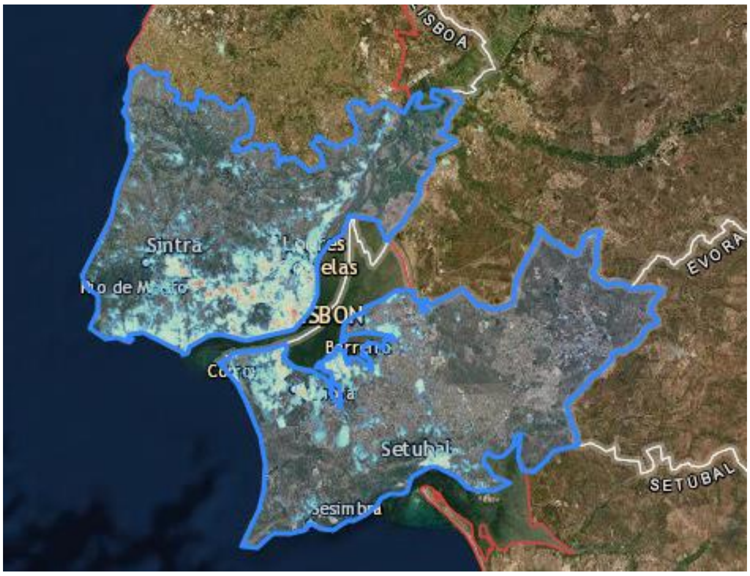


Figure 12 - Lisbon and Tagus Valley heating needs' map

The projection is performed by updating heating needs considering renovation rates and its impacts in thermal performance for each period of construction. The built area is also adjusted according to the evolution of population in the area. The Toolbox provides a reference scenario for all the required parameters.

However, it was considered that this reference scenario should be adjusted according to a set of new policies and measures expected to have significant impacts on the building stock:

- the Portuguese NECP (National Energy and Climate Plan 2021-2030) (NECP, 2020);
- the refreshed EPBD Directive (EPBD, 2018), that is just now being transposed to national legislation (SCE 2020), including the required national Long Term Building Renovation Strategy;
- the EU "Renovation Wave" strategy (EC, 2020).

In practice this means assuming higher renovation rates and larger decreases of specific energy needs than at the HoTMAPS reference scenario.

It is also remarked that the Portuguese population is projected to decrease in the following decades; however, statistics still show some inflow of rural population and minor towns to suburban areas, that partially counteracts this situation.

The quantitative assumptions made are listed in Table 1.

Table 1 - Assumptions for projecting heating and cooling needs.

Renovation rate:	
all renovations	2%
only those renovations with impact on thermal performance	1%
Reduction of floor area compared to reference scenario:	
construction period before 1975	110%
construction period 1975-1990	105%
construction period after 1990	100%
Reduction of specific energy needs compared to reference scenario:	
construction period before 1975	125%
construction period 1975-1990	115%
construction period after 1990	105%
Annual population change:	
in mainland Portugal	-0.3% per year
in LVT	-0.1% per year

The projection obtained are provided in Table 2. Although the exercise was carried up to 2040, the results are presented for 2030 i.e., giving around average values for the period of interest 2021-2040. In essence, the projection points out to a 5.7% reduction of heating needs in the area surveyed. Similar exercises for the other NUTS II regions, but with population reduction 0.2% per year, yielded the values reported in Table 3.

Table 2 - Projection of heating needs 2014-2030

Population		
2000	2,63	M
2005	2,74	M
2010	2,81	M
2015	2,81	M
2030	2,75	M
Heated Area		
2014	153,1	Mm²
2030	152,2	Mm²
Heated area per capita		
2015	54,4	m²/capita
2030	55,3	m²/capita
Energy Consumption		
2014	5 613	GWh
2030	5 262	GWh
Specific Energy Consumption		
2014	36,7	kWh/m²
2030	34,6	kWh/m²
Estimated area per construction period in 2014		
until 1975	87,0	Mm²
1976-1990	27,3	Mm²
1991-2014	38,8	Mm²
Non-renovated estimated area per construction period in 2030		
until 1975	80,2	Mm²
1976-1990	25,8	Mm²
1991-2014	37,0	Mm²
Estimated area built after 2014		
2015-2030	9,2	Mm²
Estimated energy needs per construction period in 2014		
until 1975	3597,6	GWh
1976-1990	939,2	GWh
1990-2014	1076,3	GWh
Estimated energy needs per construction period in 2030		
until 1975	3143,3	GWh
1976-1990	838,0	GWh
1990-2014	1000,0	GWh
2015-2030	280,8	GWh
Estimated specific energy needs per construction period in 2014		
until 1975	41	kWh/m²
1976-1990	34	kWh/m²
1990-2014	28	kWh/m²
Estimated specific energy needs per construction period in 2030		
until 1975	39	kWh/m²
1976-1990	32	kWh/m²
1990-2014	27	kWh/m²
2015-2030	30	kWh/m²

Table 3 - Relative reduction in heating needs from 2014 to 2021-2040.

NUTS II	Δ
North	-7%
Centre	-6%
Lisbon and Tagus Valley	-6%
Alentejo	-7%
Algarve	-7%

A conservative value of -6% can thus be used. This estimate will be used to adjust heating needs’ density and thresholds in the following sections. As mentioned before, for cooling needs the Toolbox does not provide a similar calculation module, so the same -6% value will be assumed.

3. Methodology

3.1. Scenarios

The logic underlying the HoTMAPS project in general, and the Toolbox in particular, is that HC demand nearly matches HC needs; or stating it in another way, that occupants of residential and services buildings enjoy and pay for comfort, with the exception of people stricken by energy poverty. This we will call the "Full Comfort" scenario (hereafter, FC), which indeed corresponds to the situation at many parts of mainland EU, under temperate cold continental climates.

However, anyone acquainted with Portuguese living will readily recognize that it is not a realistic scenario for the country. During the heating season the indoor temperatures at residences are often below 18 °C, and during the cooling season, above 25 °C. Therefore, a second scenario will be defined, to be called the "Socioeconomic" scenario (hereafter, SE).

It is tempting to attribute the lack of high comfort standards to energy poverty[3] but the reality is much more complex. It is difficult to distinguish an inability to keep comfortable indoors due to economic reasons from a widespread cultural habit to occasionally endure indoor temperatures much lower or much higher than usually accepted comfort temperatures.

Let us consider first that at the coastal zones where the highest urban concentrations are located, the weather may be cold on occasions but is seldom life-threatening. Return periods for snow are larger than 30 years. Cold waves are usually of short duration and interspersed with sunny weather days or rainy periods that also bring about higher air temperatures due to release of latent heat. In this context, the Portuguese in general do not feel that the continuous use of heating devices is necessary. Rather than paying for heat, they typically use more clothing and intermittent heating at limited zones, such as the living room. At zones away from the littoral that endure more climatic extremes, these strategies cannot be used as easily.

Regarding cooling of residences, also the use of active cooling devices (like domestic HVAC) is not usual, although it is becoming more frequent. In most cases the cultural habit is to use ventilation (seeking significant indoor air speeds), shading devices, less clothing, and drink cold beverages.

These observations are supported by the results of cost-optimal studies (DGEG, 2019a, 2019b) required by the EPBD Directive. They suggest that at the coastal zones, in most cases it is possible to achieve comfort status more than 90% of the time using the strategies discussed above, considering an adaptive thermal comfort algorithm instead of a fixed thermal comfort band criterium.

However, if cheap heat or cool could be available through DHC, it is very likely that people would be willing to pay for more comfort. Therefore, the SE scenario must not be a "business-as-usual" scenario: it should allow for significantly higher indoor comfort than enjoyed nowadays.

Finally, it should be considered that heating needs data are likely to overestimate actual heating needs because there is a significant proportion of unoccupied or only seasonally occupied buildings, like second homes used or rented for vacations, especially in coastal touristic locations, such as – but not only – at Algarve. This also can be accounted in the SE scenario.

For services buildings, the situation is different from residential buildings. Due to due to large internal gains they typically require more cooling than heating. Most are equipped with HVAC that is used to control the

[3] An official definition of energy poverty for Portugal has not yet been published at the time of writing.

indoor temperature. Even so, the cultural habit is to allow some seasonal change in the indoor temperature band and compensate with clothing.

Adjustment factors for HC demand relative to the HC needs provided by the Toolbox, are listed in Table 4 to Table 7. These are to be applied weighting by the residential and non-residential gross floor areas.

Table 4 – Residential heating demand reduction relative to nominal heating needs at the SE scenario.

NUTS II	Coastal band	Interior
North	-25%	-20%
Center	-30%	-20%
Lisbon and Tagus Valley	-35%	-20%
Alentejo	-40%	-20%
Algarve	-45%	-20%

Table 5 – Non-residential heating demand reduction relative to nominal heating needs at the SE scenario.

NUTS II	Coastal band	Interior
North	-10%	-10%
Center	-15%	-10%
Lisbon and Tagus Valley	-20%	-10%
Alentejo	-25%	-10%
Algarve	-30%	-10%

Table 6 – Residential cooling demand reduction relative to nominal cooling needs at the SE scenario.

NUTS II	Coastal band	Interior
North	-40%	-25%
Center	-35%	-25%
Lisbon and Tagus Valley	-30%	-25%
Alentejo	-25%	-25%
Algarve	-20%	-25%

Table 7- Non-residential cooling demand reduction relative to nominal cooling needs at the SE scenario.

NUTS II	Coastal band	Interior
North	-30%	-15%
Center	-25%	-15%
Lisbon and Tagus Valley	-20%	-15%
Alentejo	-15%	-15%
Algarve	-10%	-15%

In summary, we will assess DHC potential using two scenarios, FC that corresponds to a theoretical or desirable comfort standard, and SE that corresponds to a more realistic socioeconomic and cultural practice.

3.2. Assessment steps

This study will now progress through successively more complex assessment phases, as follows.

In a first phase, preliminary identification of candidate areas for DH will be done using energy needs' maps and thresholds for energy needs' density. The data will be scaled considering the demand projections and the SE scenario adjustment factors. The whole territory will be surveyed in this phase.

In a second phase, the delimitation of candidate areas will be refined using a Toolbox calculation module and adequate thresholds for the minimum energy demand to be satisfied by a DHC network. This assessment identifies coherent areas only, meaning that it seeks to find continuous areas, i.e. districts, and discards isolated buildings.

In a third phase, an economic viability analysis will be done, by examining if the DH grid distribution and transmission costs for the candidate areas stand below internationally accepted economic viability thresholds (in €/MWh supplied).

In a fourth phase, and even for areas that failed to pass the test at the previous phase, it is examined if they could benefit from very low energy supply costs using eventual nearby sources of geothermal or waste heat, so that DH could be make viable after all.

A final phase examines some cases of non-economically viable situations where, nevertheless, it can make sense to install a DHC system, such as historical and tourist neighbourhoods.

For DC, it is only possible to carry out the first phase described, as the Toolbox does not contain tools as sophisticated as for DH. Nevertheless, a parallel with DH can be used to obtain valuable conclusions.

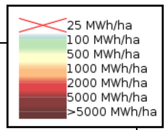
4. Analysis of District Heating Potential

4.1. Heating needs' density thresholds

An exhaustive search for candidate areas for DH will now be performed. The assessment requires a threshold for energy needs' spatial density, below which DH is not considered viable. Typical density values for successful existing DH are above 400 MWh/ha per year, but in principle it is possible to install DH in areas with lower demand. For continental Europe, Project STRATEGO (2016) proposes a value of 100 TJ/km², i.e., about 278 MWh/ha; while Project HoTMAPS (2016) proposes 333 MWh/ha per year. We will use an intermediate value of 300 MWh/ha adjusted for demand reduction projections (see Table 3), thus 318 MWh/ha.

4.2. Survey of candidate areas for district heating

A preliminary survey has shown very low heat and cool demand density at low density towns and villages, as expected considering the mild climate of Portugal. Hereafter, cf. Figure 13, we provide a systematic survey of heating needs' maps for the main urban centres, from mid-size cities to large metropolitan areas, examining the zones of highest building density and/or with the largest heat demand. The objective would be to identify candidate areas for DH zones with heating requirements larger than 318 MWh/ha per year. However, as later a more sophisticated method will be used, all zones 20% below this level, viz. 254 MWh/ha was also considered to select candidate areas for DH, however this ended up having no practical impact.



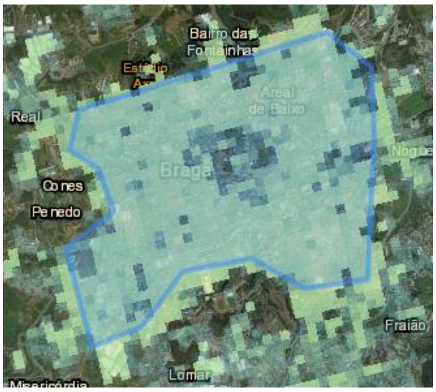
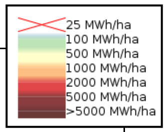
Braga	Viana do Castelo
 TC: 147 MWh/ha per year SE: 115 MWh/ha per year	 TC: 127 MWh/ha per year SE: 99 MWh/ha per year

Figure 13 - Systematic preliminary survey of candidate areas for district heating.



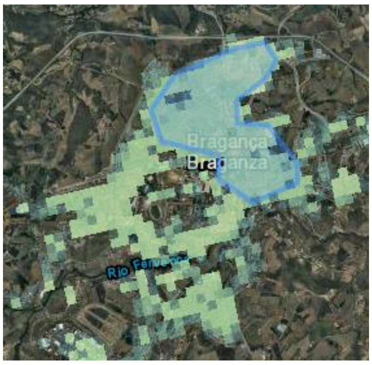
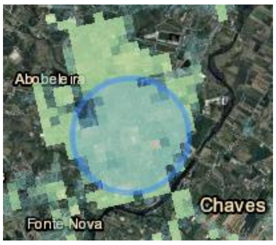
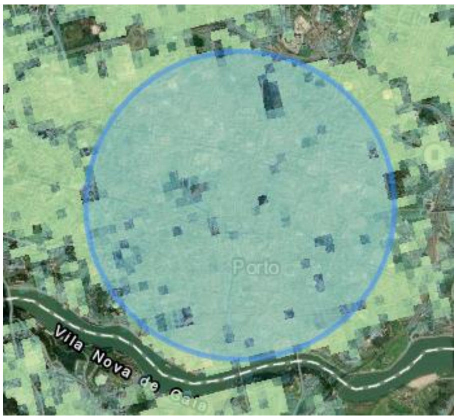
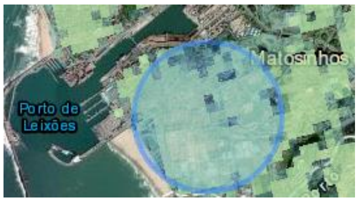
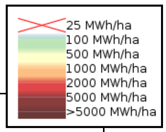
Bragança  TC: 171 MWh/ha per year SE: 140 MWh/ha per year	Chaves  TC: 173 MWh/ha per year SE: 142 MWh/ha per year
Porto – historical centre  TC: 144 MWh/ha per year SE: 112 MWh/ha per year	Matosinhos  TC: 152 MWh/ha per year SE: 119 MWh/ha per year
Vila Real  TC: 158 MWh/ha per year SE: 130 MWh/ha per year	Aveiro  TC: 116 MWh/ha per year SE: 85 MWh/ha per year

Figure 13 (continued) - Systematic preliminary survey of urban areas for district heating potential.

Viseu	Guarda



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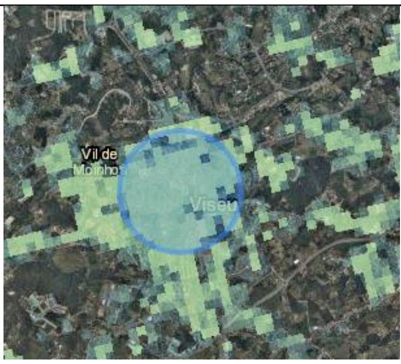
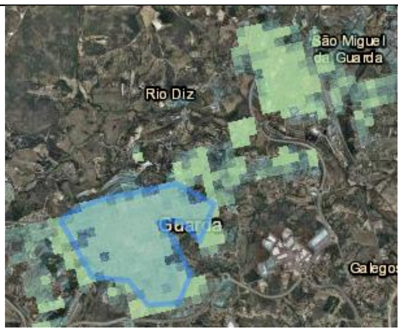
<tr><td>
TC: 126 MWh/ha per year
SE: 103 MWh/ha per year</td><td>
TC: 135 MWh/ha per year
SE: 111 MWh/ha per year</td></tr>
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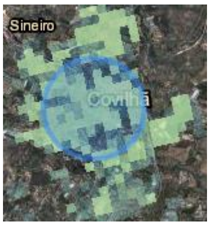
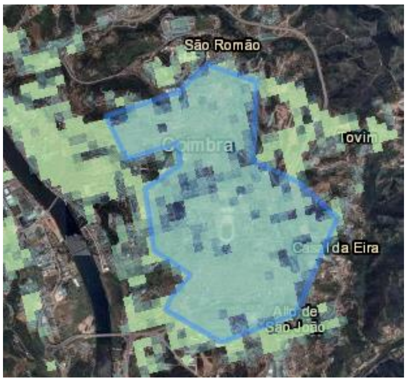

TC: 97 MWh/ha per year
SE: 80 MWh/ha per year</td><td>Coimbra

TC: 117 MWh/ha per year
SE: 85 MWh/ha per year</td></tr>
<tr><td>Castelo Branco

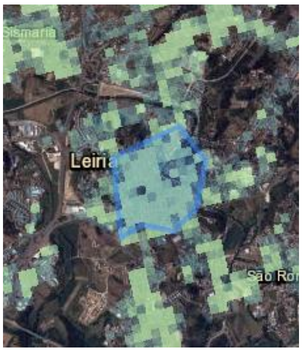
TC: 151 MWh/ha per year
SE: 124 MWh/ha per year</td><td>Leiria

TC: 96 MWh/ha per year
SE: 70 MWh/ha per year</td></tr>
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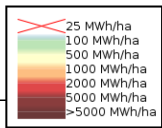
Figure 13 (continued) - Systematic preliminary survey of urban areas for district heating potential.



Portalegre	Santarém

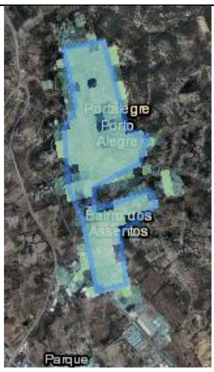
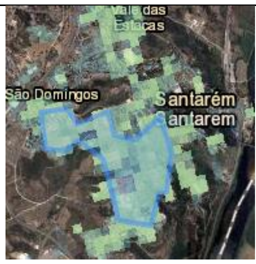
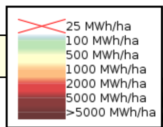
 TC: 137 MWh/ha per year SE: 112 MWh/ha per year	 TC: 143 MWh/ha per year SE: 117 MWh/ha per year
Cascais  TC: 120 MWh/ha per year SE: 82 MWh/ha per year	Oeiras / Paço de Arcos  TC: 233 MWh/ha per year SE: 158 MWh/ha per year
Algés / Linda-a-Velha  TC: 324 MWh/ha per year SE: 220 MWh/ha per year	Agualva / Cacém  TC: 400 MWh/ha per year SE: 272 MWh/ha per year
Queluz / Monte Abraão / Massamá  TC: 341 MWh/ha per year SE: 232 MWh/ha per year	Amadora  TC: 321 MWh/ha per year SE: 218 MWh/ha per year

Figure 13 (continued) - Systematic preliminary survey of urban areas for district heating potential.

Lisbon – historical center E	Lisbon – Benfica



TC: 358 MWh/ha per year

SE: 243 MWh/ha per year

TC: 317 MWh/ha per year

SE: 216 MWh/ha per year

Almada

TC: 226 MWh/ha per year

SE: 154 MWh/ha per year

Barreiro

TC: 160 MWh/ha per year

SE: 109 MWh/ha per year

Seixal

TC: 170 MWh/ha per year

SE: 116 MWh/ha per year

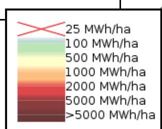
Setúbal

TC: 180 MWh/ha per year

SE: 122 MWh/ha per year

Figure 13 (continued) – Systematic preliminary survey of urban areas for district heating potential.

Évora	Beja



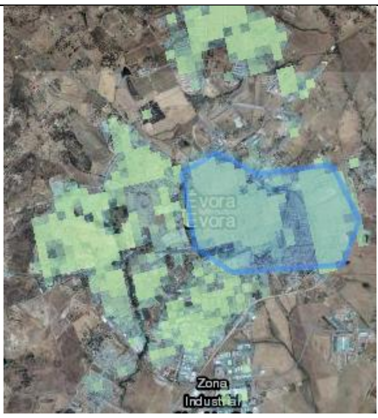
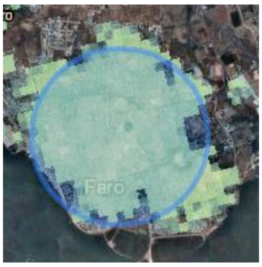
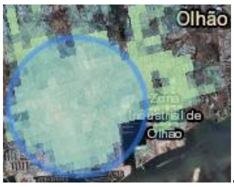
 TC: 111 MWh/ha per year SE: 91 MWh/ha per year	 TC: 132 MWh/ha per year SE: 108 MWh/ha per year
Lagos  TC: 136 MWh/ha per year SE: 79 MWh/ha per year	Portimão  TC: 163 MWh/ha per year SE: 110 MWh/ha per year
Quarteira  159 MWh/ha per year SE: 110 MWh/ha per year	Faro  TC: 193 MWh/ha per year SE: 95 MWh/ha per year
Olhão  TC: 192 MWh/ha per year SE: 111 MWh/ha per year	Vila Real de Sto. António  TC: 190 MWh/ha per year SE: 110 MWh/ha per year

Figure 13 (continued) – Systematic preliminary survey of urban areas for district heating potential.

Under the "Total Comfort" scenario, the promising zones are marked in Figure 13 with a light-yellow background. As can be appreciated, only at the Lisbon Metropolitan Area, north of the Tagus river, are there zones deserving a closer analysis. Although there are urban areas located at the north and interior of the country, that are much colder than at Lisbon metropolitan area, the building density there is too low to make an interesting business case.

In the Lisbon Metropolitan Area, two types of situations favourable for DH can be recognized. A first one is at the east side historical core of the city, with moderate urban density but featuring old houses with bad thermal performance. This zone has a complicate topography and is criss-crossed with old subterranean infrastructures, making it difficult and expensive to add yet another network. A second situation seems to be related to sub-urban areas that experienced rapid expansion during the 1970’s and 1980’s, with high density of multistorey buildings with low thermal performance. Although other areas later experienced also rapid growth – such as, but not only, south of the Tagus river – these were built already with better thermal standards (1990 and 2006 building codes), and that is probably why they do not show high enough potential. It is remarked that the analysis for the oriental zone of Lisbon, where the only existing large DHC is located (Climaespaço network), has not shown good district heating potential in this type of analysis.

Under the “Socioeconomic” scenario, considered more realistic, there would be no candidate zones for DH in Portugal at all.

4.3. *Detailed delimitation of coherent candidate areas for district heating*

For the FC scenario, we will now proceed to a more accurate delimitation of coherent candidate areas, using the respective Toolbox calculation module, the 318 MWh/ha energy needs’ density threshold and a minimum energy demand of 30 GWh to be satisfied by a DH network (the Toolbox default). The results are provided in Figure 14.

Figure 14 - Coherent candidate areas for district heating in Portugal, “Total Comfort” scenario.

It can be appreciated that the Algés / Linda-a-Velha zone has not passed this step of analysis, but there are now two coherent zones at downtown Lisbon, east and west of the Avenida da Liberdade axis. The other coherent areas spreaded roughly along the IC 19 highway Lisbon-Sintra. The interpretation of these results in terms of buildings’ quality and construction density is the same as for the previous analysis step.

4.4. Economic viability based on grid costs

In this phase, an economic viability analysis will be done, by calculating DH grid distribution and transmission costs for the candidate areas and finding out their stand relative to an economic viability threshold.

Table 8 - Parameters for economic viability analysis

Item	value	*Obs.*
First year of investment	2022	
Last year of investment	2040	
Depreciation time	30 years	
Accumulated energy saving	12%	*Building stock improvements, see Table 2.*
DH market share at the beginning of the investment period	10%	*Toolbox default = 30%*
DH market share at the end of the investment period	60%	*Toolbox default*
Interest rate	3%	*Toolbox default = 5%*
Construction cost constant	212 €/m	*Toolbox default*
Construction cost coefficient	4464 €/m²	*Toolbox default*

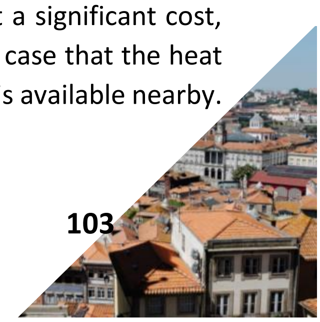
The HoTMAPS Project proposes 25 €/MWh supplied for the DH grid cost threshold; however, at this level, there would be no economic viability for DH in Portugal, even under the very favourable FC scenario. A recent study by IRENA (2017), for the EU region quotes even lower DH cost ceilings of 15 €/MWh for Poland and 20 €/MWh for Germany.

However, for Denmark, IRENA quotes the value 35 €/MWh. It was decided to also test this threshold, although IRENA considers it an extreme case. With this setup, two areas emerge as economically viable, one at Agualva/Cacém and another at Amadora, featuring with DH grid costs around 33 €/MWh. However, the captured demand by DH is just 7.7 GWh per year for Agualva/Cacém (4.2 km distribution length) and 2.5 GWh per year for Amadora (1.3 km distribution length), thus much less than the usually accepted value 30 GWh per year lower limit.

In conclusion, this analysis yielded was no economically viable DH potential in Portugal, even under a favorable demand scenario.

4.5. Geothermal and waste heat based district heating

The analysis of the previous sections considers that heat is produced and delivered at a significant cost, being at least more expensive than the grid distribution cost. However, it might be the case that the heat can be supplied at a very low cost, namely if a natural geothermal or waste heat source is available nearby.



Regarding geothermal-powered DH, two situations were identified. The first one is at the Spa area of S. Pedro do Sul, located away from the village core. The analysis has shown that the nearby construction density there is too low to support a DH system. This is not to say that a micro-grid system could not be mounted to serve existing buildings, but not a proper DH system.

The second one it at Chaves, where the geothermal Spa is located to the south but near the urban core, see Figure 15. In this case the analysis is favorable, featuring a 22 km distribution grid length, capturing a reasonable 10 GWh per year heat demand, and with DH distribution grid costs of 65 €/MWh. Therefore a levelized cost of heat would be around 70 €/MWh, which is less than the around 100 €/MWh cost estimated for the most economical decentralized alternative option, biomass-based boilers.

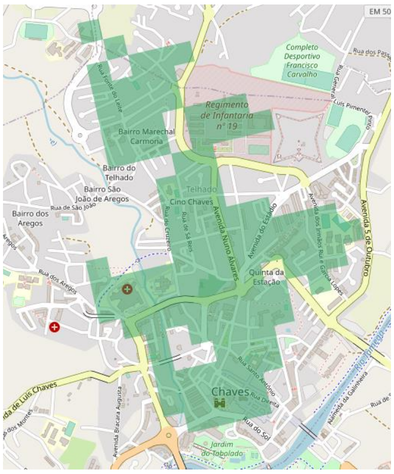


Figure 15 - Area served by a potential geothermal-based district heating system for Chaves.

A survey of excess waste heat in Portugal can be made with the Toolbox, acessing the information on industrial sites at the database. The toolbox is out of date in some regards, as from 2014 up to now several industries closed. The most relevant issues for DH are the closure of one ammonia and one steel fabrication facility in the southern region of the Lisbon Metropolitan Area; plus, during 2021, the Matosinhos refinery at the Porto Metropolitan Area will also close. Also, the Toolbox also does not map two waste incineration power plants, LIPOR at the Porto Metropolitan Area and Valorsul at the Lisbon Metropolitan Area. These corrections considered, it was found that, with two exceptions, waste heat is not available near dense enough urban areas.

The first case is related to the Valorsul incineration plant, that in principle could be used to feed heat into the Climaespaço existing DHC network; the two facilities are about 6 km apart, see Figure 16. The Climaespaço heat it is sold now around 40€/MWh. The network is already built; so, an even lower heat price using low-cost waste heat could be appealing, and even come to capture additional demand at the Moscavide and Portela neighbourhoods, to the north of the current DHC area.

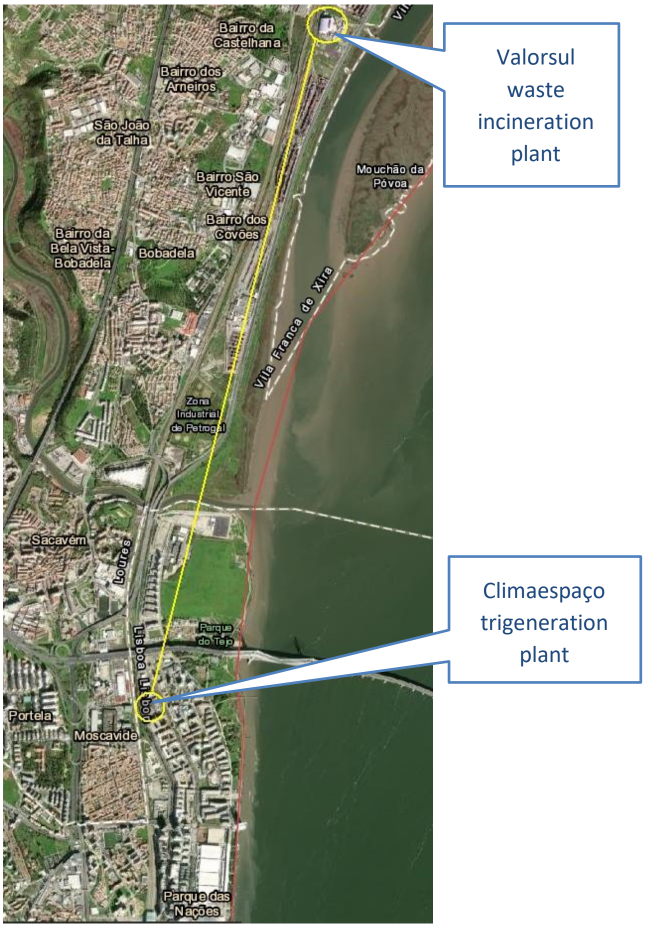


Figure 16 - Potential waste heat source for the existing Climaespaço district heating network.

The other situation respects the Benfica / east Amadora region, to the northwest of Lisbon. There is a glass fabrication unit at the at the Venda Nova industrial park, that in principle could be used to feed heat into a possible new DH network. Figure 17 shows a possible layout of the DH system: the orange circle is the BA glass factory; the green areas mark the distribution network, around 16 km length; and the orange line marks a transmission line, around 2 km length.

Figure 17 - A potential new district heating network powered by waste heat at Amadora.

The most important technoeconomic details are the following. The BA factory excess heat potential is estimated at 31 GWh per year, available within the range 200°C - 500°C. Using the financial and construction parameters at Table 8, and a DH network cost ceiling of 40 €/MWh, it is estimated that a 23 GWh demand could be captured, with distribution and transmission network costs of 39 €/MWh. The annuity for financing this grid would be about 900 000 € per year. Therefore, it is estimated that a very appealing heat cost downwards of 50 €/MWh could be reached.

5. Analysis of District Cooling Potential

5.1. Cooling needs density thresholds

There are much less internationally available information on DC than on DH. The most relevant information found was again from Project STRATEGO (2016), that concludes that DH systems (in already built areas) are more expensive to install than DH systems for the same amount of energy delivered; the difference seems to be around 50% more. So, considering the DH threshold value of 318 MWh/ha for preliminary identification of candidate areas, for cooling one might use about 477 MWh/ha. However, as it will be seen, even the Toolbox default 333 MWh/ha yields no candidate areas for DC.

5.2. Survey of candidate areas for district cooling

In a similar way to the approach used for heating needs, the cooling needs will now be investigated. A systematic survey of candidate urban areas for district cooling was conducted, and with more detail than for DH. Figure 18 displays the situations identified with cooling needs' density larger than 200 MWh/ha per year under the TC scenario; maps for the three major cities of Porto, Coimbra and Évora have also been added, just for completeness of the results shown.

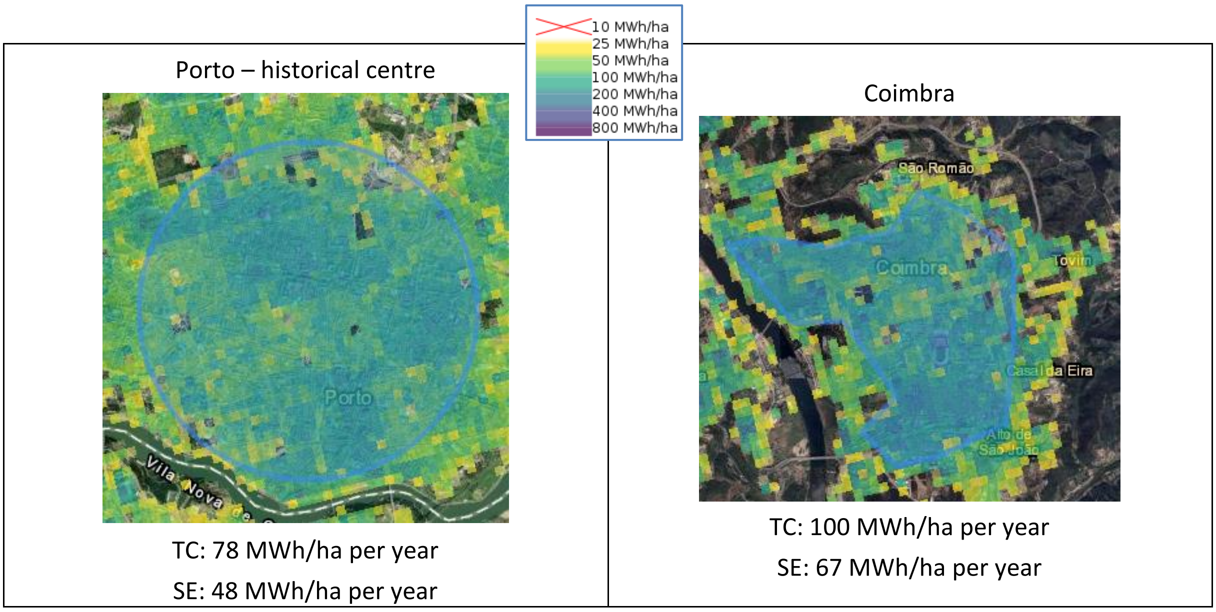
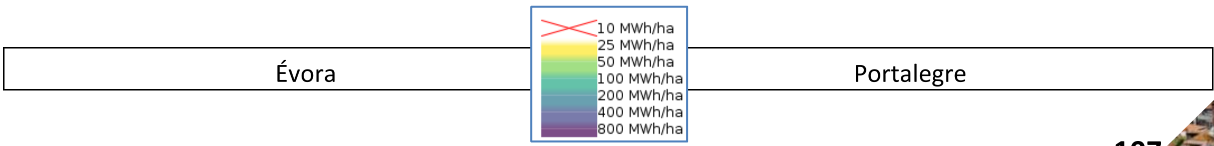


Figure 18 - Systematic survey of urban areas for district cooling potential.



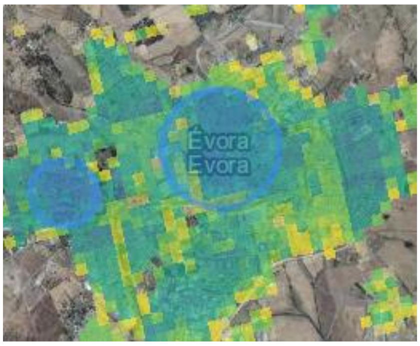
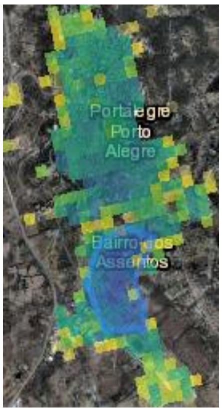
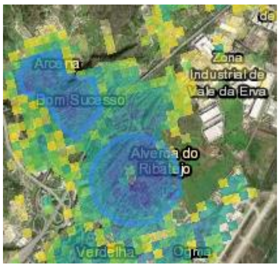
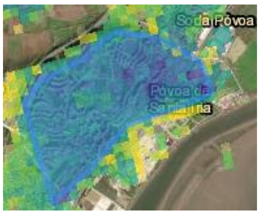
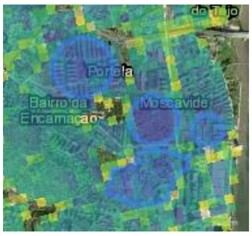
 TC: 128 MWh/ha per year SE: 99 MWh/ha per year	 TC: 215 MWh/ha per year SE: 166 MWh/ha per year
Vila Franca de Xira  TC: 249 MWh/ha per year SE: 179 MWh/ha per year	Alverca  TC: 214 MWh/ha per year TC: 154 MWh/ha per year
Póvoa de Sta. Iria  TC: 196 MWh/ha per year SE: 141 MWh/ha per year	Portela/Moscavide  TC: 287 MWh/ha per year SE: 207 MWh/ha per year
Lisbon – historical centre E  TC: 311 MWh/ha per year SE: 224 MWh/ha per year	Lisbon – historical centre W  TC: 226 MWh/ha per year SE: 163 MWh/ha per year

Figure 18 (cont.) - Systematic survey of urban areas for district cooling potential.

Algés	Linda-a-Velha

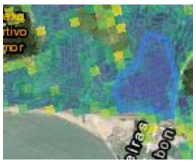
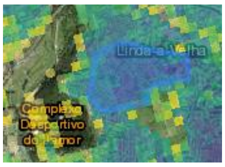
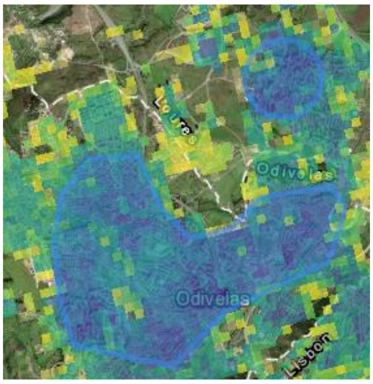
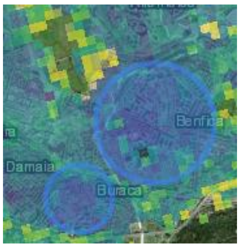
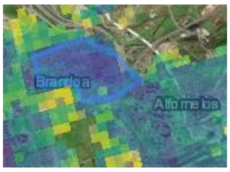
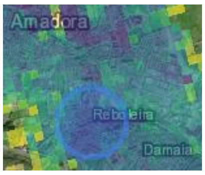
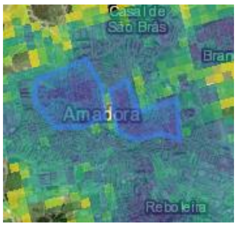
 TC: 295 MWh/ha per year SE: 212 MWh/ha per year	 TC: 231 MWh/ha per year SE: 166 MWh/ha per year
Oeiras  TC: 210 MWh/ha per year SE: 151 MWh/ha per year	Odivelas  TC: 224 MWh/ha per year SE: 161 MWh/ha per year
Lisboa – Benfica/Buraca  TC: 262 MWh/ha per year SE: 189 MWh/ha per year	Brandoa  TC: 330 MWh/ha per year SE: 238 MWh/ha per year
Reboleira  TC: 291 MWh/ha per year SE: 210 MWh/ha per year	Amadora  TC: 326 MWh/ha per year SE: 235 MWh/ha per year

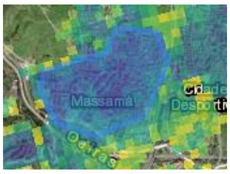
Figure 18 (cont.) - Systematic survey of urban areas for district cooling potential.

Queluz / Monte Abraão

TC: 283 MWh/ha per year

SE: 171 MWh/ha per year

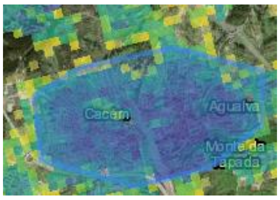
Massamá



TC: 263 MWh/ha per year

SE: 189 MWh/ha per year

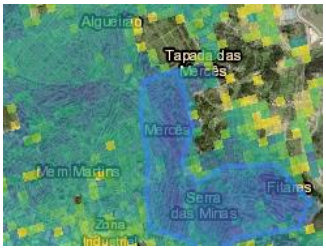
Agualva/Cacém



TC: 226 MWh/ha per year

SE: 163 MWh/ha per year

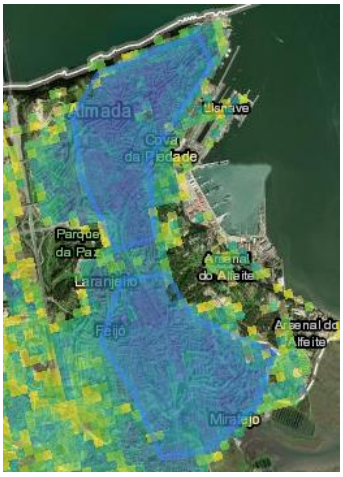
Mem Martins



TC: 227 MWh/ha per year

SE: 163 MWh/ha per year

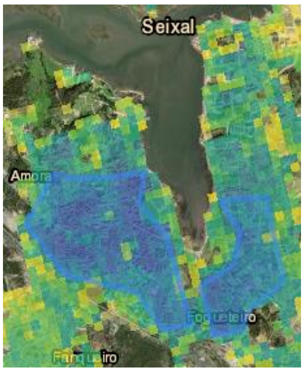
Almada



TC: 212 MWh/ha per year

SE: 153 MWh/ha per year

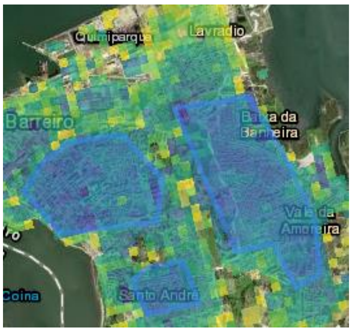
Seixal



TC: 209 MWh/ha per year

SE: 150 MWh/ha per year

Barreiro



TC: 212 MWh/ha per year

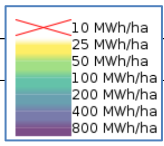
SE: 153 MWh/ha per year

Setúbal

TC: 224 MWh/ha per year

SE: 161 MWh/ha per year

Figure 18 (cont.) - Systematic survey of urban areas for district cooling potential.



Quarteira	Faro

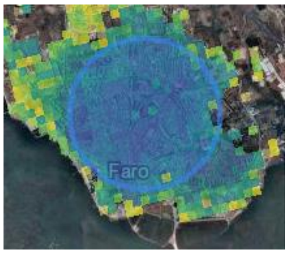
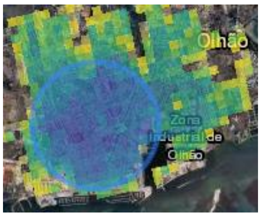
 TC: 198 MWh/ha per year SE: 162 MWh/ha per year	 TC: 225 MWh/ha per year SE: 185 MWh/ha per year
Olhão  TC: 191 MWh/ha per year SE: 157 MWh/ha per year	Vila Real de Sto. António  TC: 254 MWh/ha per year SE: 116 MWh/ha per year

Figure 18 (cont.) - Systematic survey of urban areas for district cooling potential.

The results are clear: additional DC potential was not found, whatever the scenario.

6. Additional issues

The previous two sections were focused at technoeconomic viability. We will now address some additional issues relevant for discussing additional DHC potential in Portugal.

6.1. District heating and cooling vs. building renovation

Strictly speaking the DH analysis did identified, within the coherent candidate zone of Amadora, a small sub-area, the Brandoa district, where it would be economically viable to install a DHC, see Figure 19.

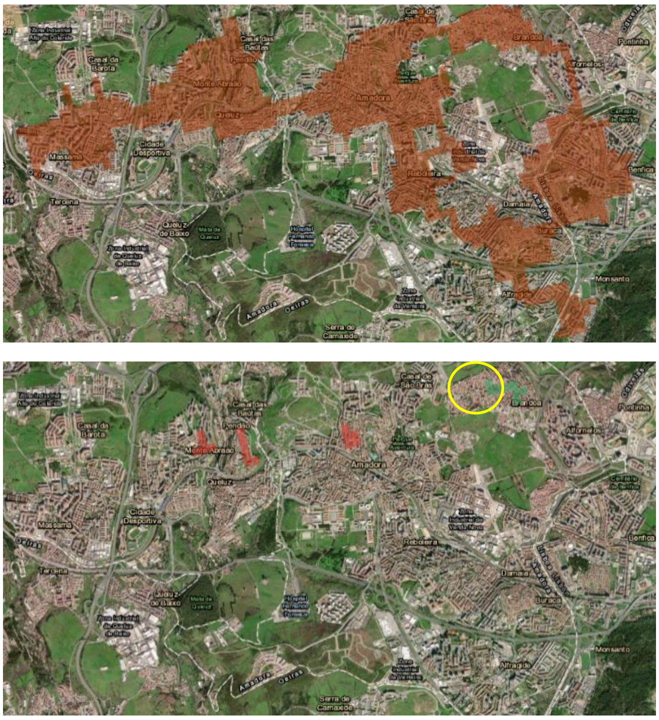


Figure 19 - District of Brandoa, signalled with positive potential for district heating and cooling.

However, this is a false positive result. As can be appreciated in Figure 20, the building stock there is mostly of very bad thermal quality; these buildings require deep renovation, maybe even demolishing and substitution, not a DHC network.

Figure 20 - A view of buildings at Brandoa.

This serves to illustrate the point that new residential DHC for a certain zone must be carefully weighted versus the alternative of refurbishing the existing buildings with wall and ceiling insulation, and modern high-performance windows. As suggested by cost-optimal studies for existing residences (DGEG, 2019a, 2019b), this should be enough to obtain thermal comfort most of the time, with no active cooling and occasional active heating.

6.2. Country-specific barriers

The better target buildings for DHC are those constructed before the issuing of the 2006 building code (SCE, 2006), in particular high-rise apartment buildings. It is noted that residences built from before 2006 seldom possess central heating. This means that a levelized cost of heat should include not only the side of the DHC owner costs with generation and distribution of heat, but also the cost at the client side. Assuming a 40 MWh heat demand for a reference 100 m² existing dwelling (DGEG, 2019a) over 18 years (i.e., 2022-2040), and a 4 000 € cost of adaptation of the dwelling to central heating, this would lead to and additional heat cost of about 100 €/MWh. This hinders the competitiveness of DHC in respect to decentralized options. And in a similar way for cooling.

Plus, apartment buildings in Portugal only in very rare instances possess piping installed compatible with DHC. Thus, there yet additional condominium costs to be added. This again impacts on competitiveness but most of all, consists in a serious practical problem as the building adaptation must be authorized at a condominium assembly. Even if it passes, dwellings not using the DCH would not be required to contribute to the building installation, augmenting the costs for the other dwellings.

As regards services buildings, it is noted that they are already equipped with HVAC systems, so DC must compete against investments already made and technical solutions already working.

All considered, the best situation for enabling DHC would be in new buildings with pre-installation of central heating, where the related costs are much diluted in the total dwelling cost. However, newly built neighbourhoods in principle will not require DHC systems. This is because the near zero energy building definition in Portugal (NZEB, 2019) was assembled in such a way that the new buildings require very little active heating and cooling. Furthermore, even if considering cold areas of the country, NZEBs must obtain 50% of the HC energy from local renewable sources, this including the energy supplied through dedicated infrastructures serving the building. Such concept clearly includes, for instance, micro-grids that harvest renewable energy; but in principle does not include large DHC systems, even if they are powered by renewable energy, as they are more akin to public utilities. Nevertheless, this is certainly an aspect that deserves further clarification in the building codes that will be published during 2021 following the new umbrella legislation for the Building Certification System (SCE, 2020).

6.3. Dissimilarities to the neighbouring country

It may be thought that since Portugal and Spain share the Iberian Peninsula space, they would share too similar climate and urban patterns – thus, the near absence of DHC potential in Portugal could look strange in comparison with its neighbouring country. In fact, not only the climate is generally harsher in Spain than in Portugal, but buildings patterns are different – e.g. gross floor areas in Portuguese urban areas much lower than in Spain. This is illustrated in Figure 21 and Figure 22 that aim to compare DHC potential in Portuguese and Spanish locations of similar latitude and size. The same technoeconomic parameters were used and a DH distribution cost ceiling of 35 €/MWh was adopted.

<table>
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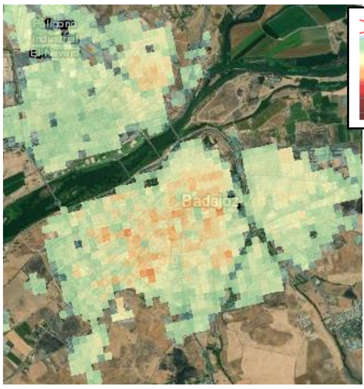
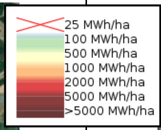
<tr><td>Heating needs map</td><td></td><td></td></tr>
<tr><td>Potential DH layout</td><td></td><td></td></tr>
</table>

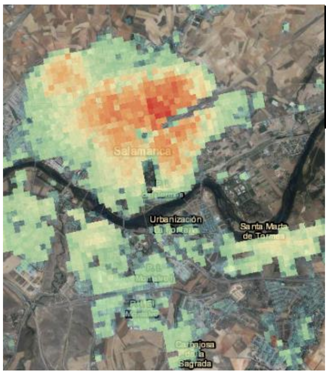
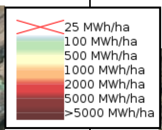
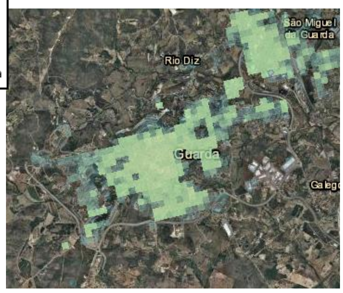
<table>
<tr><th>Site</th><th>Salamanca (Spain)</th><th>Guarda (Portugal)</th></tr>
<tr><td>Heating needs map</td><td></td><td></td></tr>
<tr><td>Potential DH layout</td><td></td><td></td></tr>
</table>

Figure 21 - Comparing district heating potential at locations with similar type and latitude across the Portugal-Spain border.

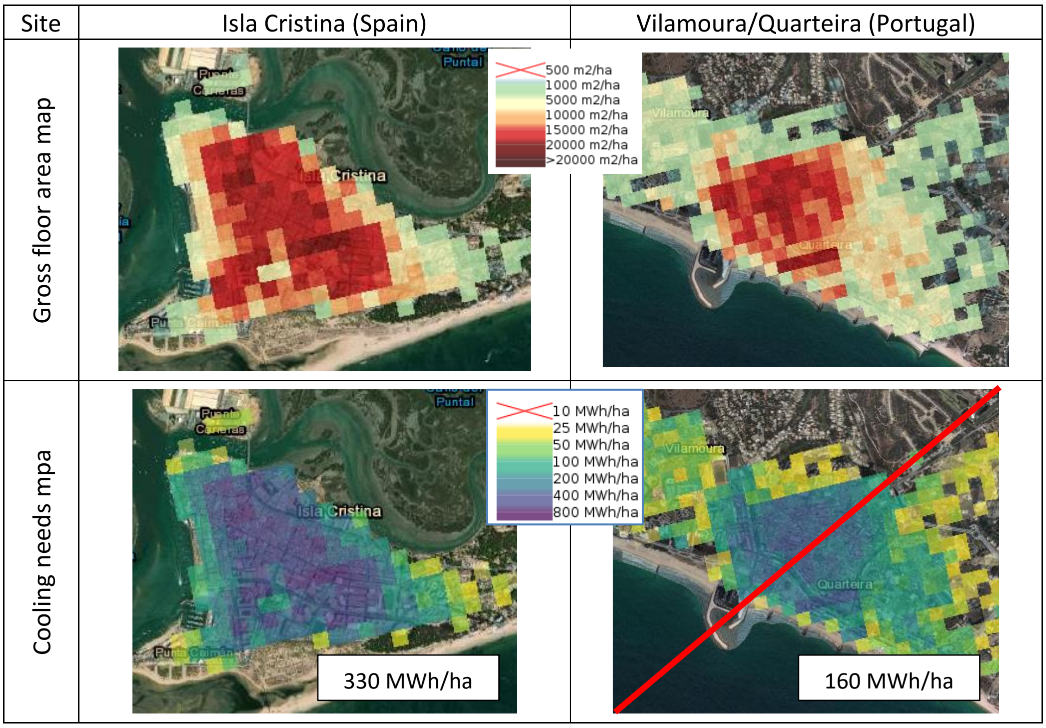


Figure 22- Comparing district cooling potential at locations with similar type and latitude across the Portugal-Spain border.

As it can be seen, the Toolbox easily find DH or DC potential at the Spanish locations but not at the corresponding Portuguese locations. The conclusion is that even for locations under similar climate, just the fact that Spanish urban areas are denser, would lead to significant differences in DHC potential between the two countries; climate differences make up for the rest.

6.4. Historical and tourist districts

An advantage of DHC in comparison with decentralized HC technologies, is that they are much less intrusive for an urban landscape. The sight or HVAC heat exchangers mounted outside of buildings is perhaps acceptable for suburban areas, but at historical and tourist districts it is certainly not aesthetical. Therefore, one can conceive that, even if a DHC system is not economically viable *per se* in these areas, municipalities could see this a as a solution for improving the living quality of the buildings therein, diminishing the impacts on the urban landscape.

We examined the case of Lisbon and Porto from this viewpoint, allowing for a high DH distribution cost ceiling of 80 €/MWh and adjusting the construction cost upwards of what is stated in Table 8, considering that it is more expensive to build a network in these old town areas (their complicated topography does not help either). The results were encouraging, see Figure 23.

Western tourist neighbourhoods of Lisbon

DH grid construction coefficient 6000 €/m²

DH heat distribution cost 55 €/MWh

Eastern tourist neighbourhoods of Lisbon

DH grid construction coefficient 6500 €/m²

DH heat distribution cost 62 €/MWh

Tourist neighbourhoods of Porto

DH grid construction coefficient 5500 €/m²

DH heat distribution cost 78 €/MWh

Figure 23 - District heating areas at tourist neighbourhoods, allowing high network costs.

As an example, the annuity for DH grid investment for the Lisbon Eastern tourist neighbourhoods (Alfama / Mouraria / Graça / Castelo) was estimated at about 1 M€ per year up to 2040. This certainly looks expensive for a municipality investment. However, European funds for urban renovation are to become available under the Renovation Wave; and other financial sources can be available. For instance, the 1 M€ cost can be compared with the *ca.* 38 M€ per year revenue of the city tourist tax.

7. Conclusions

This study found the potential for DHC in mainland Portugal to be very low or even null. The major barriers to adoption are low density of construction at interior zones, and mild climate at coastal zones; but additional economic, sociocultural, and practical barriers, also were identified. Unlike in other EU countries, DHC in Portugal holds very little potential for energy efficiency savings.

It is remarked that the guidance from the European Commission on the EED states that the adoption of measures to develop DHC in a country is only mandatory if the assessment identifies a potential whose benefits exceeds the costs, which is not the case for Portugal.

Although this study yielded negative perspectives for DHC potential, this does not definitely rule out the interest of heating and cooling networks to the country.

Firstly, some opportunities for DH do exist for a few specific situations where nearby geothermal or industrial waste heat sources are available (Chaves, Amadora, Parque das Nações). Plus, there is the possibility to adopt district heating in historical and tourist neighbourhoods to reduce the impact of other solutions such as HVAC in the urban landscape.

Secondly, although the best international wisdom available to us was applied in the study, DHC technology and its costs are constantly improving. For instance, renewable heat sources other than biomass can come to be considered as a solution to power DH and especially DC, making these viable even under large energy distribution costs.

Thirdly, this study analysed conventional DHC; while there is currently a perception that small scale networks could be a solution for many situations, this fitting neatly with the concepts of micro-grids and energy communities.

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Annex I - Indications regarding EED reporting

Regarding the reporting items required by EED related to district heating and cooling, its Annex VIII lists what "the comprehensive assessment of national heating and cooling potentials referred to in Article 14(1) shall include". The following contributions for this purpose of this study are hereafter put forward, for each item listed.

Point (a) – "a description of heating and cooling demand"

This was discussed in Chapter 2, especially in sections 2.3 and 2.4. The assessment takes advantage of GIS-based tools that very recently become available, namely the HoTMAPS Toolbox developed by Project HoTMAPS (2016). Improving on previous studies, it was possible this way to account better for climate and building stock characteristics, and enable exhaustive and detailed surveys of the territory.

Point (b) – "a forecast of how this demand will change in the next 10 years, taking into account in particular the evolution of demand in buildings (…)"

This was addressed in Chapter 2, section 2.5. The HoTMAPS Toolbox provided a reference scenario for all the parameters relevant to make a forecast. This reference scenario was adjusted according to a set public policies and measures expected to have significant impacts on the building stock: the Portuguese National Energy and Climate Plan 2030 (NECP, 2020); the refreshed EPBD Directive (EPBD, 2018), that is just now being transposed to national legislation (SCE, 2020), including the required national Long Term Building Renovation Strategy; and the EU "Renovation Wave" strategy (EC, 2020). A projection was performed by updating heating needs considering renovation rates and its impacts in thermal performance for each period of construction. The built area was also adjusted according to the evolution of population.

Point (c) – "a map of the national territory, identifying (…):

(i) heating and cooling demand points, including:
- municipalities and conurbations with a plot ratio of at least 0,3
- (…)

(ii) existing and planned district heating and cooling infrastructure;

(iii) potential heating and cooling supply points, including:
- electricity generation installations with a total annual electricity production > 20 GWh, and
- waste incineration plants,
- existing and planned cogeneration installations (…)
- district heating installations.

This is outside the scope of the present study, refer to the national report on EED Article 14(1).

However, recognizing that these items were considered in the assessment performed in this study, some observations are left here. Regarding item (i), an assessment is provided at Chapter 4, sections 4.1 to 4.3, using the GIS tool. This enabled a more accurate survey of zones with significant heating and cooling needs than with the plot ratio method. Regarding item (ii), there is only one district heating and cooling network, see Figure 16; there are some preliminary studies, but so far, no firm plans have been put forward for other networks. Regarding item (iii), information is available in the HoTMAPS Toolbox, and was completed with data for the two waste incineration plants; as for cogeneration plants, they are already supposed to satisfy *other existing heat needs, except for the one powering the single district heating network already mentioned.*

In addition to the types of potential heat supply points listed in Annex VIII, a survey was done for industrial installations of the industrial subsectors pulp & paper, steel recycling and products, glass products, and cement & lime, refer to Chapter 3 of DGEG' study "Waste Heat in Portugal – 2020 Edition".

Point (d) – "identification of the heating and cooling demand that could be satisfied by (…) district heating and cooling"

District heating potential was addressed in Chapter 4, sections 4.3 and 4.4.

Two scenarios were considered, a "full comfort" scenario where there the indoor temperature is maintained constantly in a comfort band, and a "socioeconomic" scenario that deals with comfort with more flexible strategies and it is considered more adherent to the economic and cultural reality of Portugal.

Preliminary identification of candidate areas for district heating and cooling was done using heating and cooling needs' maps, surveying the urban areas of the entire territory. Next, the delimitation of candidate areas was refined setting thresholds for the minimum energy demand to be although facing by a district heating network. Finally, an economic viability analysis was performed, examining if the district heating grid distribution and transmission costs for the areas selected were within internationally accepted viability thresholds. Using these approaches, the potential for district heating in Portugal was found to be very low. Three instances only were found: at Amadora a district heating network can eventually be powered from a glass factory that is located within the urban area; at Chaves it might be possible to install a district heating network powered by a nearby geothermal heat source; and the district heating network at Parque das Nações, Lisbon, is already built and although the current cogeneration system faces economic viability problems, it might be powered by heat from a waste incineration plant not very distant.

District cooling potential was addressed in Chapter 5. The same strategy followed for heating was employed, but the economic viability analysis has not taken place because already at the phase of finding candidate areas with demand thresholds, none was found suitable; nevertheless, there is the exception of the already built network at Parque das Nações, Lisbon, mentioned above.

The major obstacles to the adoption of district heating and cooling were identified as a construction density too low at interior zones that feature more climatic extremes, and in contrast a mild climate at the coastal zones that support the denser urban areas. This for existing urban areas, but much more so for new urban areas as they will be built under the Near Zero Energy Building standard (NZEB, 2019), which in Portugal means that will have very low heating and cooling needs, indeed close to null in vast areas of the territory. Additional economic, sociocultural, and practical barriers are discussed at Chapter 6.

Point (e) – "[(…) identification of the potential for additional high-efficiency cogeneration (…)]"

No potential was identified for additional high-efficiency cogeneration directed at powering district heating.

Point (f) – "identification of energy efficiency potentials of district heating and cooling infrastructure"

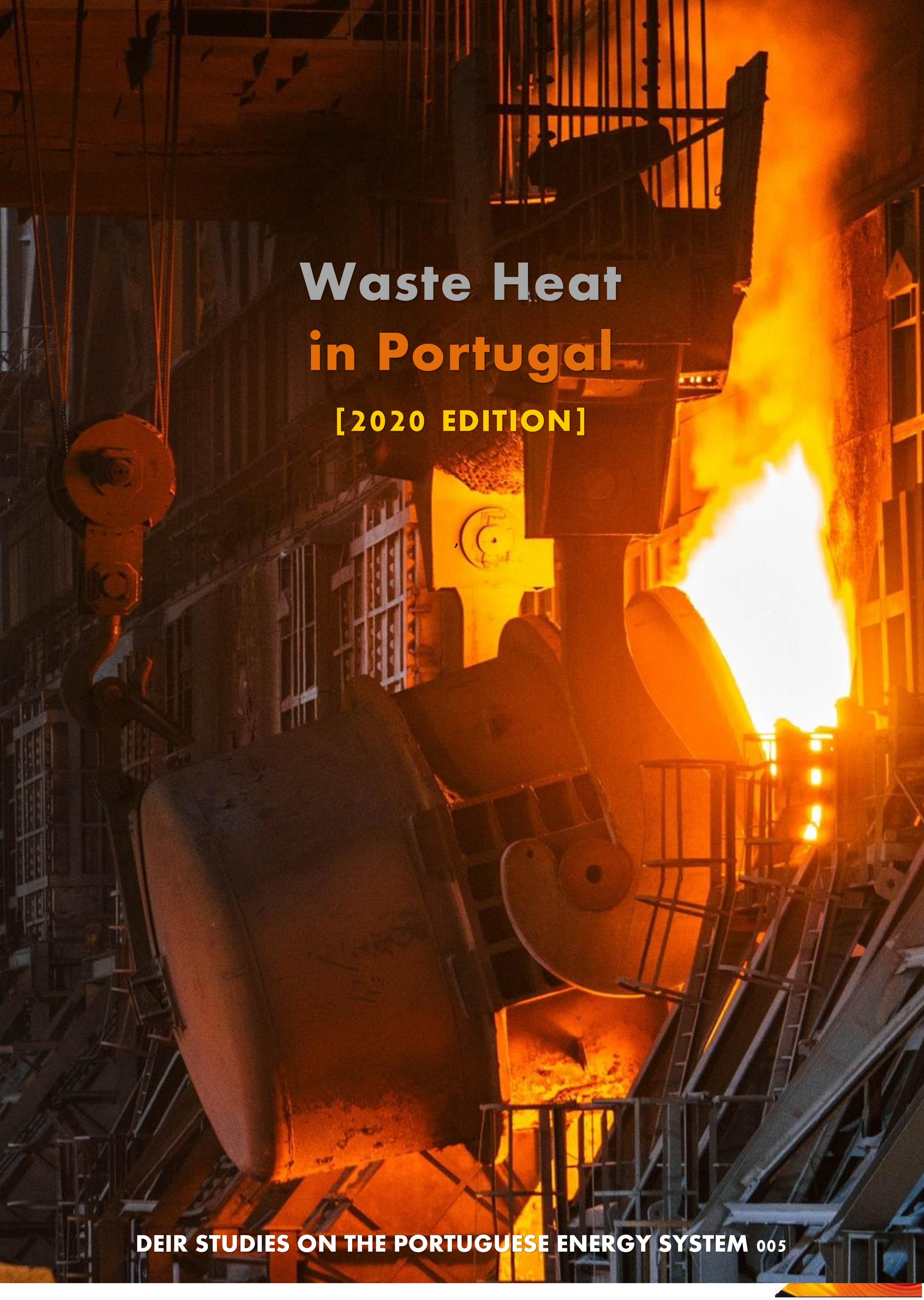
District heating powered by waste heat and geothermal heat could amount to about 0.34 PJ (i.e., 96 GWh: 55 GWh at Parque das Nações, 31 GWh at Amadora, and 10 GWh at Chaves). Unlike for most other EU *countries, for Portugal no large energy efficiency savings through the adoption of district heating and cooling cost-effective solutions could be identified.*

(g) strategies, policies and measures that may be adopted up to 2020 and up to 2030 to realise the potential in point (e) in order to meet the demand in point (d) (…)"

This is void, given the assessment results obtained.

Waste Heat in Portugal

[2020 EDITION]



DEIR STUDIES ON THE PORTUGUESE ENERGY SYSTEM 005

Date

2020 edition: January 22, 2021

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Index

1. Introduction

This study analyses the availability of industrial waste heat in Portugal and tries to identify the major facilities that could provide waste heat as an energy source for industrial utilizations as well as for heating and cooling of buildings.

It is expected that this can provide a useful contribution to the reporting obligations of Portugal[4] under the Article 14(1) of the Directive 2012/27/EU, known as Energy Efficiency Directive (EED, 2012) (amended in 2018 by Directive 2018/2002/EU, as part of the 'Clean energy for all Europeans package'). Indeed the EED specifies several reporting items related to waste heat, namely in its Annex VIII, therefore an analysis of waste heat availability and future trends should be useful in that regard.

We will start by making estimates of the maximum technical waste heat availability in the manufacturing industry and identifying other major waste heat sources such as waste incinerator and thermal power plants.

Then we will map the major facilities that may provide waste heat and examine for each one, the potential for utilization in other surrounding urban areas and industrial parks.

Finally, we will discuss the EED Article 14(1) reporting items related to waste heat as specified in its Annex VIII at the light of the information that was obtained.

[4] Meaning mainland Portugal; the autonomous regions of Madeira Islands and Azores Islands are not covered by this study as they handle their own obligations with respect to EU Directives.

2. Waste heat availability

2.1. Methodology

To estimate a maximum technical potential for waste heat utilization, we will use a top-down approach.

The procedure starts from historical records and projections of final energy demand for each (sub)sector analysed. It is assumed that all fuels are used to generated heat. Assigning an average 90% conversion efficiency to fuel demand, the heating supply from these sources is estimated. For the special case of steel products, it is known that electric arcs are used to provide high-range temperatures in Portuguese facilities (MEGASA, 2021), therefore we add 80% of the electricity demand to the heat demand of the subsector (own estimate).

Total heat demand would be obtained by adding to this heat demand estimate, the cogeneration heat and solar heat use statistics. However, these two types of energy consumption are not considered to be sources of further excess heat.

To calculate excess heat potentials, we use the method proposed by the Project HoTMAPS (2016), described in the respective supporting materials (HoTMAPS, 2020 a). Briefly, excess heat factors are obtained, defined as waste heat generated per unit of fuel consumed. To estimate waste heat available, these excess heat factors are multiplied with the part of energy demand supplied directly by fuels. Finally, additional share factors enable to estimate the heat available in several temperature ranges.

The excess heat factors used for industry are those proposed by Brückner (2016), see Table 9. These data derive from surveys of German industry by Kemmler et al. (2016); unfortunately, we could not find factors specific for the Portuguese industry. It is also remarked that the excess heat factors of Brückner include excess heat coming from process heat as well as space heat generation and hot water and do not include excess heat generated by electricity based applications.

Table 9 - Excess heat factors at industry subsectors.

Subsector	Excess heat factor	Temperature distribution %]			
		< 100°C	100-200°C	200-500°C	>500°C
Manufacture of food products	0,10	10	90	0	0
Manufacture of beverages	0,14	10	90	0	0
Manufacture of tobacco products	0,12	10	90	0	0
Manufacture of textiles	0,29	10	60	30	0
Manufacture of wearing apparel	0,06	10	60	30	0
Manufacture of leather and related products	0,20	10	60	30	0
Manufacture of wood and products of wood and cork *	0,10	10	60	30	0
Manufacture of paper and paper products	0,09	10	90	0	0
Printing and reproduction of recorded media	0,03	10	60	30	0
Manufacture of chemicals and chemical products	0,09	10	90	0	0
Manufacture of pharmaceutical products	0,08	10	90	0	0
Manufacture of rubber and plastic products	0,17	10	90	0	0
Manufacture of other non-metallic mineral products	0,15	0	20	80	0
Manufacture of basic metals	0,19	0	10	90	0
Manufacture of fabricated metal products **	0,19	0	50	50	0
Manufacture of electronic and optical products	0,18	10	60	30	0
Manufacture of electrical equipment	0,31	10	60	30	0
Manufacture of machinery and equipment n.e.c.	0,16	10	60	30	0
Manufacture of motor vehicles, trailers and semi-trailers	0,12	10	40	50	0
Manufacture of other transport equipment	0,38	10	40	50	0
Manufacture of furniture	0,12	10	60	30	0
Other manufacturing	0,08	10	60	30	0
Repair and installation of machinery and equipment	0,05	10	60	30	0

(*) except furniture (**)except machinery and equipment

2.2. Heat demand at industry

We take the most widely used approach to projection of final energy demand at industrial subsectors, which is to make it proportional to its Gross Value Added (GVA). We first take the national Gross Domestic Product (GDP), projections of the National Strategy for Hydrogen (EN-H2, 2020), which in turn are based on those of the National Energy and Climate Plan 2030 (NECP, 2020) scenario with adjustments for the impact of Covid-19 pandemic (DGEG, 2020 a), see Figure 47.

Then the historical GVA shares for 14 manufacturing industry subsectors are projected in a conservative way, yielding absolute values when multiplied by the GDP, see Figure 48.

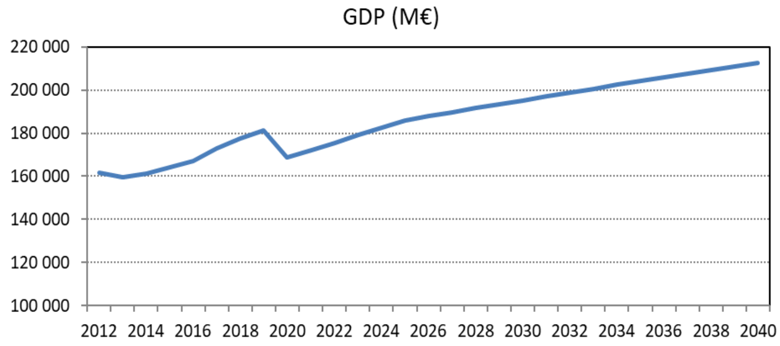

Figure 24 - Gross Domestic Product scenario.

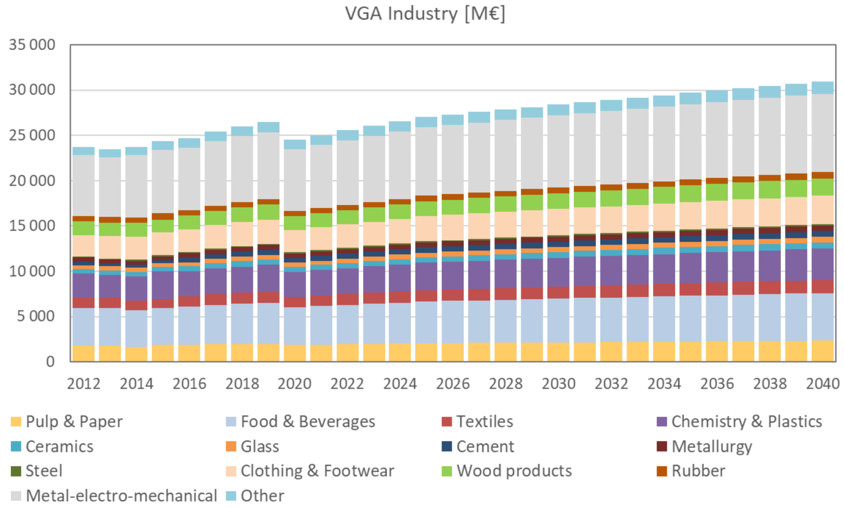

Figure 25- Gross Value Added of 14 manufacturing industry subsectors.

The final energy consumption at each subsector is considered proportional to its GVA, without elasticities. Expected energy efficiency gains are factored in via energy intensity drops in respect to GVA. Finally, the historical shares of the different fuels consumed in each industrial subsector are projected and multiplied by the overall subsector energy demand to obtain final energy demand of each fuel – this is the most delicate and uncertain step. However, guidance can be obtained from the Carbon Neutrality Roadmaps 2050 (CNR, 2019), National Energy and Climate Plan 2030 (NECP, 2020) and National Strategy for Hydrogen (EN-H2, 2020). We also considered the cogeneration phase-out trend proposed in DGEG's Cogeneration Outlook for Portugal (DGEG (2021 b) for the cases of fossil fuel and of renewable fuels of non-biological origin inputs.

The overall demand mix of the manufacturing industry obtained in this way is shown in Figure 49. The part of this demand that allows for excess heat is seen to represent today about 40% of total energy demand, 50% in the long-term.

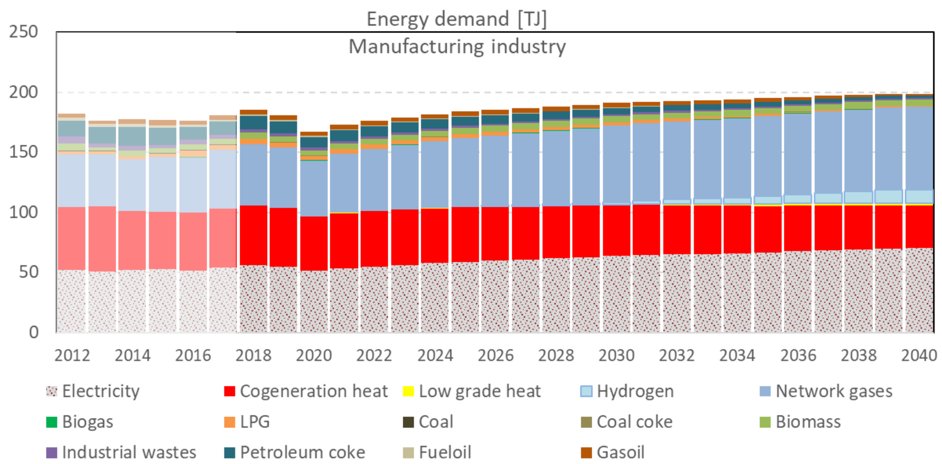

Figure 26 - Final energy demand mix of the manufacturing industry.

2.3. Excess heat availability at industry

Using the methodology described at section 3.1, the estimates for maximum waste heat availability are depicted in Figure 27. The subsectors are represented from bottom to top by order of waste heat potential.

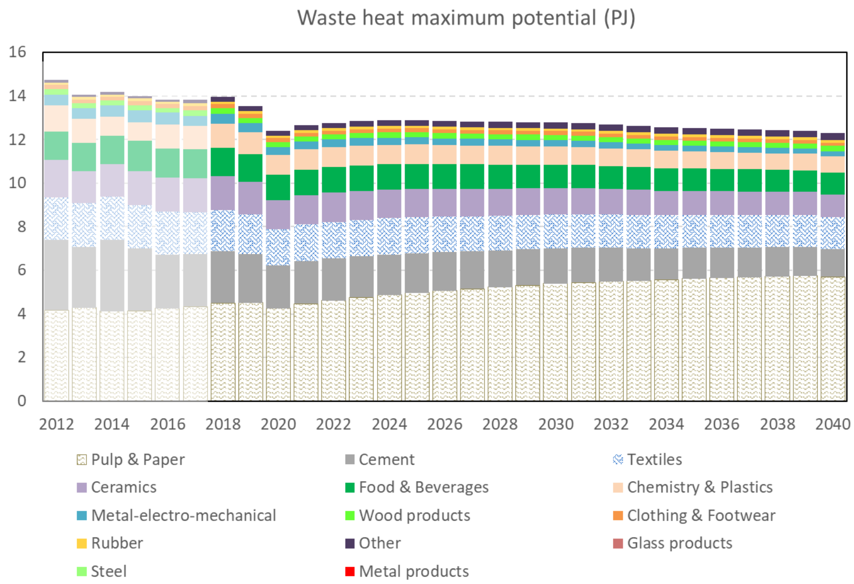

Figure 27 - Excess heat by industrial subsectors.

As can be appreciated, the overall potential is about stable, slightly increasing up to 2024 and then slightly decreasing towards 2040. The pulp & paper subsector is revealed as the one with the most potential. Its importance in this context increases with time; this is due to the phase-out of gas-based cogeneration in the subsector. In contrast the potential of the second most important sector, fabrication of cement (and lime), decreases with time due to activity reductions and more recycling of materials. For the remaining subsectors, the outlook is about stable.

Figure 28 shows the data for overall waste heat availability by temperature range, for selected years. As could be expected from the excess heat factors in Table 9, most of the potential stands at the 100 °C to 200

°C range, but the potential at the 200 °C to 500 °C range is also relevant – this result mainly from the contribution of the subsectors that handle fabrication of steel products and metal equipment and products.

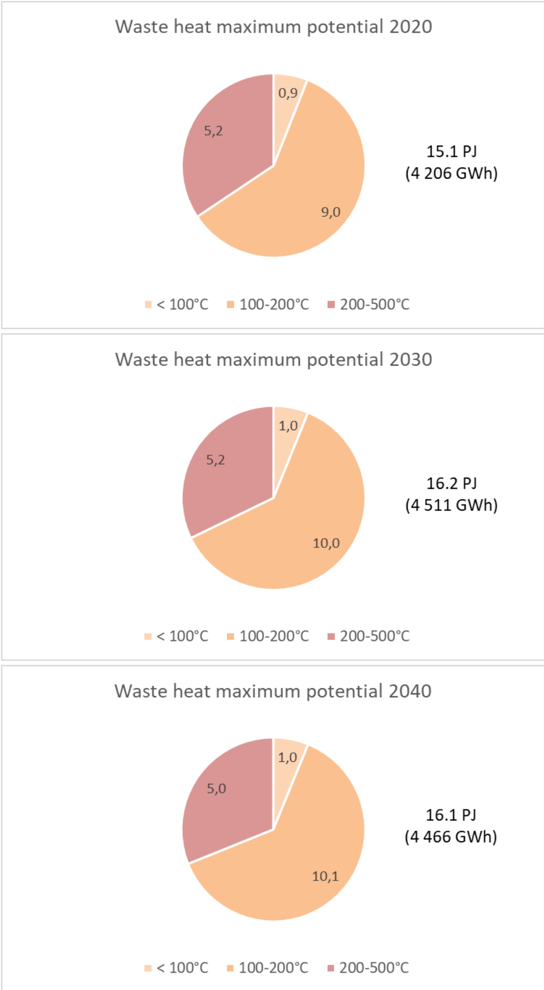

Figure 28 - Excess heat by temperature range.

In summary, the estimate for *maximum potential* of excess heat from industry is around 9% (by 2020) to 8% (by 2040) of the total energy demand. Of which, 60% to 63% in the range 100 °C to 200 °C, and 31% to 34% in the range 200 °C to 500 °C.

2.4. Excess heat availability at other sectors

In the EU there are 461 waste-to-energy plants (Scarlat et al., 2018), of which 221 are cogeneration type, 158 electricity-only only type, and the remaining 78 are heat-only type. Mainland Portugal possesses two municipal waste incinerator electricity-only plants, LIPOR and Valorsul. No information on amounts of waste heat could be obtained nationally or in the general literature, nevertheless their cases will be analysed in the next section.

Thermoelectric power plants produce excess heat, but as it will be seen in the next section, in practice in Portugal it will be difficult or impossible to use that kind of energy source.

3. Waste heat utilization potential case studies

Usually, maximum technical potential of an energy source is much higher than feasible technical potential; and the later, higher than then economically viable potential. To investigate this aspect, in this section we will analyse a set of 17 case studies that correspond to the largest excess heat producing facilities, see the map at Figure 29.

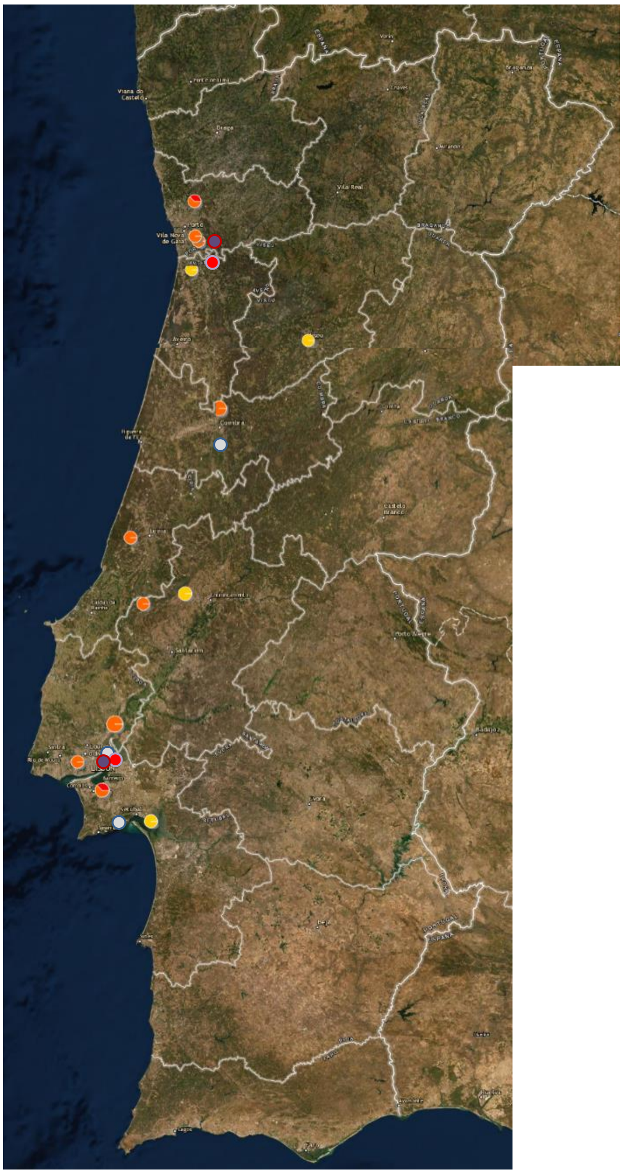

Figure 29 – Map with location of case studies.

These case studies were selected with basis on the industrial sites database provided by HoTMAPS (2020 b); in addition, also the two waste incineration power plants (LIPOR and ValorSul) and the three natural gas combined cycle power plants (Tapada do Outeiro, Ribatejo, Pego). Coal based power plants were not examined as they face decommissioning until summer of the current year (2021).

Hereafter, Figure 30 to Figure 46 show maps of the facilities selected and their surroundings, size 10 km x 10 km with the facility at the center: Also depicted are the heat demand of buildings and areas with potential users – industrial parks or dense enough urban areas –, indicated by yellow ellipses: the more promising areas drawn with a solid line, the less promising or considered unfeasible areas drawn with a dotted line. A comment is provided for each case study.

3.1. Pulp & Paper industries

The case study of Figure 30 is the “The Navigator Company” complex to the east of Setúbal. Three industrial parks are within a range of a few km, that possibly include industrial installations, and even commercial buildings, that may use excess heat. Dense urban areas (Setúbal center) are too far away.

Figure 30 – The Navigator Company facilities at Setúbal and nearby potential users of excess heat.

Renova’s Almonda paper factory, see Figure 31, is located far from any potential users.

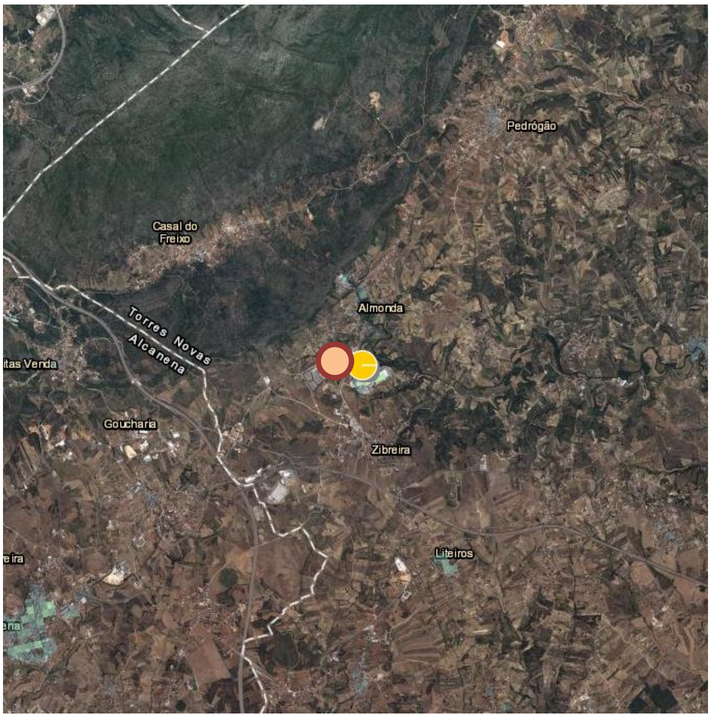

Figure 31 – Renova’s Almonda paper factory and nearby potential users of excess heat.

The Zarrinha Paper and Cardboard factory, see Figure 32, has two nearby industrial zones to the west of the facility, plus three other industrial zones further away. The surrounding urban areas have a density and aggregated heat demand too low to support district heating.

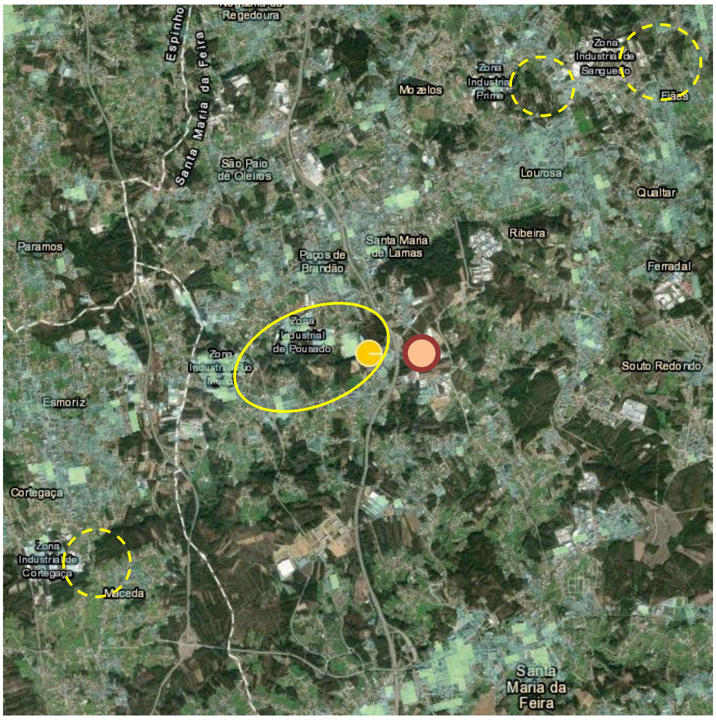

Figure 32 – Zarrinha Paper and Cardboard factory near Sta.Maria da Feira and nearby potential users of excess heat.

3.2. Steel industries

The case study of Figure 33 examines the Megasa/Siderurgia Nacional complex at Seixal. One industrial / commercial zone is located a few km to the south. The surrounding urban areas (Amora / Seixal / Barreiro) have a density and aggregated heat demand that are almost are below but close to the low limit for district heating viability, however there are two hindrances: constructions are of low thermal quality, they need from refurbishment rather than a district heating network; and anyway, possible heat transport paths are longer than it would seem has they have to circumvent water bodies.

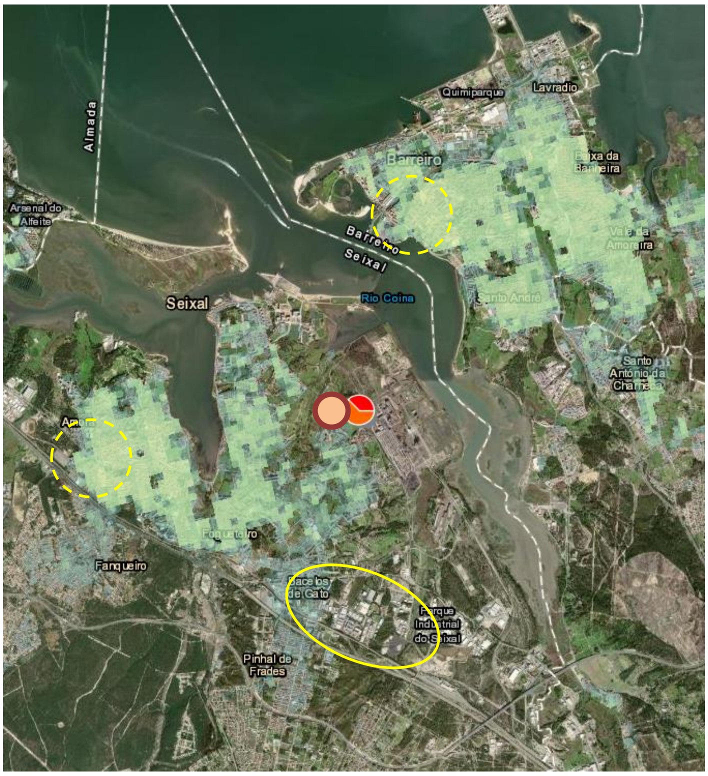

Figure 33 - SN Seixal facilities and nearby potential users of excess heat.

The case study of Figure 34 examines the Megasa/Siderurgia Nacional complex at Maia, very near an industrial zone to the west. Other facilities are identified to the north, but it is not clear if they are industrial buildings or simply warehouses; and another industrial zone is located to the south but far away. No viable district heating areas nearby.

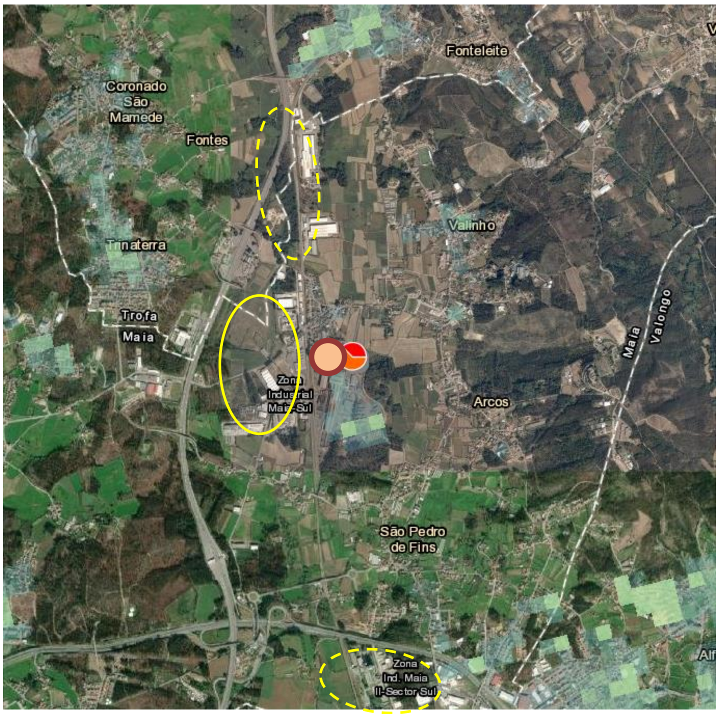

Figure 34 - SN Maia facilities and nearby potential users of excess heat.

3.3. *Glass industries*

Here we examine three facilities of the firm Barbosa & Almeida (BA) in three very different contexts.

The facilities at Amadora are located in an urban region that have several neighbourhoods with construction density and aggregated heat demand enough to support district heating, roughly located to the north of the IC 19 highway, such as Benfica, Amadora, Queluz, Massamá, Cacém/Agualva. The other zones identified in the Figure would seem to also support district heating, but, they feature constructions of very low thermal quality, whose priority is refurbishment.

This is a situation that had already been identified as promising at a previous study of this series, “Assessment of District Heating and Cooling Potential in Portugal” (DGEG, 2021 a).

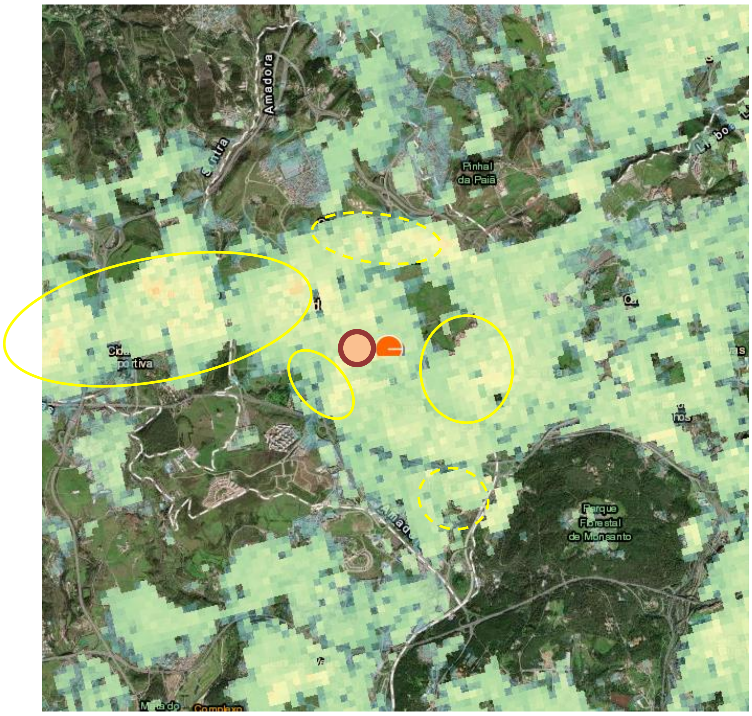

Figure 35 – BA Vidro factory at Amadora and nearby potential users of excess heat.

The BA factory at Avintes, Figure 36, is situated within an industrial area. The urban heating needs identified seem to result from wrong identification of industrial buildings as commercial ones, but close analysis would be needed. The BA factory at Marinha Grande, Figure 37, seems located nearby other industries, however our analysis suggests that these are themselves potential suppliers of excess heat.

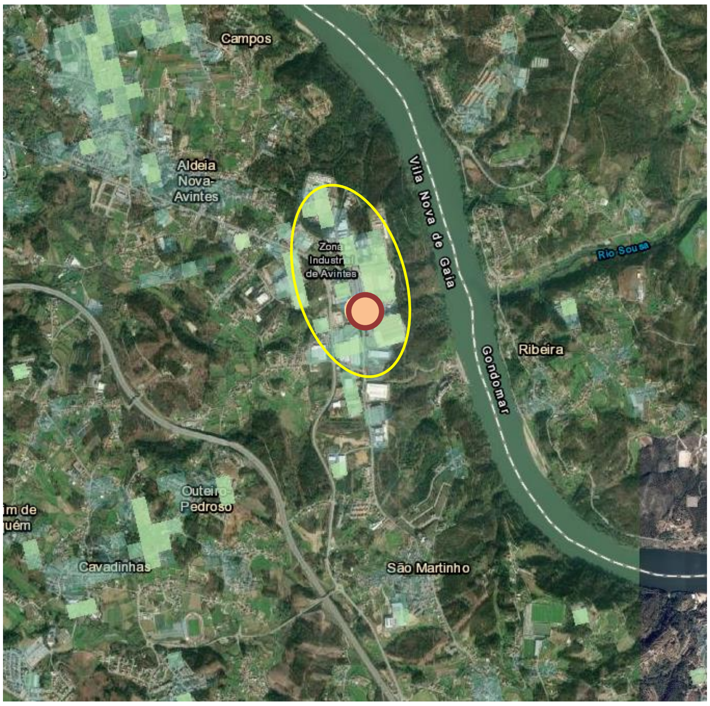

Figure 36 – BA Vidro factory at Avintes and nearby potential users of excess heat.

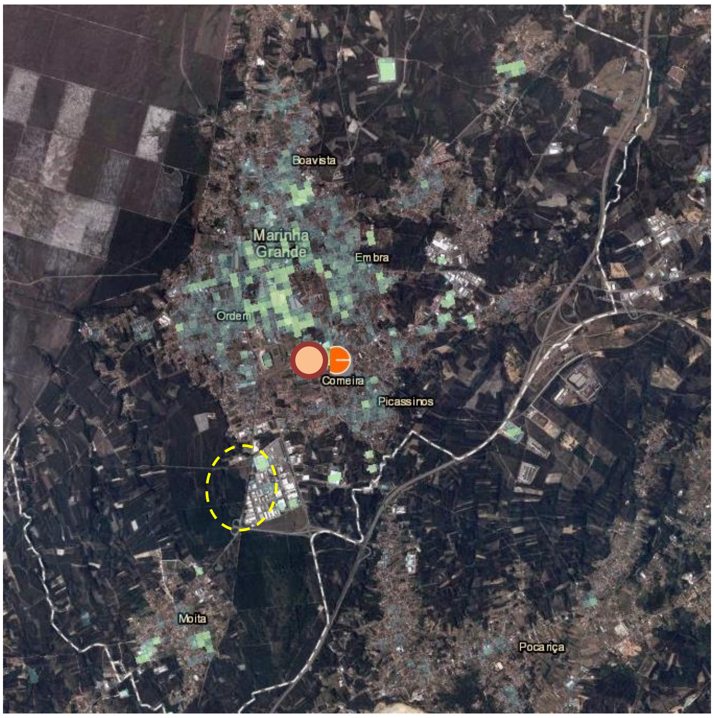

Figure 37 – BA Vidro factory at Marinha Grande and nearby potential users of excess heat.

3.4. Cement and Lime industries

The case study of Figure 38 examines the CIMPOR cement factory at Alhandra, that is near two industrial zone to the southwest. No viable district heating areas nearby. The CIMPOR factory ar Souselas is in an isolated region, see Figure 39.

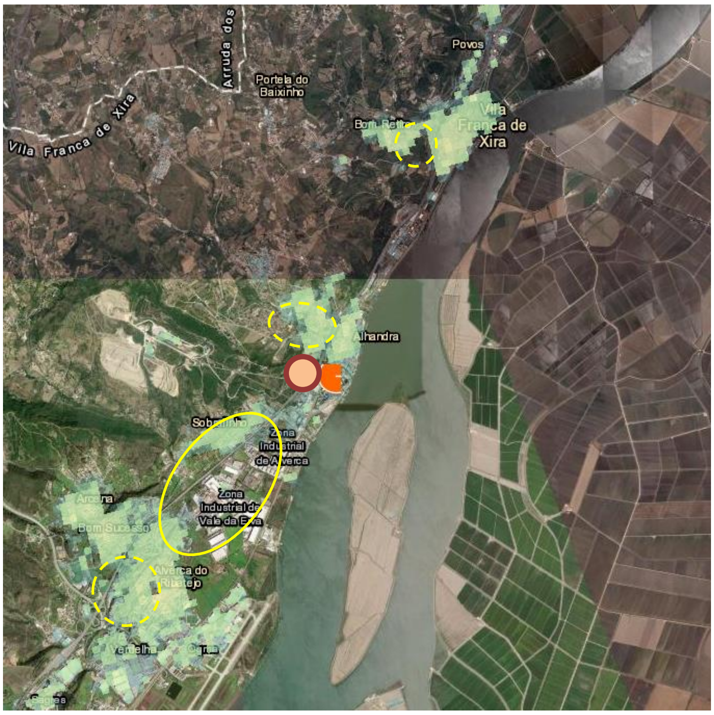

Figure 38 – CIMPOR factory at Alhandra and nearby potential users of excess heat.

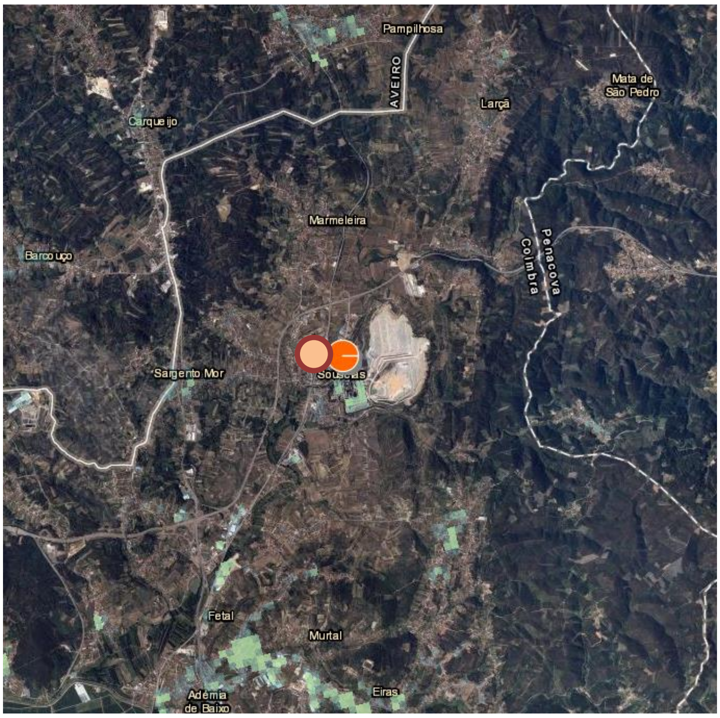

Figure 39 – CIMPOR factory at Souselas and nearby potential users of excess heat.

The SECIL factory at Outão, has potential urban users of excess heat at the Setúbal city, to the northeast. However, a possible heat transport line would have to cross a zone of very adverse topography, and plus, classified as Protected Area, so this is considered unfeasible.

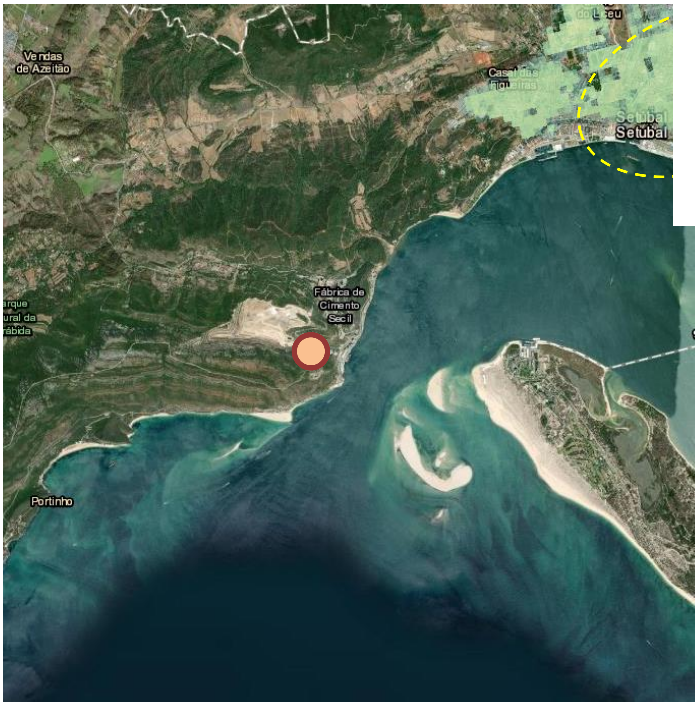

Figure 40 – SECIL factory at Outão and nearby potential users of excess heat.

The lime factory of Lhoist / Companhia Lusitana de Cal at Valverde is in a mountainous isolated region (Serra de Aire), see Figure 41.

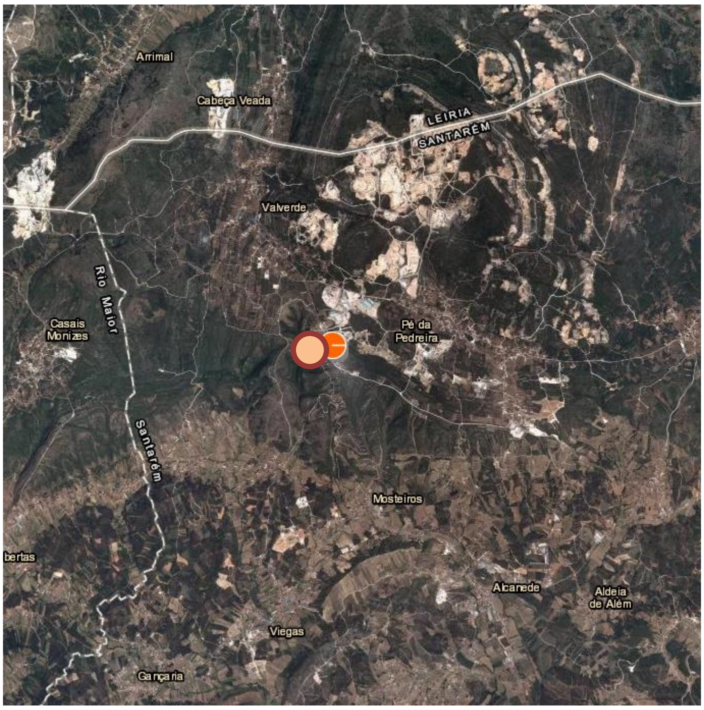

Figure 41 – Lusical lime factory at Valverde and nearby potential users of excess heat.

3.5. Thermoelectric power plants

The first case study in this category is EDP's NGCC "Ribatejo" power plant located near Carregado. Although isolated, two industrial areas not very far away are identified, at Carregado to the northwest and along the A1 highway to the southwest.

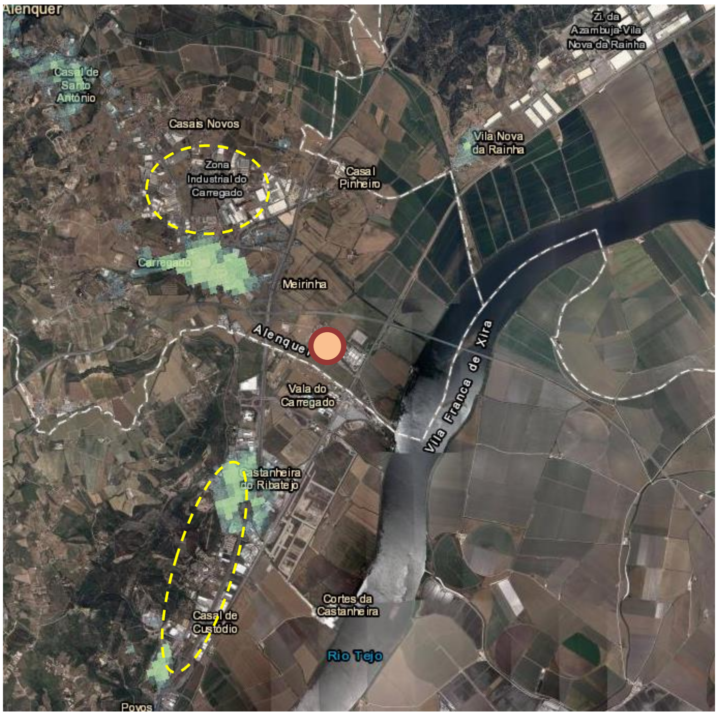

Figure 42 – EDP's Ribatejo thermoelectric power plant and nearby potential users of excess heat.

This type of thermoelectric power plants usually satisfied electrical base load and thus waste heat was almost permanently available. However, their role in the energy system is foreseen in the mid to long-term rather as providers of system services and backup power when renewable electricity is not available for weather variability reasons. Therefore, their operation is becoming more intermittent and we no longer can consider them reliable suppliers of heat.

Anyway, the other two case studies of TrustEnergy's power plants, one at Pego, see Figure 43, and another at Tapada do Outeiro, see Figure 44, are set in regions without potential users for waste heat.

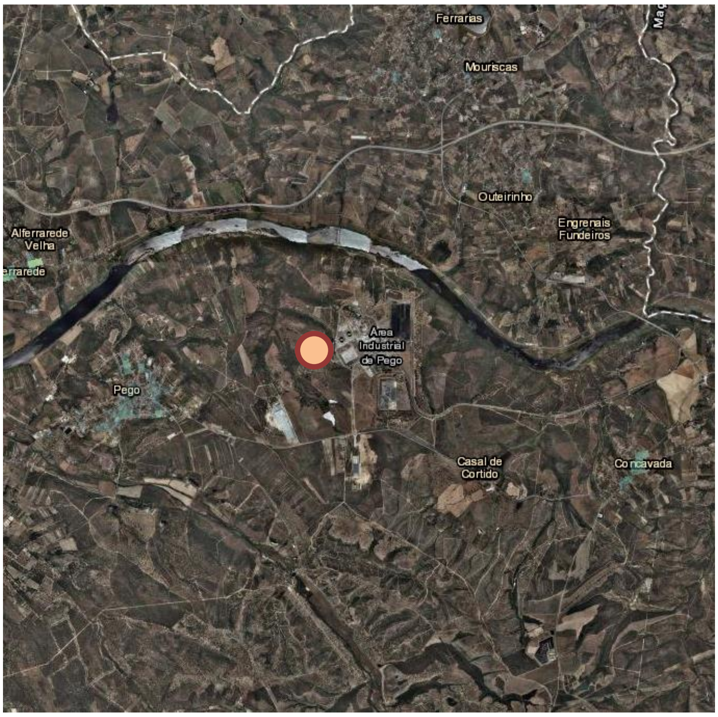

Figure 43 – TrustEnergy's Pego thermoelectric power plant and nearby potential users of excess heat.

Figure 44 – TrustEnergy's Tapada do Outeiro thermoelectric power plant and nearby potential users of excess heat.

3.6. Waste incinerators

Mainland Portugal possesses two municipal waste incinerator electricity-only plants, LIPOR at Gondomar (see Figure 45) and Valorsul to the northeast of Lisbon (see Figure 46). The fact that they are not of cogeneration type testifies that no economically viable uses for heat were available at the time of construction.

Nowadays, in the case of LIPOR we can find three small zones with industries nearby. The surrounding urban zones are two sparse to support district heating (DGEG, 2021 a).

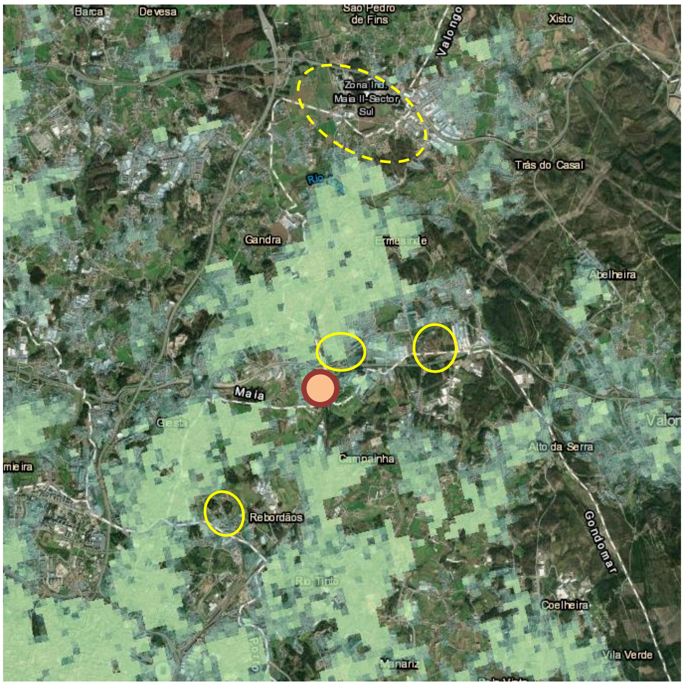

Figure 45 – LIPOR municipal waste incineration plant at Gondomar and nearby potential users of excess heat.

The case of Valorsul seems more promising. It is located near an industrial zone, with another further north. But most of all, it is not too far from the ClimaEspaço district heating network at "Parque das Nações" (eastern Lisbon). Therefore, waste heat could in principle be transported to replace heat currently being supplied by the natural gas based cogeneration unit that powers the network, but faces economic viability challenges as the cogeneration feed-in tariff nears the end of its allowed period. This opportunity was already was identified at a previous study of this series, "Assessment of District Heating and Cooling Potential in Portugal" (DGEG, 2021 a), wherein a more detailed analysis can be found.

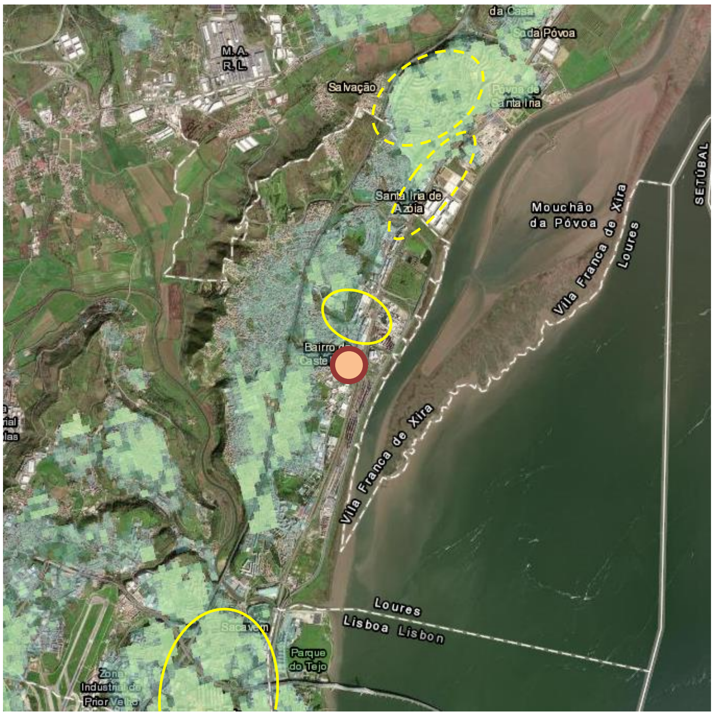

Figure 46 – Valorsul municipal waste incineration plant at S. João da Talha and nearby potential users of excess heat.

4. Conclusions

Considering the case studies in section 3, we can now complete the top-down analysis of section 2. We estimate that about 30% of the maximum “theoretical” potential could be faced as technically feasible. A more accurate estimate would require bottom-up surveys at local scale, a line of action that we must leave for other academic researchers, or for another edition of the current study.

Besides the feasible technical potential, there is still the economic viability issue. For the moment we can only provide estimates based on expert judgment from experience with assessments with other types of energy sources: a 60% success of this further type of analysis is assigned. In addition, we assume 40% situations were, although economic viability exists, there are barriers (like low capacity for investment) or there are other energy efficiency measures are more attractive, e.g. changing fuels, installing regenerative burners (Micke, 2019) or integration of processes to improve the utilization of waste heat itself (e.g. for the cement industry, see Boldyryev, 2018).

Accounting for all this, we end up with the estimate for technically and economically viable utilizations of waste heat around 1% of the total energy demand of industry.

This is not an insignificant figure but must be contrasted with other energy efficiency alternatives. For instance, substitution of recuperative burners by regenerative burners can improve the efficiency by several percentual points, and integration of processes can be even more effective. Therefore, as waste heat utilization outside the heat producing facility involves substantial investments for recovering, transporting, and distributing the excess heat, very likely it will not rank first among energy efficiency measures in industry. However, for a few district heating cases it can be an interesting option, as discussed in section 3 and in DGEG (2021 a).

It is also remarked that while the potential for waste heat utilization is small at country level, it may make important contributions at the specific situations when it is employed, be it for powering district heating or for industrial facilities.

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Annex I - Indications regarding EED reporting

Regarding the reporting items required by EED Article 14(1), related to waste heat and listed at its Annex VIII, the following contributions can be taken from this study:

Point (e) "(…) identification of the potential for [additional high-efficiency cogeneration, including from the refurbishment of existing and the construction of new generation and] industrial installations or other facilities generating waste heat"

Two potential cases were found, the a glass factory at Amadora and an waste incineration plant to the east of Lisbon.

Point (g) "(…) strategies, policies and measures that may be adopted up to 2020 and up to 2030 (…) including, where appropriate, proposals to:"

(…)

"(ii) develop efficient district heating and cooling infrastructure to accommodate the development of high-efficiency cogeneration and the use of heating and cooling from waste heat and renewable energy sources;"

In conjunction with the analyses and conclusions of the report "Assessment of District Heating and Cooling Potential in Portugal" (DGEG, 2021 a), other than for the case of Amadora that was already mentioned before, no clear cases were fond to justify additional district heating and cooling infrastructures.

"(iii) encourage new thermal electricity generation installations and industrial plants producing waste heat to be located in sites where a maximum amount of the available waste heat will be recovered to meet existing or forecasted heat and cooling demand;"

Considering the high level energy-emissions planning of Portugal, viz. Carbon Neutrality Roadmap (CNR, 2019), National Energy and Climate Plan (NECP, 2020), and National Strategy for Hydrogen (EN-H2, 2020), there are no new thermal power plants planned for at least the next decade; neither does the industry outlook supports expectations of additional industrial plants producing waste heat.

"(iv) encourage new residential zones or new industrial plants which consume heat in their production processes to be located where available waste heat, as identified in the comprehensive assessment, can contribute to meeting their heat and cooling demands (…);"

New residential zones will be built under the Near Zero Energy Building standard (NZEB, 2019), which in Portugal means that will have very low heating needs, indeed close to null in vast areas of the territory; as regards co-location of industrial plants near waste heat sources, it is indeed a possibility but it must remarked that in many situations it will not be possible (see section 4) and also that the outlook for new industries is not favorable (see section 3) and using electricity instead of heat is preferred.

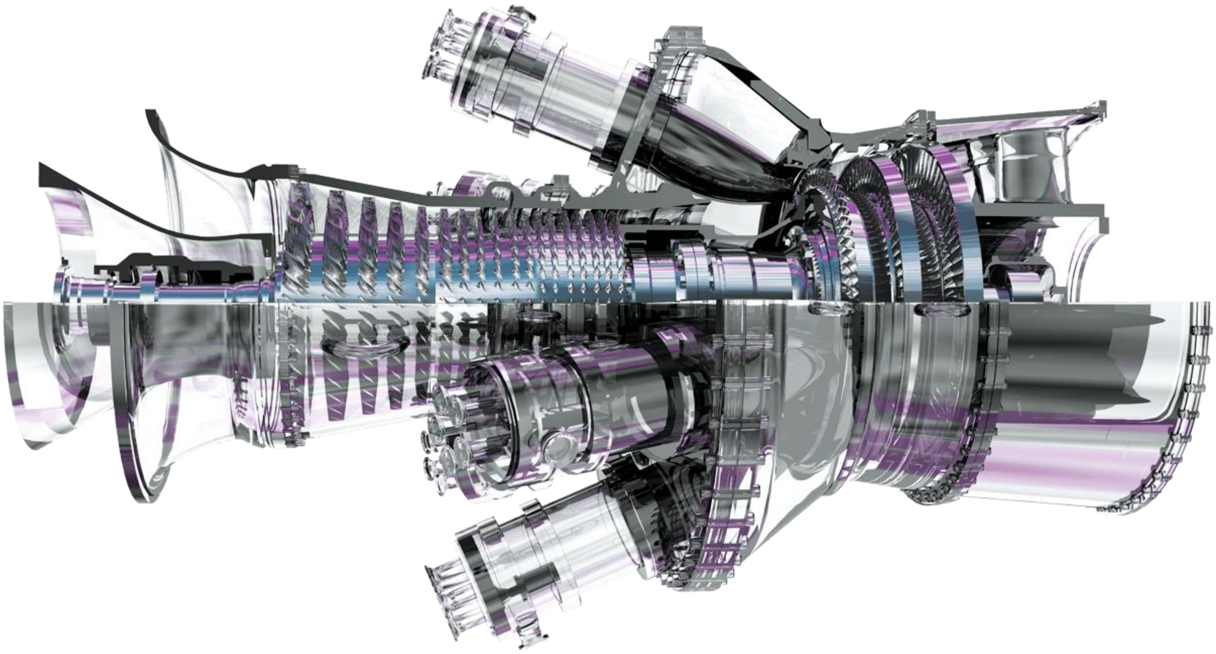
“(v) encourage thermal electricity generating installations, industrial plants producing waste heat, waste incineration plants and other waste-to-energy plants to be connected to the local district heating or cooling network;”

Only a single potential case was identified, namely the binomial the district heating network at Parque das Nações, Lisbon, and an waste incineration plant located not too far from it; to the best of our knowledge, this solution may already be receiving attention..

(…)

“(i) an estimate of the primary energy to be saved;”

The feasible technical and economic potential energy savings at the manufacturing industry are estimated at 1% of its final energy demand, meaning for 2020, ca. 2.1 PJ (575 GWh) in terms of primary energy. To this, district heating powered by waste heat could add around 0.3 PJ (86 GWh: 31 GWh at Amadora and 55 GWh at Parque das Nações). Although currently there are no commitments from promotors or specific measures from public policies aimed at securing these amounts, there are however policies and measures in the NECP to meet 2030 EED country obligations that can lead to choices of action from the part of industries to capture this potential.



Cogeneration Outlook for Portugal

DEIR STUDIES ON THE PORTUGUESE ENERGY SYSTEM 004

Date

First edition: January 17, 2021

Addresses

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Index

1. Introduction

This study is meant to examine the potential and trends of cogeneration of heat and power (CHP) in Portugal, from the microlevel point of view of owners of CHP units as well as from a country level point of view of public policies for achieving sustainability through renewable energy and carbon neutrality.

This work is also conceived as a contribution to the reporting obligations of Portugal[5] under the Article 14(1) of the Directive 2012/27/EU, known as Energy Efficiency Directive (EED, 2012), amended in 2018 by Directive 2018/2002/EU, as part of the 'Clean energy for all Europeans package'. Relevant extracts of EED are provided at Annex I, wherein it can be checked that many reporting items (underlined in that text) are covered by this study.

Let us start by briefly reviewing the logic and benefits of CHP. As compared to separate production of electricity and thermal energy production *using the same fuel sources*, there are:

- efficiency gains - CHP requires less fuel to produce a given energy output, because the combined heat production and electricity production efficiency is larger than using separate processes; also, it avoids transmission losses and some distribution losses that occur when transporting the electricity generated at a distant fuel-based power plant.
- environmental benefits – as less fuel is burned with CHP, emission of greenhouse gases and other air pollutants is reduced in comparison with the separate processes.
- reliability – at microlevel enables continuous operations whereas the utility grid service can sometimes failure (due to storms, etc.); at country level it contributes for security of supply.
- economic advantages - due to the difference between fuel and electricity costs, it makes sense to produce cogeneration electricity locally; for instance, in the first semester of 2020 the natural gas price in Portugal for industrial consumers averaged 34.7 €/MWh (DGEG, 2020 c) whereas electricity costs averaged 124.8 €/MWh (for a same consumption band of 3 GWh to 30 GWh per year), thus in this case a 3.6 difference (spark ratio) exists. Furthermore, there might be an extra revenue from selling electricity under regulated tariffs, that Governments often have attributed because of the mentioned efficiency and environmental benefits.

It is remarked that EED assumes that it is always beneficial to implement more CHP, provided a cost-benefit analysis is positive. Many all-Europe studies (e.g. Artelys, 2020) do find a large CHP potential yet to be tackled. However, it will be shown that, for Portugal, in some cases the new energy-emissions paradigm comes to challenge that assumption as well as the usually mentioned benefits listed above.

We will start by examining the potential for additional CHP (or lack thereof) using a traditional approach, projecting heat demand for each economic sector and estimating if and how much could be satisfied by CHP.

Then we will examine if the conventional logic of CHP still holds or must be adjusted, under the Portuguese national energy-emissions roadmaps and plans and its objectives, especially for the cases of fossil fuel based CHP and network gas-based CHP. Potential micro-CHP application will also be discussed in this section.

[5] Meaning mainland Portugal; the autonomous regions of Madeira Islands and Azores Islands are not covered by this study as they handle their own obligations with respect to EU Directives.

2. Conventional perspectives for cogeneration

The conventional approach to assess additional cogeneration potential is typically composed of a macro and a micro assessment. First, it is assessed the evolution of the heat demand at for each economic sector, based on projections of some activity index, typically gross value added (GVA). Then, to satisfy and/or capture extra heat demand, a micro scale economic viability study is done for various cogeneration technologies – in respect to each other as well as in respect to other options for supplying electricity and heat. Hereafter we present for Portugal the macro assessment part of this approach, based on the Portuguese NECP. However, for reasons to be apparent later in this study, a micro assessment will be delayed until after we analyse the impact of the energy transition and the related new public policies on the cogeneration perspectives.

2.1. Cogeneration at Industry

We start by presenting the scenarios that will base the analysis, slightly adapted from those of the National Strategy for Hydrogen (EN-H2, 2020b); then, perspectives for each subsector of the manufacturing industry, by order of the respective current cogeneration heat demand.

For each subsector, it is presented the final energy demand (2012-2017 historical; 2018-2040 projection), at a scale adequate to appreciate the energy mix, and in particular the role of cogeneration heat. Also, it is presented the cogeneration energy input mix and outputs (heat and electricity). A short comment will be provided in each case. Note that in Portugal, the glass, metallurgy, and steel subsectors do not possess cogeneration.

At the end of this section, we will examine the aggregated cogeneration power, energy input and output for the whole manufacturing industry sector.

2.1.1. Sectorial activity and energy demand projections

We take the most widely used approach to projection of final energy demand at industrial subsectors, which is to make it proportional to its Gross Value Added (GVA). We first take the national Gross Domestic Product (GDP), projections of EN-H2, which in turn are based on those of the National Energy and Climate Plan 2030 (NECP, 2020) scenario with adjustments for the impact of Covid-19 pandemic (DGEG, 2020 a), see Figure 47.

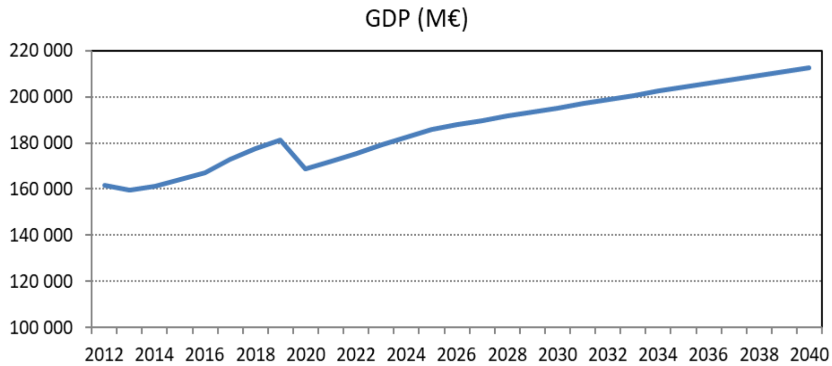

Figure 47 - Gross Domestic Product scenario.

Then the historical GVA shares for 14 manufacturing industry subsectors are projected in a conservative way, yielding absolute values when multiplied by the GDP, see Figure 48.

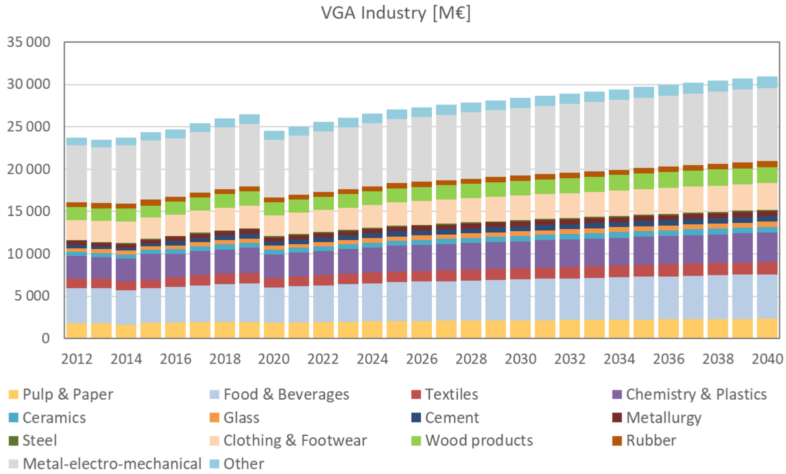

Figure 48- Gross Value Added of 14 manufacturing industry subsectors.

The final energy consumption at each subsector is considered proportional to its GVA, without elasticities. Expected energy efficiency gains are factored in via energy intensity drops in respect to GVA. Finally, the historical shares of the different fuels consumed in each industrial subsector are projected and multiplied by the overall subsector energy demand to obtain final energy demand of each fuel. This is the most delicate and uncertain step; however, guidance is provided by the high-level energy strategy of long-term plan or roadmap in use.

As an example, the overall demand mix of the manufacturing industry is shown in Figure 49. cogeneration heat, electricity and network gases dominate the picture. Notice the emergence of (renewable) hydrogen from 2030 onwards. As we will discuss later, network gases today mean just natural gas, but hydrogen will also be present in the gas blend from 2022 onwards, and synthetic fuels made with hydrogen, from 2025 onwards. There is a trend for larger electrification of the sector, although not very intense. Fossil fuels phase out slowly. Biomass appears as a minor contributor to the mix; however, we are dealing with final energy demand, so in fact, through electricity, and especially through cogeneration, biomass plays a much more significant implicit role.

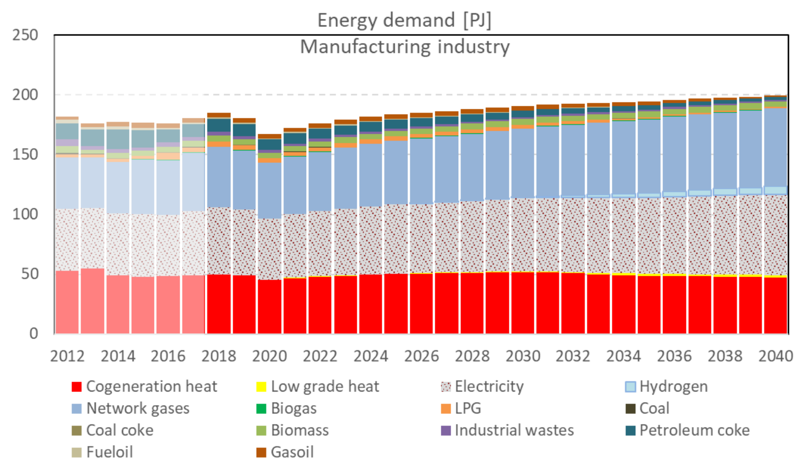

Figure 49 - Final energy demand mix of the manufacturing industry.

2.1.2. Pulp & Paper

This sector is an excellent case of cogeneration use. As can be appreciated in Figure 50, the cogeneration heat supplies about 73% of the final energy demand related to heat. This demand is expected to growth until 2030 due to more subsector activity, but then decrease somewhat due grow of paper recycling amounts. The cogeneration input is dominated (ca. 72%) by biomass fuels: forest wastes and black liquors obtained from the industry's own processes. The output is strongly biased towards heat. The outlook for the installed power is stable, as it can accommodate the variations in demand.

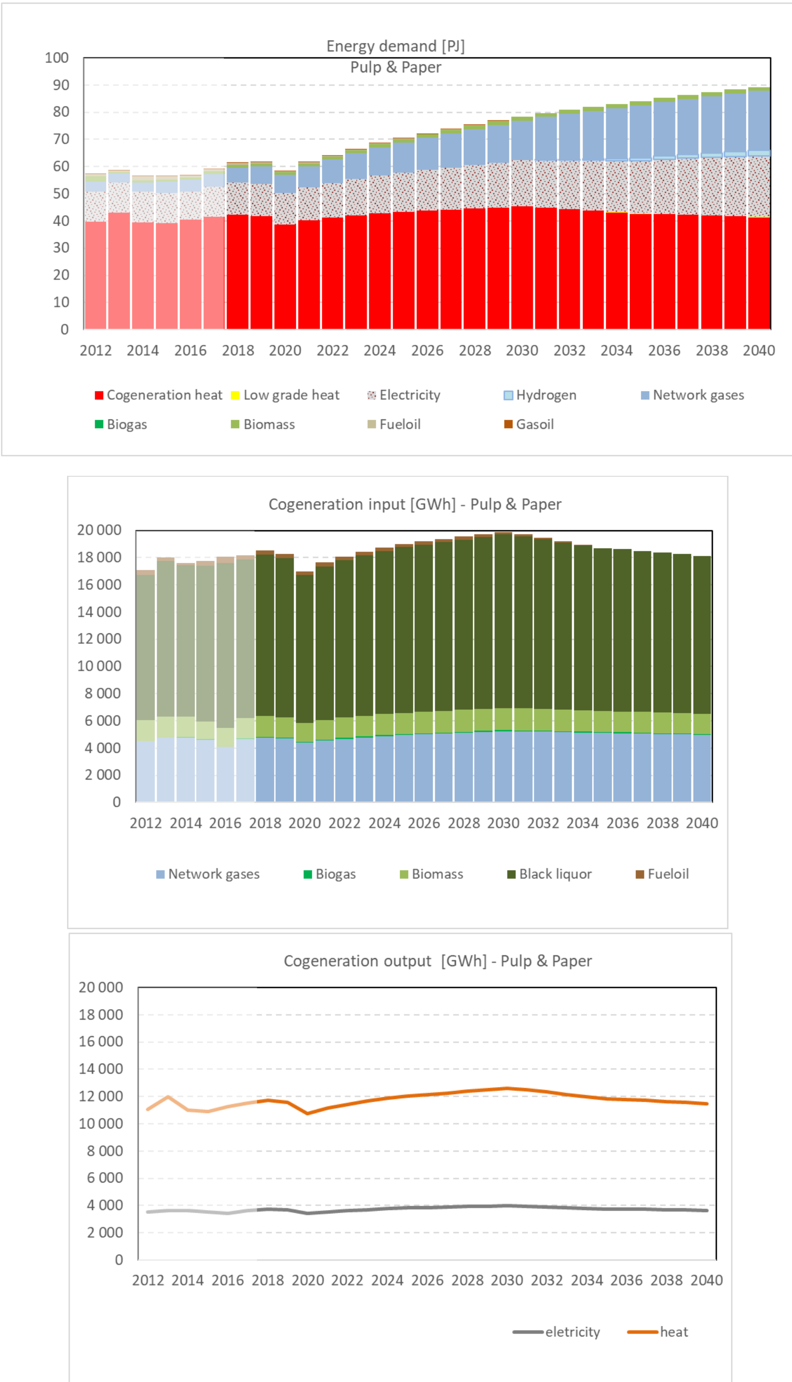

Figure 50 - Historical record and forecasts for final energy demand and cogeneration at the pulp & paper subsector.

2.1.3. Textiles

As can be appreciated in Figure 51, the cogeneration heat supplies about 24% of the final energy demand related to heat. This is expected to decrease somewhat due to electrification and less activity at the subsector. Fueloil-based cogeneration was discontinued in 2014, only network gases are currently used. The output is biased towards electricity, not heat, which suggests that some installations might originally have been dimensioned to be viable under electricity feed-in tariffs, now being phased-off. Even if this analysis is not correct, the outlook for the installed cogeneration power is negative due to overall energy demand reduction and electrification.

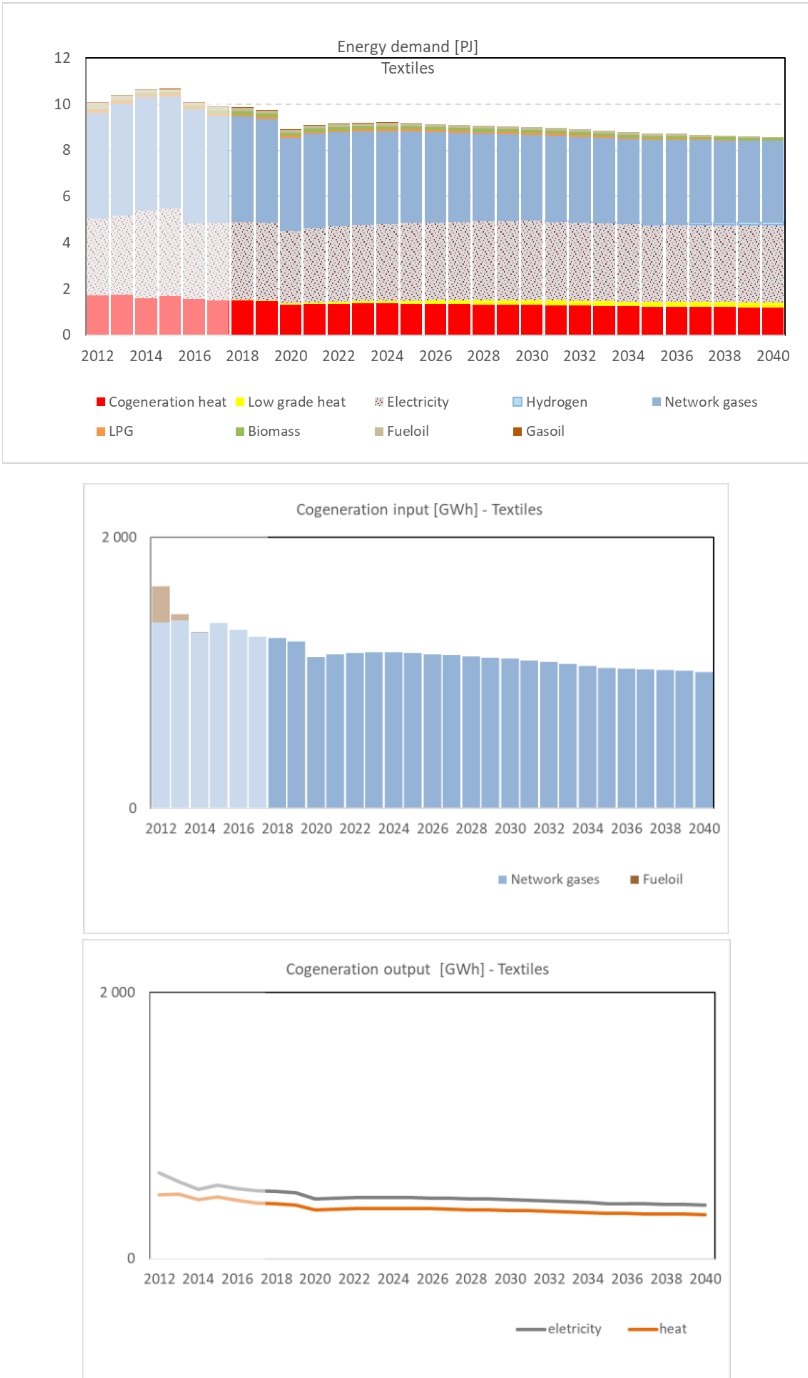

Figure 51 - Historical record and forecasts for final energy demand and cogeneration at the textiles subsector.

2.1.4. Chemistry & Plastics

As can be seen in Figure 52, the cogeneration heat supplies about 23% of the final energy demand related to heat, which can be seen as low when compared with the 90% potential estimated by Klotz et al. (2014) for this subsector (although it refers only to temperatures below 300 °C). The predominant input to cogeneration is network gases, but still gas (non condensable gases from petrochemistry) is also important. A phase-out of fueloil is expected. Chemistry and plastics are expected to retain their importance; and cogeneration, especially from still gas generated by the chemical processes themselves, makes much sense. So, the outlook for the installed cogeneration power is stable.

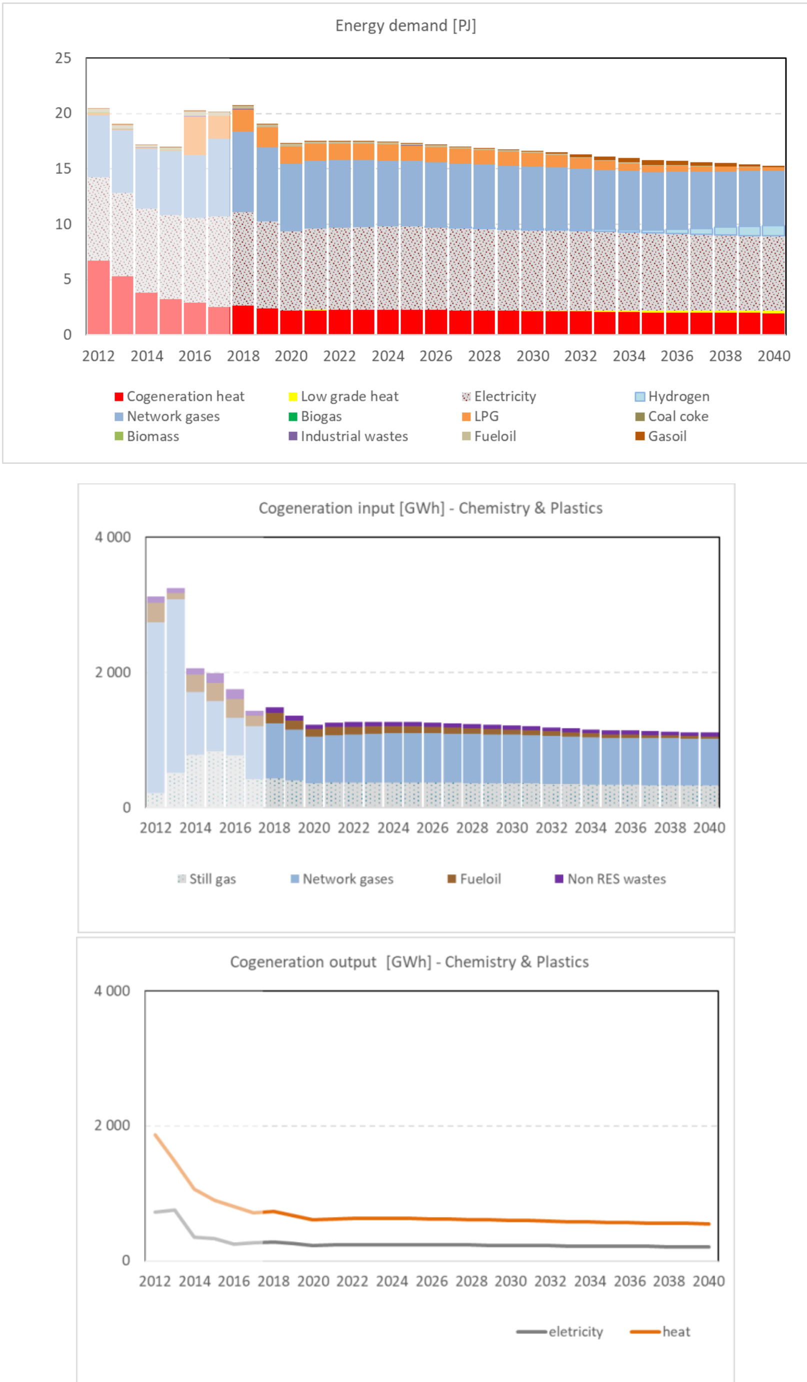

Figure 52 - Historical record and forecasts for final energy demand and cogeneration at the chemistry and plastics subsector.

2.1.5. Food & Beverages

As can be appreciated in Figure 53, the cogeneration heat supplies about 16% of the final energy demand related to heat, low in comparison with the 100% potential estimated by Klotz et al. (2014). The cogeneration input mix is dominated by network gases, fueloil is expected to enter in phase-out. The outlook for the installed cogeneration power is stable.

From this point on, the contribution of subsector cogeneration to the overall industry panorama is very small, nevertheless we will continue to review all subsectors.

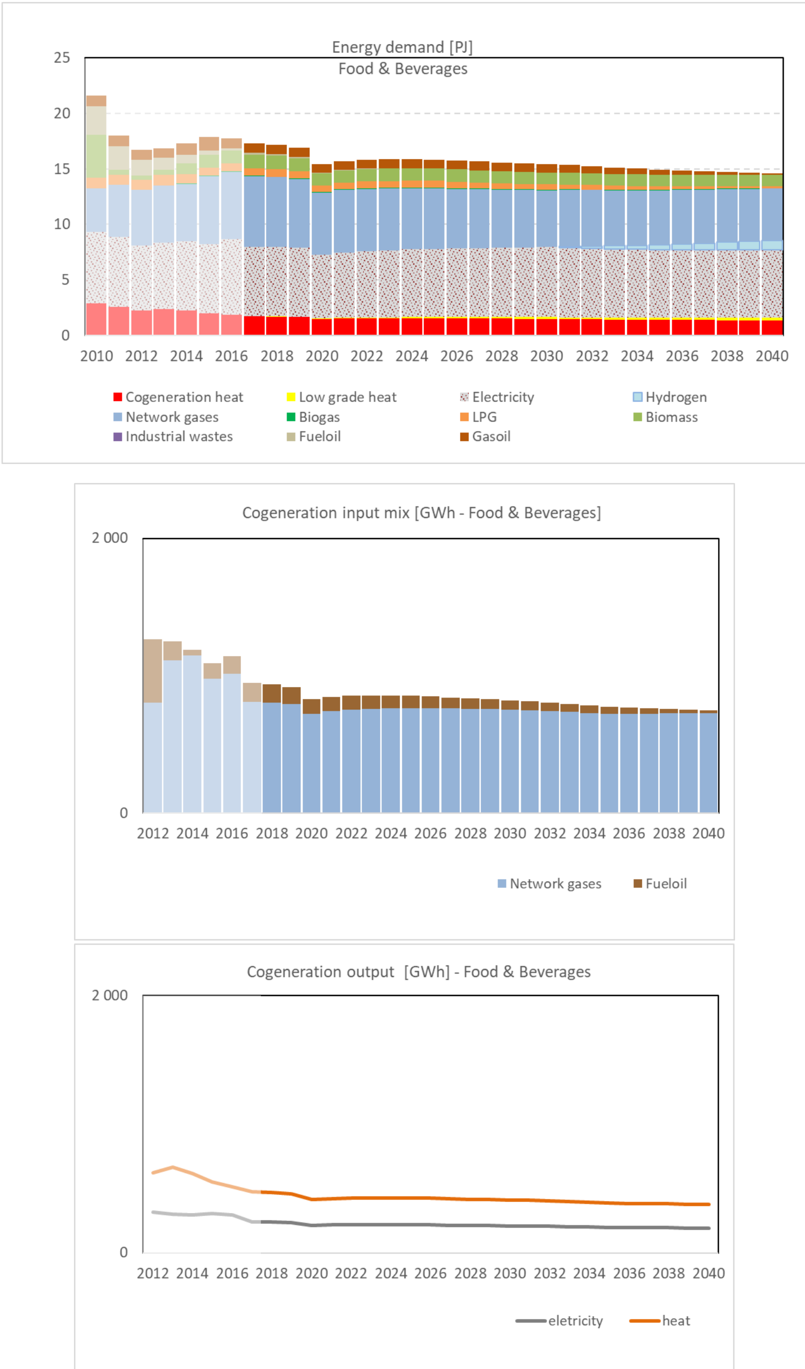

Figure 53 - Historical record and forecasts for final energy demand and cogeneration at the food & beverages subsector.

2.1.6. Ceramics

Energy demand at this sector is dominated by high range heat for ceramic ovens; therefore, as seen in Figure 54, cogeneration supplies less 7% of the final energy demand related to heat. This is a very high value as Klotz et al. (2014) estimate such a value to be the maximum potential for this subsector. The cogeneration input is almost only network gases, fueloil is by now almost phased-out. The outlook for the installed cogeneration power is stable.

Figure 54 - Historical record and forecasts for final energy demand and cogeneration at the ceramics subsector.

2.1.7. Wood products

Figure 55 shows that the cogeneration heat supplies about 13% of the final energy demand related to heat; Klotz et al. (2014) provide no estimates in this case, but at least 80% maximum potential can be assumed. The cogeneration input mix is dominated by biomass wastes obtained from the own resource and fabrication processes of this sector. Fueloil is a minor input and is expected to be progressively substituted by network gases. The outlook for the installed cogeneration power is stable.

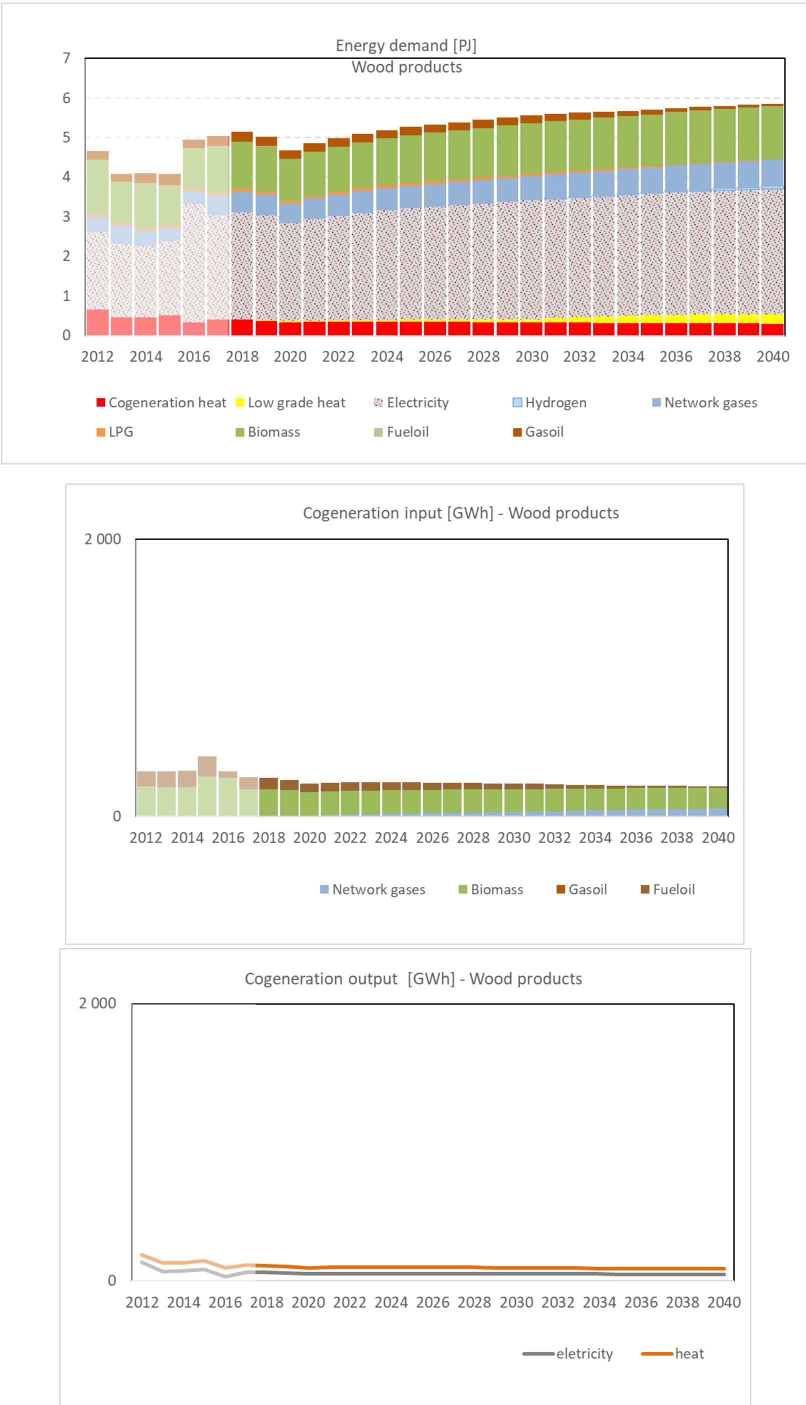

Figure 55 - Historical record and forecasts for final energy demand and cogeneration at the wood products subsector.

2.1.8. Rubber

The rubber subsector has very low importance in the context of the energy consumption of industry in Portugal, but it a subsector with one of the highest percentages of heat attended by cogeneration, around 65%, see Figure 56 (Klotz et al. give a full 100% as maximum potential). The cogeneration input mix is dominated by network gases but there is a contribution from the wastes generated by this industry's own fabrication processes. The outlook for the installed cogeneration power is stable.

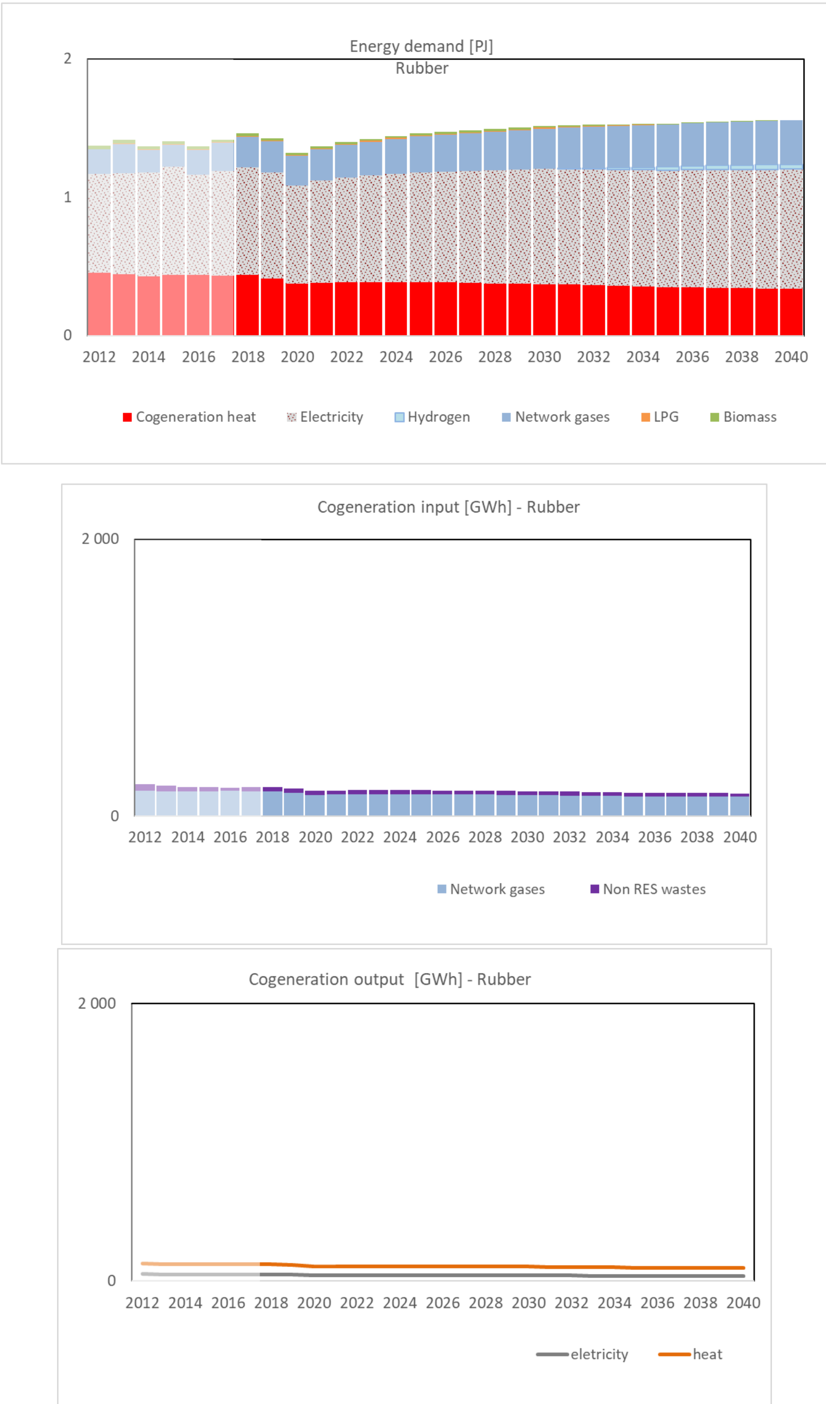

Figure 56 - Historical record and forecasts for final energy demand and cogeneration at the rubber subsector.

2.1.9. Cement

Cogeneration is of low importance to the cement subsector, because of the high temperatures required by some phases of the fabrication processes and because of the availability of waste heat fluxes from these processes (Boldyryev, 2018). Indeed in Portugal, cogeneration heat represents under 0.5% of the entire final heat related energy demand (too small to be visible at Figure 57). The input mix is dominated by network gases. The outlook for the installed cogeneration power is stable.

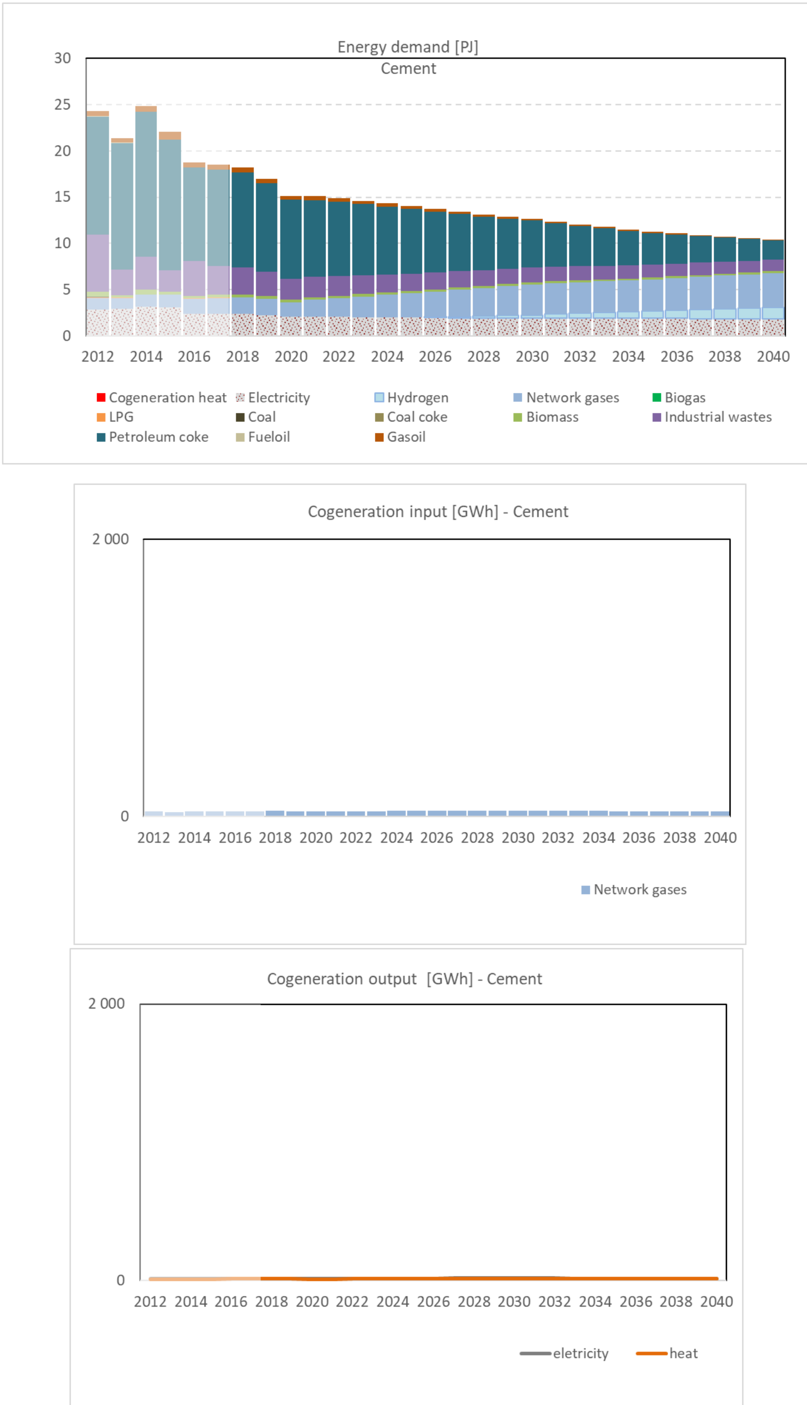

Figure 57 - Historical record and forecasts for final energy demand and cogeneration at the cement subsector.

2.1.10. Clothing & Footwear

As can be appreciated in Figure 58, cogeneration supplies about 10% of the final energy demand related to heat; Klotz et al. (2014) provide no estimates in this case, but an 80% maximum potential can be assumed. The cogeneration input has been made solely of network gases. The outlook for the installed cogeneration power is stable.

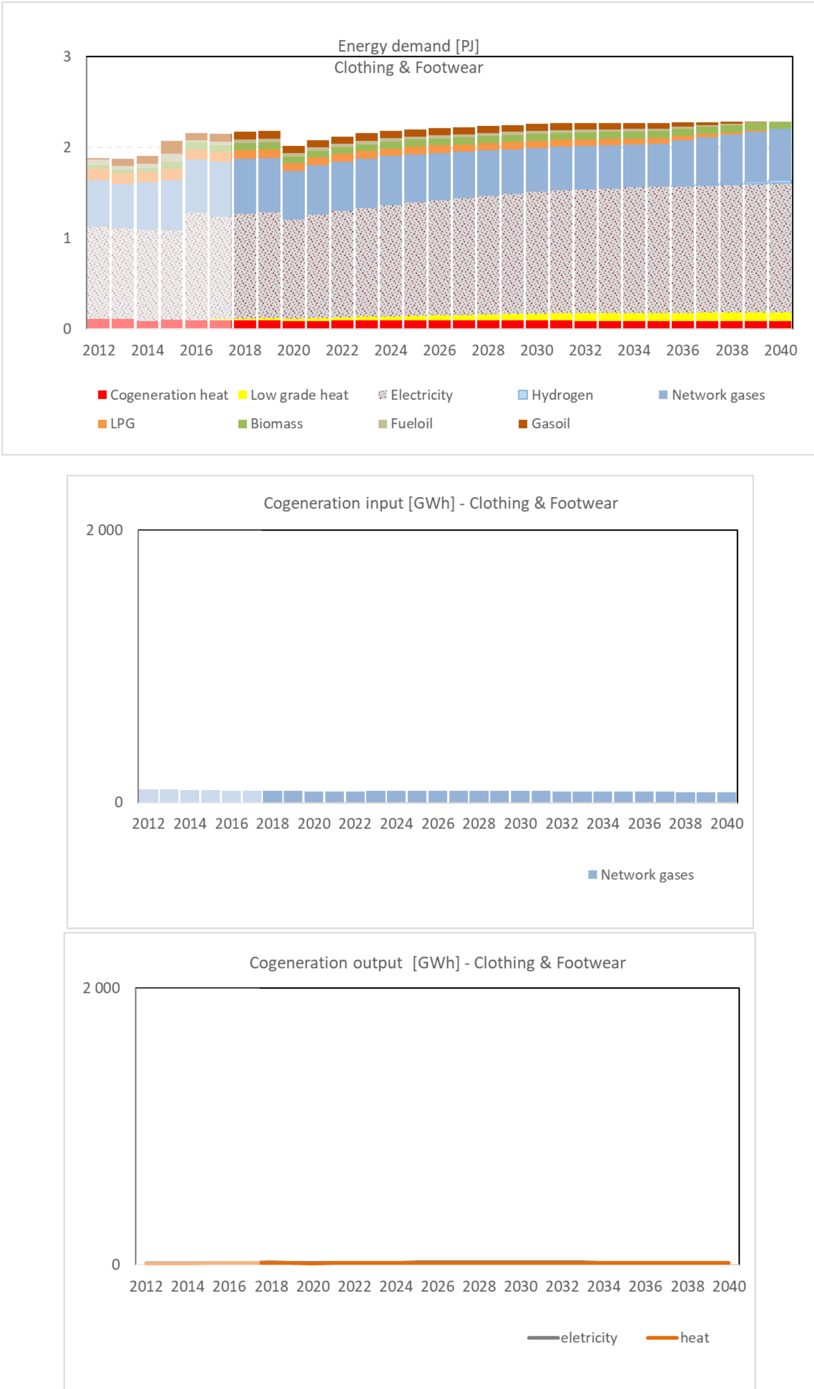

Figure 58 - Historical record and forecasts for final energy demand and cogeneration at the clothing and footwear subsector.

2.1.11. Metal-electro-mechanics

Again, at this subsector the contribution of cogeneration to final heat demand is of low importance: around 1%, too small to be visible at Figure 59. ; Klotz et al. (2014) mentions a maximum potential of 19%, but it must be recalled that this is estimated just for temperatures below 300 °C. The cogeneration input consists of network gases. The outlook for the installed cogeneration power is negative, due to electrification and reduction of energy demand.

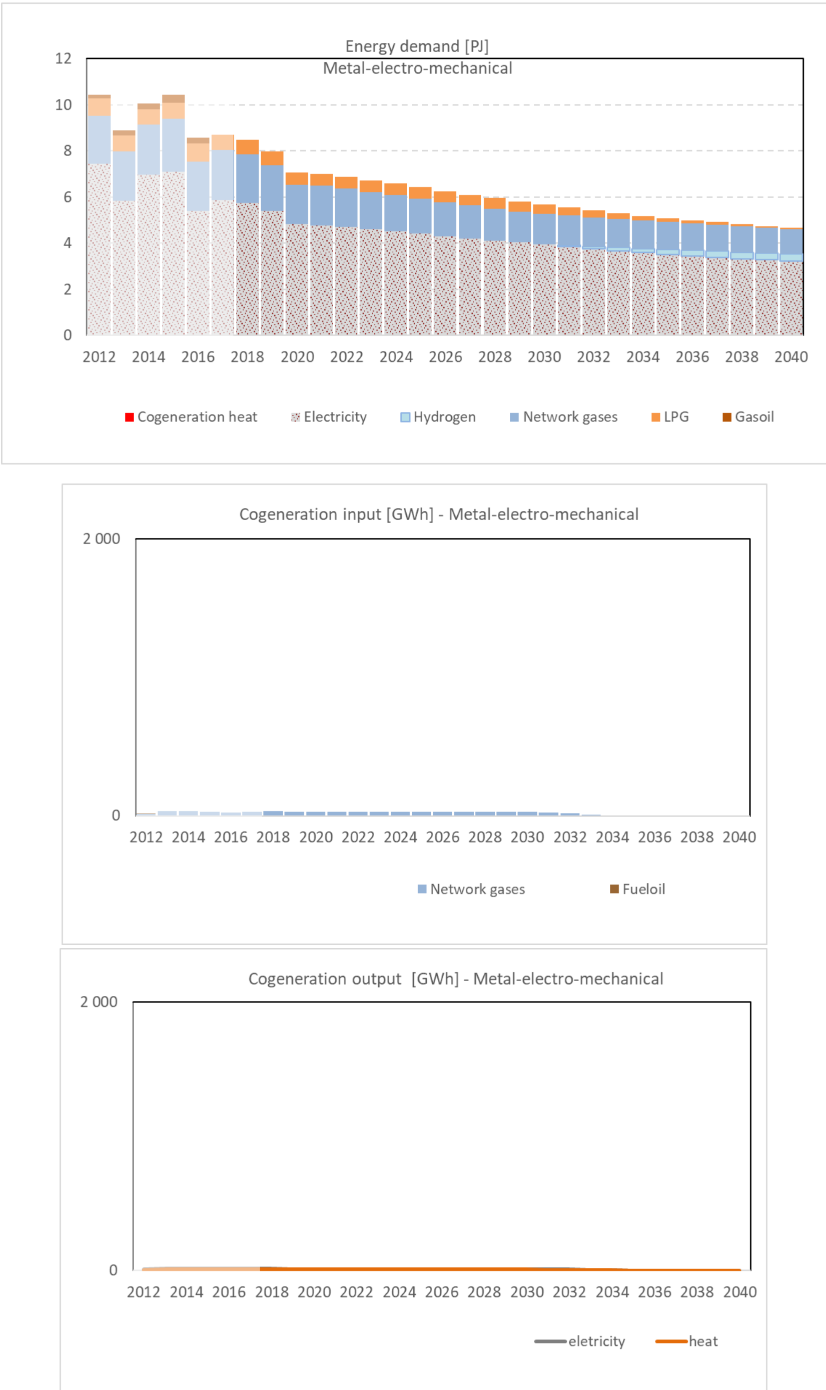

Figure 59 - Historical record and forecasts for final energy demand and cogeneration at the metal-electro-mechanics subsector.

2.1.12. Other

The remainder cogeneration units are dispersed by several minor subsectors and activities, contributing to final heat demand around 3%, barely visible at Figure 60. The cogeneration inputs are biogas and network gases. The outlook for the installed cogeneration power is stable.

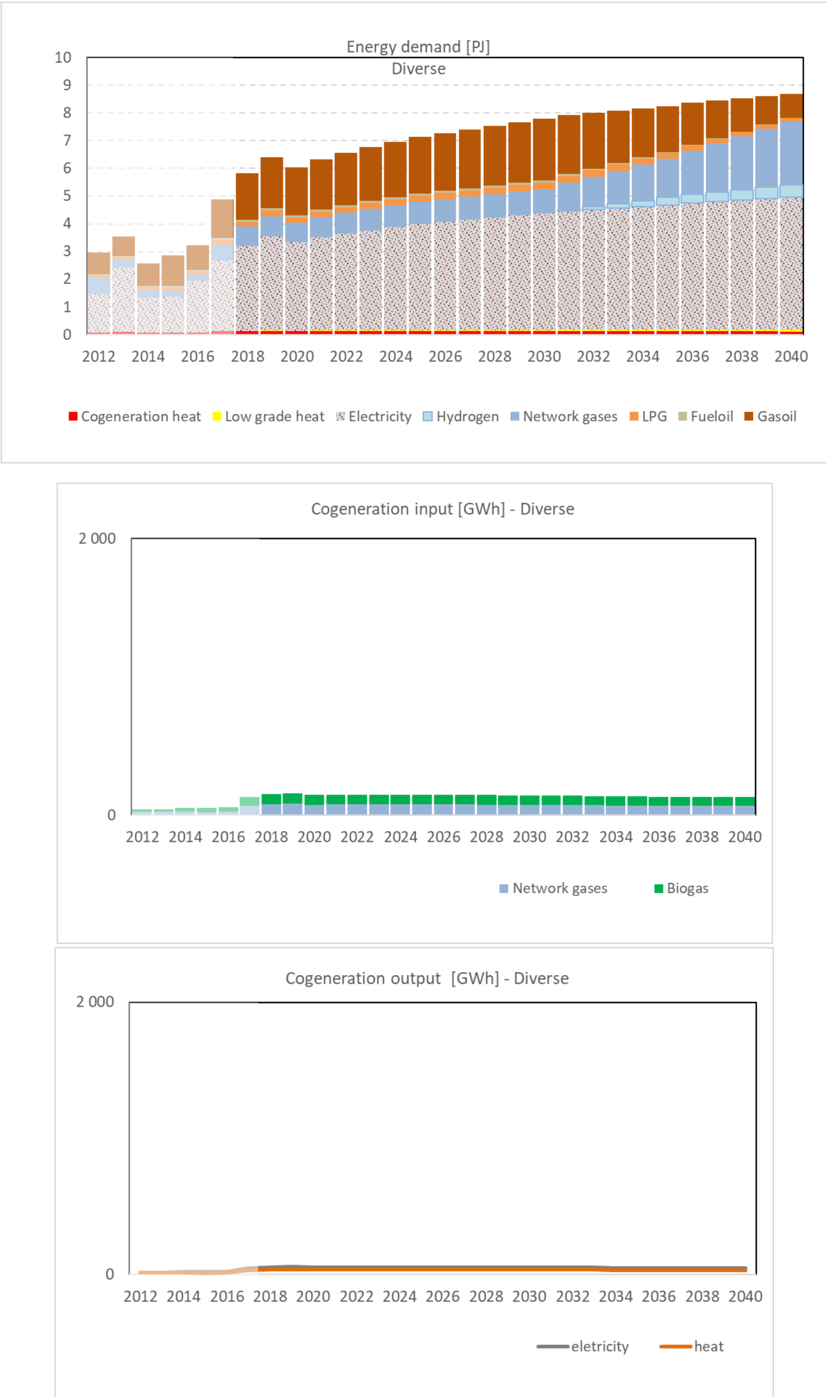

Figure 60 - Historical record and forecasts for final energy demand and cogeneration at other minor subsectors.

2.1.13. Overall

Aggregating results for the whole manufacturing industry, the cogeneration outlook is essentially stable. For the installed power, the projections show a slight reduction after 2030, see Figure 61.

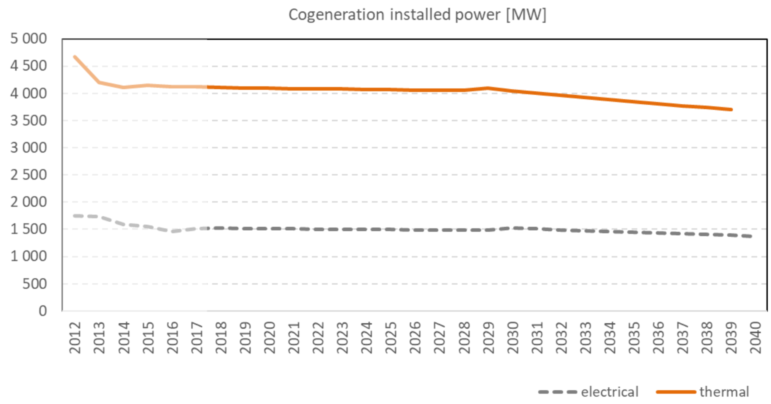

Figure 61 - Historical record and forecasts of the installed power of industrial cogeneration.

Figure 62 displays the cogeneration electricity and heat outputs, in a manner that enables to compare the relative importance of each subsector. Clearly, the cogeneration at the pulp & paper subsector dominates the panorama (about 85% of the outputs), including the long-term trend.

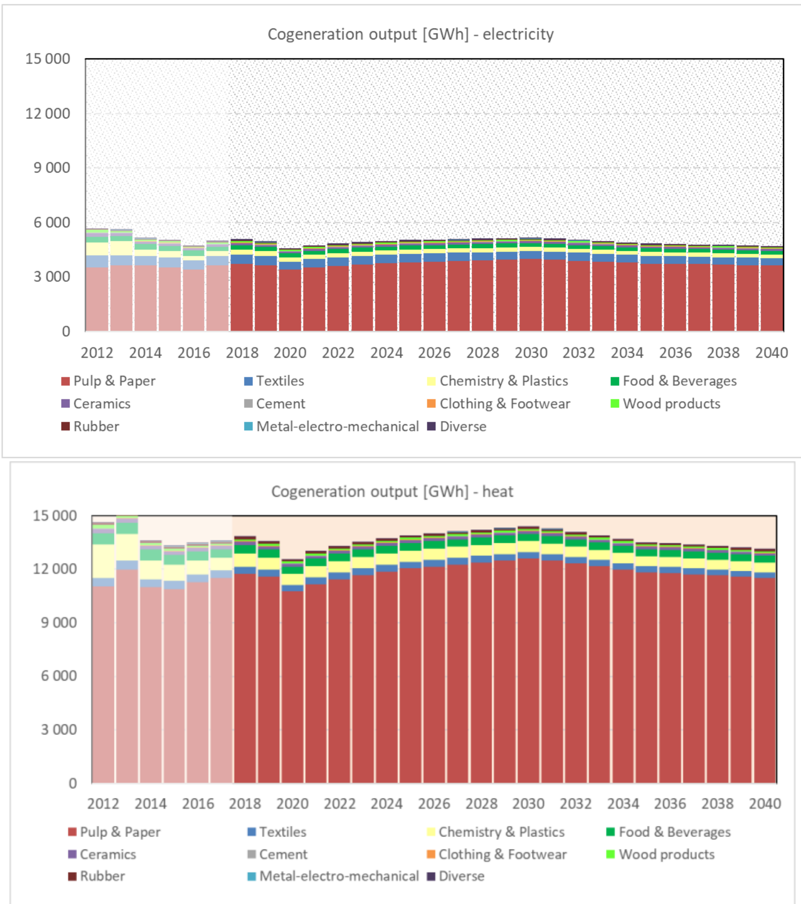

Figure 62 – Historical record and forecasts of the outputs of industrial cogeneration.

The aggregated energy input mix is displayed in Figure 63. It is dominated by black liquors (ca. 53%) and network gases (ca. 36%); biomass wastes (ca. 7.5%) are also relevant – all this essentially translating what happens at the pulp & paper subsector. At a large distance stands still gas (ca. 1.5%); fueloil is currently significant (ca. 3%) but suffers rapid phase-out.

Therefore, the input mix has an about 60% share of renewable biomass, the rest being mainly network gases. As the use of conventional biomass resources is saturating (see the observations for the pulp & paper subsector), it seems difficult to increase further the renewable share from a purely economical viewpoint.

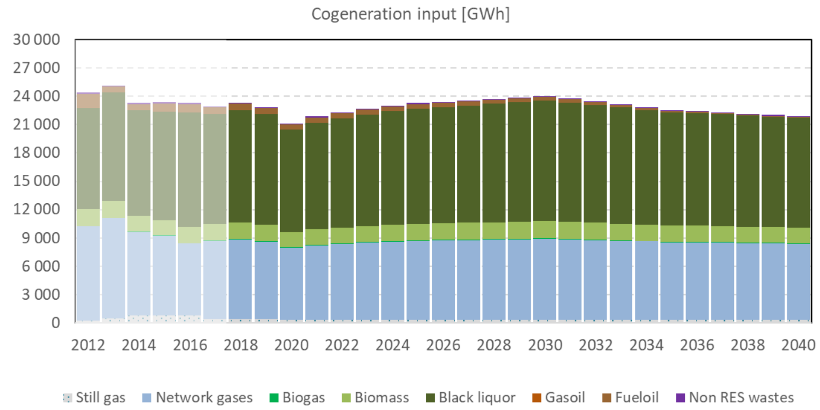

Figure 63 – Historical record and forecasts of the energy input mix of industrial cogeneration.

2.2. Cogeneration at buildings

We will now turn our attention to the demand sector of residential and services buildings. Here, cogeneration is often seen as a prime solution for powering district heating. However, consider that Portugal features mild climate in costal high building density zones, and low building density where climate is more severe. This is an obstacle to district heating in general and CHP-based district heating in particular. Seemingly to confirm this, there is only one such system in Portugal, viz. the Climaespaço network at eastern Lisbon, with 6.1 MW nominal capacity.

So, the potential for CHP must be based on a detailed assessment of district heating potential, then on economic viability studies – such as, comparison of levelized cost of heat considering alternative solutions such as renewable heat and waste heat sources.

A detailed assessment of district heating potential for Portugal was recently made available, “Assessment of District Heating and Cooling Potential in Portugal” (DGEG, 2021), which belongs to the same series of *DEIR Studies on the Portuguese Energy System* as the present document.

This assessment has taken advantage of GIS-based tools that very recently become available, including from the project HoTMAPS (2016). Two scenarios were considered, a “full comfort” scenario where there the indoor temperature is maintained constantly in a comfort band, and a “socioeconomic” scenario that deals with comfort with more flexible strategies and it is considered more adherent to the economic and cultural reality of Portugal. Candidate areas for district heating were identified using heat maps, surveying all urban zones. Then the delimitation of candidate areas was refined setting thresholds for the minimum energy demand to be satisfied by a district heating system. Next an economic viability analysis was performed, examining if the district heating grid distribution and transmission costs for the candidate areas were within internationally accepted viability thresholds. The potential for district heating in Portugal resulted very low or close to null. In consequence, neither does CHP for district heating considered to have significant potential.

In regard to small networks and individual large buildings, the electrical capacity of CHP units installed is about 36 MW. Of these the major part, *ca.* 25 MW, correspond to CHP at 10 large hospitals, and the rest is installed at an academic/technological park (Tagus Park) and a large commercial centre (Colombo). The installed capacity has been stable for more than a decade, which suggests a stable outlook.

2.3. Cogeneration at refineries

Hereafter we explore the cogeneration potential and perspectives at the energy transformation side of the Portuguese energy system, meaning at fossil fuel refineries. There are two such facilities in Portugal, one at Sines and another at Matosinhos, owned by the utility holding GALP. The largest cogeneration plants in Portugal are located there, totalling 98.3 MW_e at Sines and 90.9 MW_e at Matosinhos, according to information obtained from the Electric Energy Department of DGEG. The production in 2020 was 1325 GWh of electricity and 2867 GWh of heat (GALP, 2021). To make a comparison, this is around 20% of the production at the manufacturing industry sector, therefore very relevant. The energy input is nowadays natural gas; heat is absorbed in the refinery processes; the electricity has priority access to the utility grid and is sold at a regulated tariff.

The NECP perspectives for cogeneration at refineries follow the same logic as for the whole of refinery activity and production. A reduction of demand is expected, mainly due from electrification of the road transportation sector. Nevertheless, the huge vehicle stocks imply a large inertia of the transport sector adaptation process, so that the reduction of activity of the refineries will be small and smooth until at least 2035. Then, the activity drop will accelerate, until by 2040-2045 the processing of fossil fuel will end at one of the facilities, and by 2045-2050 at the other. Note that this not necessarily mean that the existing facilities will be closed, as they can adapt meanwhile to fabrication of, for instance, advanced biofuels, hydrogen, and synthetic fuels.

In this context, the electricity production at the refineries results as presented in Figure 64 – computed with the national energy model JANUS 5.1 (DEIR, 2020b), but updating for Covid-19 impacts the GDP and energy demand of the NECP scenario.

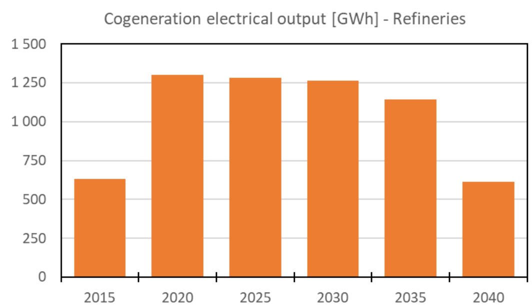

Figure 64 – Electricity production from cogeneration at refineries.

The outlook for cogeneration at refineries under these assumptions is therefore stable until 2030 and negative onwards.

2.4. Other sectors

Finally, there are CHP units at the agriculture sector – *ca.* 7 MW_e –, the extractive industry sector – *ca.* 18 MW_e –, and some more 1 MW_e related to other activities. In comparison with the installed capacity at the rest of the sectors these are very small figures, so the outlook is simply assumed stable.

3. Energy transition views of cogeneration

The analysis and outlook presented at the previous section was basically done from the viewpoint of the owners and promoters of CHP installations. However, the country level viewpoint of public policies and its goals, must also be taken into account. Energy transition pathways, carbon neutrality and sustainability are important issues to consider and as we will see, bring a considerable modification of the conventional perspectives discussed before.

3.1. Cogeneration and national energy-emissions planning

The conventional framework that, until recently, has based public support schemes to CHP is summarized in Figure 65. The example provided is for a CHP installation with: energy input consisting of only natural gas; thermal efficiency (ε_{th}) of 60%; electrical efficiency (ε_{th}) of 33%, thus a combined efficiency of 93%; the reference efficiencies for separate processes (i.e. burner and power plant) are those specified by the EU Commission's Delegated Act 2015/2402 EU; the electrical transmission and distribution losses avoided (ρ) are 3%. The gas transmission and distribution losses are very small, so not considered; other minor issues such as climate effects are also discarded.

The CHP plant consumes 100 MWh of natural gas and the cogeneration equipment and processes are sized and balanced in a way that 66 MWh of heat and 33 MWh of electricity are produced. To simplify, the greenhouse gases emissions (GHG) are represented only by carbon dioxide: with a typical factor of 56.1 kg/GJ consumed, 20 ton CO_2 are emitted. In comparison the separate heat and power solution needs 134 MWh of gas and emits 27 ton CO_2. The Primary Energy Savings (PES) is thus 34 MWh or 24%, and the GHG reduction is 7 ton CO_2 or 35%. Following this logic, CHP is classified as highly efficient (PES > 10%) and should be preferred over the separate heat and power production processes.

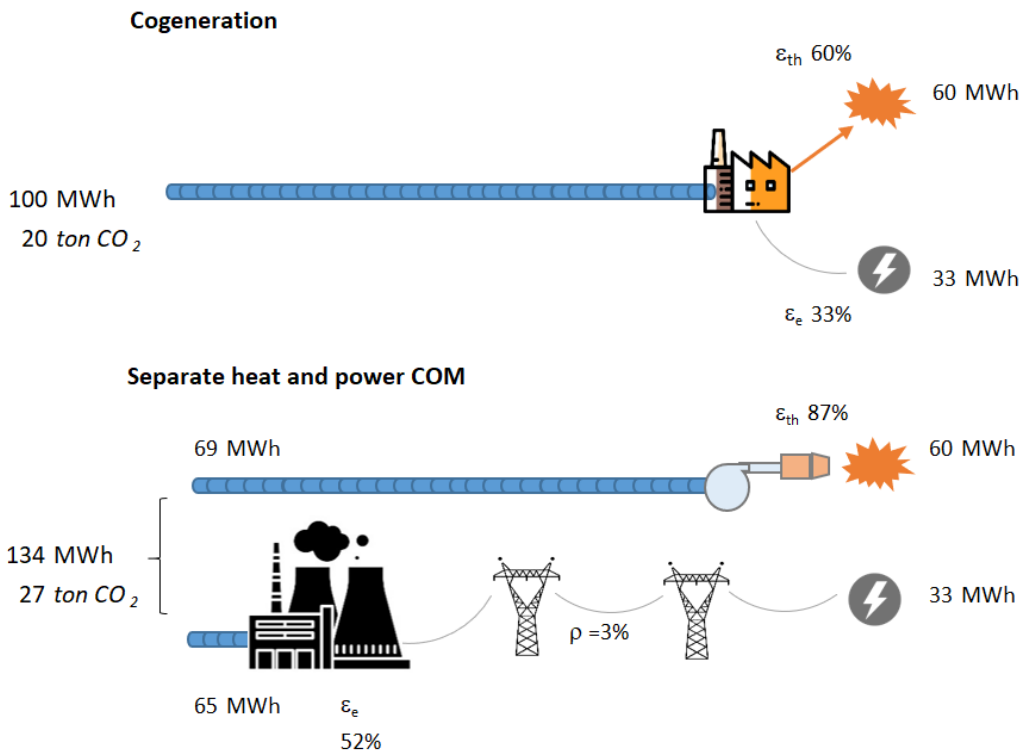

Figure 65 - Conventional view of cogeneration logic and benefits.

However, when considering medium and long-term energy-emissions planning towards sustainability and carbon neutrality, this view must be challenged if the inputs to cogeneration are fossil fuels. Consider the assumption that the alternative to CHP is using the same fuel source for a separate heat and power process. This is correct thinking within the fossil fuel based energy system paradigm, but no longer obvious if the purpose is to reduce fossil fuel use and avoid – not just abate – greenhouse gas emissions.

Precisely, the Portuguese Carbon Neutrality Roadmap for 2050 (CNR, 2019) takes an alternative view when finding an optimal cost-effective path towards a new energy system paradigm, renewable energy based and very low carbon. It proposes full electrification of heat and power production in this case (viz. fossil fuel inputs), as represented in Figure 66. Heat in this case is to be produced e.g. by resistances or electric arcs.

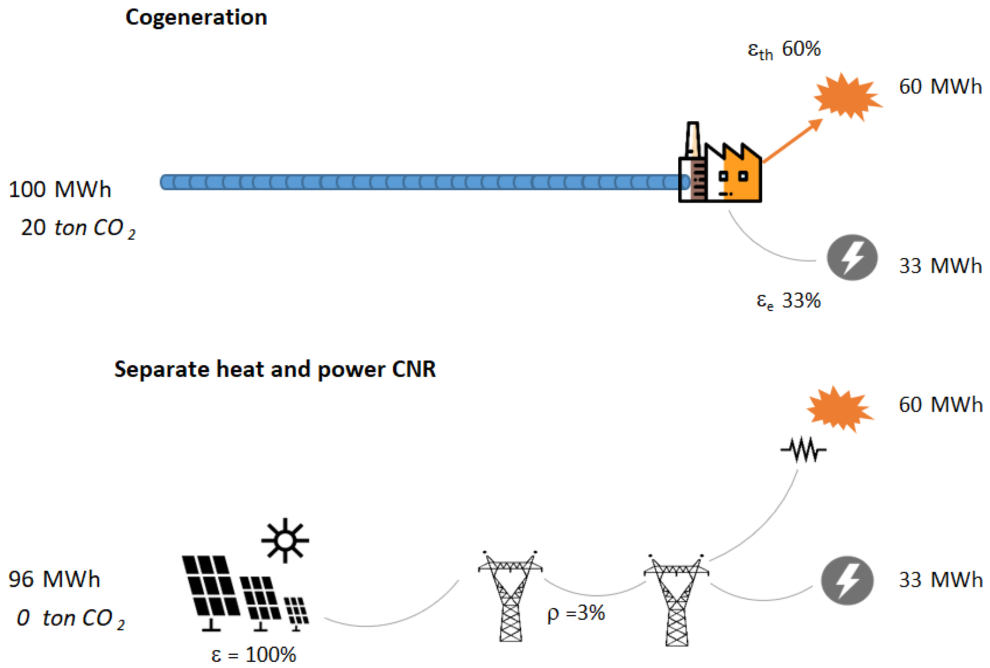

Figure 66 - Carbon Neutrality Roadmap long term challenge to cogeneration logic.[6]

The PES of cogeneration viewed this way in this example would be *negative* (-4%, not +24%), and the GHG would *increase* by 20 ton CO_2. Thus, cogeneration with fossil fuels emerges as harmful to the long term energy system.

It is important to remark that cogeneration using other types of inputs is still viewed as beneficial, namely when relying on renewable fuels like biomass and biogas (e.g. at the pulp & paper subsector, or at the wood products subsector), and even using other fuels such as non-renewable wastes (e.g. rubber subsector) and still gas (chemistry & plastics subsector) where byproducts of the industrial processes are available. Only the *ca.* 36% CHP based on natural gas and *ca.* 3% based on fueloil are under scrutiny.

The National Energy and Climate Plan 2030 (NECP, 2020) is less radical in this respect that the Carbon Neutrality Roadmap, mainly because its scope is just 2021-2030 and gives more importance to issues such as lost assets, capacity for investment, and availability of technologies. As represented in Figure 67, it still allows for heat production to be done from fossil fuels using boilers and burners. However, the electricity

[6] N.B. This only applies for the case of fossil fuel supply to cogeneration.

is to be supplied from renewable energy, not from coal or natural gas based power plants. The target for renewable electricity by 2030 is 80% (the energy modelling points to much more, see DGEG, 2020 a), which is coherent with this view. Under these conditions, in the example under discussion the cogeneration PES would be 3% and the GHG reduction 1 ton CO_2. Thus, fossil fuel based CHP would still be beneficial – but no longer highly efficient (PES < 10%). Therefore, while fossil fuel based cogeneration retains economic interest for the CHP installation owners (microscale level), it loses the strategic interest for the country in terms of environmental and security of supply benefits, and much of the efficiency benefits (macroscale level).

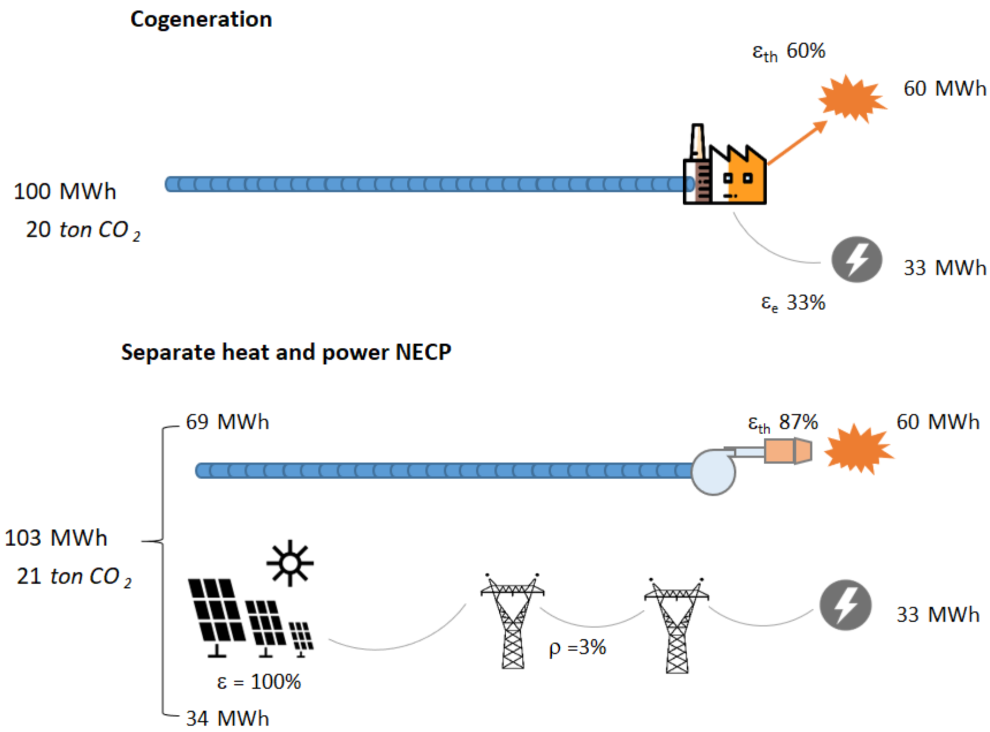

Figure 67 - National Energy and Climate Plan 2030 view of cogeneration logic. [7]

The National Strategy for Hydrogen (EN-H2, 2020) came to change these views of RNC and NECP even further. It still sees the future energy system as exclusively based on renewable energy, but recognizes that in many situations, using electricity directly for heating would be uneconomical and technically difficult. It also wants to address the problem of security of supply, in a system relying too much on intermittent renewable energy sources, namely hydro, wind and solar. Renewable hydrogen, to be generated mostly from renewable electricity (around 95% in the long term), see Figure 68, is to have a key role in connecting the electricity and heat systems.

[7] N.B. This only applies for the case of fossil fuel supply to cogeneration.

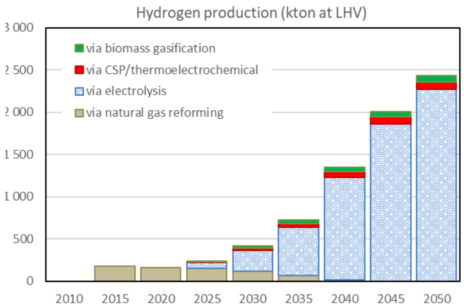

Figure 68 - Production of hydrogen by technology in the National Strategy for Hydrogen.

Hydrogen can be used directly to produce heat, but can also be used for assembling synthetic fuels, most notably methane in the case of EN-H2. The natural gas circulating in the gas network is planned to be blended with synthetic methane and hydrogen. In the long term (2050) the natural gas is almost completely phased-out, see Figure 69.

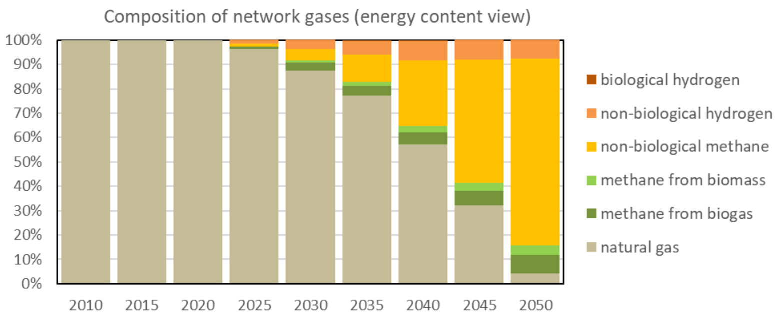

Figure 69 - Blend of gases in the gas network according to the National Strategy for Hydrogen.

Under these conditions, the CHP example that we have been analysing is represented in Figure 70.

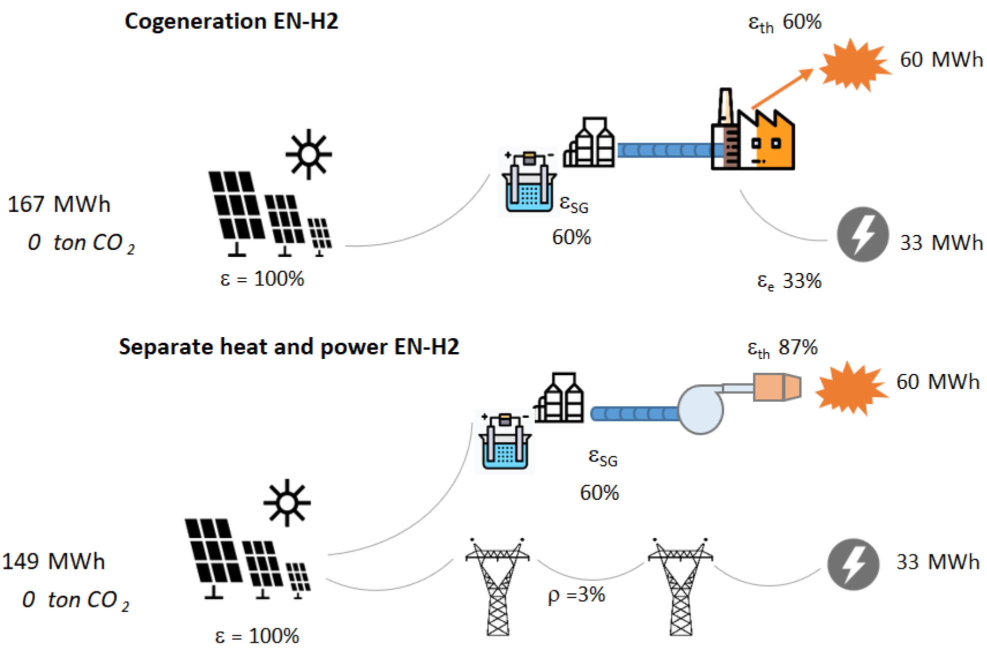

Figure 70 - National Strategy for Hydrogen long term logic of cogeneration.

The introduction of an efficiency for fabricating renewable fuels (ε_{SG}) changes profoundly the view of cogeneration at country level. In the example under discussion the cogeneration PES becomes -12%; although, no GHGs are emitted in both alternatives. Thus, gas based CHP would no longer have environmental impacts but would be inefficient (PES < 0%). Also, at microscale level, it is not clear if it would have economic benefits for CHP installation owners anyway, as synthetic gas fabricated with electricity would in principle be more expensive than electricity itself (negative spark ratio).

There is a transition process on the way, so the analysis at Figure 65 to Figure 67, plus Figure 70, must be weighed by renewable electricity and renewable gases percentages circulating in the energy system as the time passes. The results or this exercise are displayed in Figure 71. In summary, from a country level viewpoint, gas based CHP shows up not highly efficient, and is even harmful to the Portuguese energy system starting 2033 (sensitivity analysis yields 2030-2035).

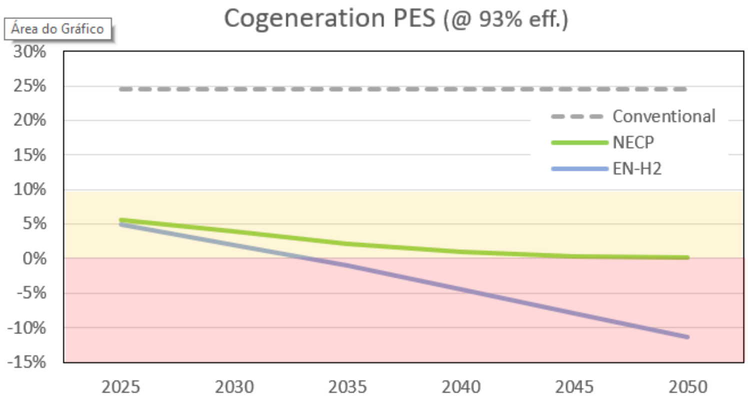

Figure 71 – Primary energy savings for network gas based cogeneration under various national energy strategies.

3.2. A new view of long-term cogeneration trends

When considering ways to mitigate the decrease of CHP installed power, the most appealing option would be to substitute gas (and fueloil) by biomass. However, this may be difficult. First, there is a problem of lost assets and high investment required, as CHP technologies for gas are not the same as for biomass (Gambini et al, 2019). Second, recruiting additional biomass for cogeneration is also a problem, because various other end uses are also seeking to use biomass in the coming decades: in particular, production of biogas, fabrication of advanced fuels, and fabrication of methane by biomass gasification. Third, while the biomass used in the pulp & paper and wood products subsectors derives from the respective industrial processes, additional biomass to power CHP may have to be transported and processed, maybe even purchased, hindering the economic viability of this solution. Nevertheless, the pulp & paper seem optimistic in this respect, and the biggest company has a carbon neutrality goal by 2035 (The Navigator Company, 2020). In the case in the case of the wood products subsector, already there is one biomass-based CHP installation seeking to be licensed (pellet fabrication).

Anyway, in coherence with the Portuguese energy-emissions planning (viz. CNR 2050, NECP 2030, EN-H2), a phase-out of the gas-based (and fueloil based) CHP should be initiated. For instance, in the case of manufacturing industry, a desirable evolution of the mix would be represented in Figure 72, thus increasing the contribution of biological fuels and reducing the contribution of fueloil and network gases.

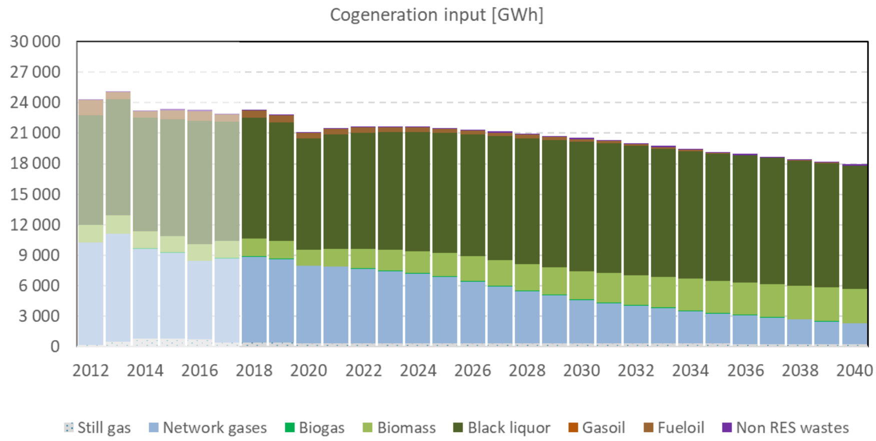

Figure 72 – New perspectives for the mix of energy sources for cogeneration at industry

A possible phase-out path was computed considering rapid end of fueloil CHP and the substitution of end-of-life gas-based CHP units by boilers and burners. It also includes the impact of a recent decision of GALP to close the Matosinhos refinery, and the probable decommissioning of the district heating CHP at Climaespaço, assuming adaptation of this network to waste heat supply (see DGEG, 2021). However, gas based CHP at hospitals is maintained due to the importance of reliability for these buildings.

The results are summarized in Figure 73, showing only the evolution of electric nominal capacity. It points to a decline of installed capacity up to 2025, starting with a large drop at 2021 that results from the decommissioning of the Matosinhos refinery CHP, but then the outlook is very stable.

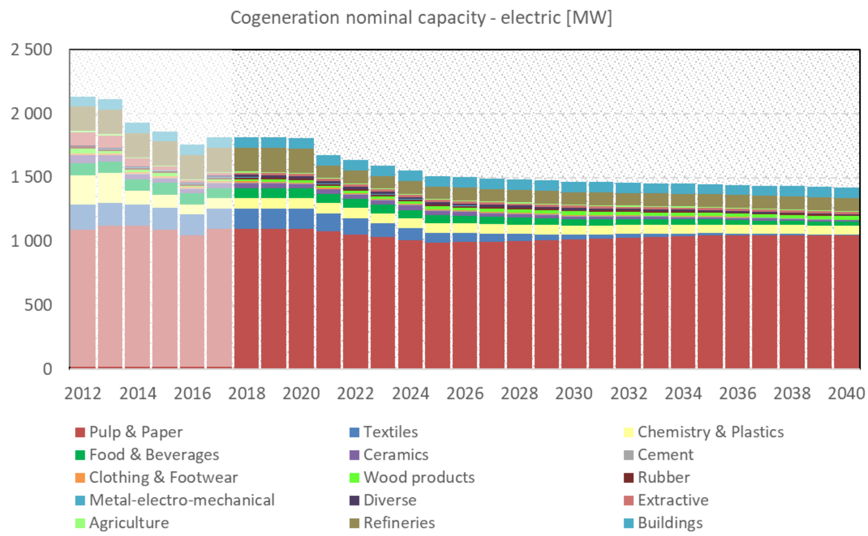

Figure 73 – Trend of cogeneration electric capacity in coherence with national energy-emissions planning.

We remark that these new perspectives were not fully considered in the scenarios that support NECP or EN-H2. Preliminary runs of the JANUS 5.1 model at DGEG to investigate these issues, have shown that the long-term impact on national energy performance indicators would be beneficial, although small. This seems to be mainly because the energy system becomes a bit more efficient with this new strategy for CHP but also because less curtailment of renewable energy power plants occurs that partially compensates for the phased-out CHP, and less need to import or fabricate network gases.

3.3. Innovative roles of cogeneration

Although the analysis of section 3.1 of gas-based and fueloil-based CHP holds for any type and size of the installations, it is possible that gas based CHP still retains interest for a few cases where reliability is important, as in the already mentioned case of hospitals.

In a general way, decentralized CHP for services buildings, may be interesting if it can be made compatible with the energy transition. One example are hotels, that have large specific requirements of heating and cooling because they require a small temperature comfort band to be maintained; this opportunity for cogeneration, or rather, for trigeneration, is explored for instance in Clito and Rocha (2016).

Regarding residential applications, Atanasoae (2016) analysed the technical and economic viability of conventional micro-cogeneration systems, concluding that the investment in a micro-cogeneration system can be attractive and economic performances can ensure the profitability of such an investment. However, as in many other similar assessments (e.g. Gandiglio et al., 2020), case studies are examined that correspond to climatic conditions much more severe and with larger extremes than those experienced at the Portuguese coastal bands where most buildings are located. In fact, DGEG's statistical information reports 21 micro-cogeneration registered facilities in Portugal, with 18 units in the range 1-10 kW_e aggregating 39 kW_e, plus 3 units of more than 60 kW_e adding 227 kW_e. These very modest values seem to confirm the low suitability of dedicated conventional micro-cogeneration systems in Portugal.

Micro-cogeneration via fuel cells may offer more possibilities. An early assessment by Dorer et al. (2005) already concluded that fuel cell CHP is appropriate to be used in residential and small-scale commercial applications, because of their very high efficiency and no (local) greenhouse emissions. We provide at Annex I more information on micro-cogeneration technologies.

The analysis in section 3.1 holds for any size of CHP, thus one might think that only biomass-based CHP could be interesting for the future. However, it is likely that innovative business cases using micro-CHP fuel cells may be conceived for off-grid situations. Consider for instance a model where a large building has adjoining space for installing a PV power plant, or perhaps an energy community with PV and/or wind power plants. Given the cost reduction of renewable electricity and the expected fast dropdown of costs and rise of efficiency and reliability of electrolysis, hydrogen could be obtained locally. With careful sizing of the renewable power systems, excess electricity could be used to obtain hydrogen. Then, it could be used in CHP during winter, or perhaps even better, be available to cope through fuel cell CHP with the intermittent nature of renewable energy sources like solar and wind.

We consider it is too soon to assess the potential of such novel applications but want to signal that they very probably will start appearing in the coming years.

4. Conclusions

The potential for additional CHP in Portugal until 2040 was examined from a conventional perspective and then from the perspective of public policies working towards energy sustainability and carbon neutrality.

The conventional approach could not identify significant opportunities for additional CHP. This was mainly because of electrification trends and demand reductions at some industrial subsectors, lack of potential for CHP-based district heating, and decreasing activity of refineries.

Nevertheless, the outlook was about stable, as the major CHP sector is by far the pulp & paper subsector, and this has a slightly favourable outlook and already features more than 60% biomass related inputs to CHP from their own industrial processes. The predicted CHP energy mix continues to be dominated by biomass sources, then network gases. However, capturing additional biomass for CHP seems difficult due to competition with other uses, such as fabrication of advanced fuels, biological hydrogen, biological methane, and biogas, as well as low economic viability.

Such a conventional approach is however not enough: a proper outlook must be coherent with the national high-level energy-emissions planning strategies. The Carbon Neutrality Roadmap and the NECP seek electrification of end uses, very high percentage of renewable sources in the electricity mix, phasing-out of fossil fuels, and avoidance of greenhouse gas emissions. Under these conditions it is shown that, for the Portuguese energy system, primary energy savings of fossil fuel based CHP are not as large as in the traditional view; and that greenhouse gas emission reductions are not achieved with fossil fuel based CHP. Plus, no such CHP can be classified as highly efficient – and thus, the EED call for cost-benefit analysis of highly efficient CHP of these types is not possible as it simply cannot be classified as such. For the other types, lack of additional energy sources is a major obstacle.

In addition, the National Strategy for Hydrogen has recently introduced in the long term planning mechanisms for producing hydrogen and synthetic renewable gases, that participate in the blend of gases circulating in the national gas network. It was demonstrated that using renewable hydrogen and renewable synthetic methane as CHP input, would actually yield *negative* CHP primary energy savings.

All these issues considered and using the energy-emissions modelling and scenarios developed by DGEG in support to public policies, the conclusion is that by 2030-2035, both fossil fuel and network gas based CHP will start to be harmful for the efficiency of the national energy system. Thus, such types of CHP should start to be phased-off now, to avoid new investments and technological lock-in with these undesirable solutions. Public policies could include for instance lower emission ceilings or demanding life cycle analysis at the renovation or new licensing requests. A consistent phase-out path of the undesirable CHP was developed and tested, showing a beneficial impact on the performance indicators and targets of the high-level energy-emission plans, resulting essentially from more use of biomass and less need to import natural gas or fabricate renewable gases.

It is recalled that the majority of CHP is already biomass based, and that another part uses fuels resulting from industrial processes (e.g., still gas, wastes); these CHP types should continue to be supported. Plus, in the context of large buildings and energy communities, an analysis has identified some opportunities for micro-CHP, especially with fuel cell technologies, that are still niche applications but may become to have a significant role.

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Annex I - Micro-cogeneration technologies

Production units considered to be micro-cogeneration installations must have maximum installed power of less than 50 kW, as defined in the Decree-Law no. 68-A/2015, of April 30. Micro-cogeneration equipment generally operates as heating-oriented equipment, providing heat for centralized heating and sanitary hot water, mainly in residential and services buildings.

Micro-cogeneration covers diversified technologies, including micro-turbines and small internal combustion engines, already in consolidation in the market, but also fuel cells and Stirling engines, still with little significant commercialization and with room for major development.

Conventional micro-cogeneration technologies include gas turbines, steam turbines, combined cycle and alternative or internal combustion engines, see Table A2.1.

Table A2.1 – Conventional cogeneration technologies

Technology	Advantages	Disadvantages
Gas turbine	• high reliability • low level off polluting emissions and vibrations • no refrigeration needs • supplies heat at high temperatures usually from 500 degrees Celsius to 600 degrees Celsius • Fast and simple maintenance • fast startup	• low efficiency when at partial load • operation with high pressure gas • output power decreases with increasing environmental temperature • lower efficiency in processes with low thermal requirements • Fuel type limitations
Steam turbines	• high global efficiency • possibility of operation with different types of fuel • supply very high temperature heat • high reliability • high useful lifetime • high pressure steam	• low electrical efficiency • slow startup
Alternative motors or internal combustion	• good performance add partial load • high electrical efficiency • fast startup • operation with low pressure gas • offers 2 levels of temperature: exhaust fumes and cooling engine	• high maintenance costs • only supply low temperature heat • highest level off polluting emissions • need of cooling • emission of low frequency noise

Regarding micro-cogeneration via fuel cells, technical characteristics of some second generation of fuel cells are presented at Table A2.2.

Table A2.2 - Technical characteristics of the systems to be deployed through project PACE.

Technical Specification	SenerTec Dachs 0.8	Remeha eLecta 300	Vitovalor PT2	Buderus GCB and SOLID power BlueGEN fuel cell	BlueGEN	Sunfire-Home 750
Fuel cell type	PEM	PEM	PEM	SOFC	SOFC	SOFC
Operational mode	Heat-led	Heat-led	Heat-led	Electricity-led	Electricity-led	Heat-led
Electrical output	0,75 kW	0.75 kW	0.75 kW	1.5 kW	Up to 1.5 kW	0.75 kW
Thermal output	1,1 kW + 21.8 kW	1,1 kW + 21.8 kW	1,1kW [11/19/26/32]	0.6 kW	Up to 0.85 kW	1.25 kW [+ peak boiler]
Electrical efficiency	38%	38%	37 %	60%	Up to 57%	38 %Hi
Overall efficiency	92%	92%	92 %	88%	Up to 90%	88 %Hi
Fuel flexibility	H Gas, L Gas, H2 ready	H Gas, L Gas, H2 ready	H Gas, L Gas, H2 ready up to 5%	H Gas, L Gas, Bio natural gas	H Gas, L Gas, Green –gas, 20% H2 ready	LPG, H Gas, L Gas, H2 ready
On-off cycles	4 000 cycles	4 000 cycles	4 000 cycles	Continuous operation	6 cycles /year+ modulation	1 cycle/ 1 000 h
Stack lifetime	80 000 h	80 000 h	80 000 h	60 000 h	40 000 h	40 000 h
System life	20 years	20 years	12 years	15 years	15 years	15 years

In Europe, Project Ene-field (http://enefield.eu/) demonstrated their initial technology readiness and installed more than 1000 micro-CHPs in 10 European countries from 2012-2017. Ene-field successor, the PACE project (https://pace-energy.eu/), aims to deploy more than 2800 of the next generation Fuel Cell micro-Cogeneration units in 10 European countries by 2021. The German KfW433 Programme (www.kfw.de/433), supported around 4500 units up to June 2020. None of these projects or financing programs supported the use of fuel cell micro-cogeneration in Portugal.

Annex II - Indications regarding EED reporting

Regarding the reporting items required by EED related to cogeneration of heat and power, its Annex VIII lists what “the comprehensive assessment of national heating and cooling potentials referred to in Article 14(1) shall include”. The following contributions for this purpose of this study are hereafter put forward, for each item listed.

Point (a) – “a description of heating and cooling demand”

This is provided at section 2.1 of this study. For the manufacturing industry, as well as for each of its statistical 14 subsectors, see pp. 5-19. For buildings, refer to the study “Assessment of District Heating and Cooling Potential in Portugal” (DGEG, 2021). For refineries, this is provided in p. 20.

Point (b) – “a forecast of how this demand will change in the next 10 years, taking into account in particular the evolution of demand [in buildings] and the different sectors of industry”

Same indications as for item (a).

Point (c) – “a map of the national territory, identifying (…): (i) heating and cooling demand points (…); (ii) existing and planned district heating and cooling infrastructure; (iii) potential heating and cooling supply points (…)

This item is outside the scope of the present study, refer to the national report on EED Article 14(1).

Point (d) – “identification of the heating and cooling demand that could be satisfied by high-efficiency cogeneration, including residential micro-cogeneration [and by district heating and cooling]”

Same indications as for item (a).

Point (e) – “identification of the potential for additional high-efficiency cogeneration, including from the refurbishment of existing and the construction of new generation and industrial installations [or other facilities generating waste heat]”

A comprehensive and detailed analysis for this point is provided at section 2, “Conventional perspectives for cogeneration”, pp. 5-20. In brief, the outlook for CHP installed power is stable or negative, depending on the industrial subsector, and it is negative for refineries, thus no additional CHP potential was identified.

Point (f) – “identification of energy efficiency potentials of district heating and cooling infrastructure”

This item is handled at the study "Assessment of District Heating and Cooling Potential in Portugal" (DGEG, 2021).

Point (g) – "strategies, policies and measures that may be adopted up to 2020 and up to 2030 to realise the potential in point (e) in order to meet the demand in point (d) (…)"

As no additional CHP potential was identified, this could be left void when reporting.

However, it is important to highlight the results of the additional analysis of CHP that was carried out in section 3 "Energy transition views of cogeneration". The interest and role of CHP was examined from an energy transition viewpoint, and specifically for Portugal considering its national energy-emissions goals and medium to long-term planning: Carbon Neutrality Roadmap 2050 (CNR, 2019), National Energy and Climate Plan 2030 (NECP, 2020) and National Strategy for Hydrogen (EN-H2, 2020).

A major finding is that fossil fuel based CHP cannot be considered highly efficient from a country level perspective, as it does not lead to more than 10% primary energy savings in comparison with the separate production of heat and electricity as foreseen in the said national energy-emissions plans and policies; furthermore, this kind of CHP also increases to greenhouse gas emissions. In fact, this study shows that, starting 2030-2035, fossil fuel based CHP, but also all CHP using the blend of fossil, biological and non-biological renewable gases circulating at the gas network, will turn harmful for the efficiency of the Portuguese energy system. So instead of discussing additional CHP potential, and policies and measures to promote such kinds of CHP, as EED Article 14(1) calls for all input fuels, a path for phasing out the harmful installations was developed, conceived in such a way that it has a beneficial impact at the national energy-emissions indicators.

It is remarked that the NECP (2020) includes policies to eliminate tax breaks for fossil fuels, viz. no VAT when used for energy production, but fossil fuel based CHP continues to be supported with a feed-in tariff. As discussed, Portugal should only be interested in pursuing CHP based on biomass wastes and on eventual byproducts of industrial processes, such as still gas (refineries, chemistry & plastics subsectors), industrial wastes (rubber subsector) and black liquors (pulp & paper subsector), that already are used to a great extension, see section 2 of the study). However, because the availability of the said byproduct energy sources is tied to the own activity of these subsectors, and their outlook sees only modest variations of demand (either increasing or declining), it seems difficult to develop additional CHP using these by-product energy sources, the existing capacity being enough to handle the expected variations of demand.

Therefore, the only open path to significantly increase CHP seem to be using biomass. Indeed, the promotion of utilization of forestry biomass has been pursued by the Portuguese governments for more than a decade, in particular the aspect of collecting and burning forestry wastes (undergrowth biomass, materials from forest thinning, etc.) with the objective of reducing wildfires, a serious environmental problem in Portugal. At strategic energy planning level, the NECP (2020) recently reinforced that public policies should take this direction. As specific measures, Decree-Law no. 64/2017 from June 12, already supported the involvement of municipalities, or intermunicipal communities, in new biomass-based power plants; Ordinance no. 410/2019, from December 27, established the respective feed-in tariff. More recently, Decree-Law *no. 120/2019, from August 22, came to limit this support to the cases where thermal energy is produced, seeking the appearance of new CHP units, smaller and more easily supplied with forestry wastes than conventional biomass power plants for producing electricity. Regarding buildings, cogeneration in general was promoted in Ordinance no. 349-D/2013, from December 2, that established the requirements of thermal quality of the envelope of buildings, and of the efficiency of technical systems at new and deep renovated buildings. It declared that CHP in large commercial and services buildings was required, except when not economically viable. But* recently *Ordinance no. 42/2019, from January 30 (SEE, 2019), has come to limit this obligation only to biomass-based CHP.*

However, it must be said that the success of these policies has been low for the building sectors. As respects individual buildings, it must be recognized that the demonstration of economic viability had no clear rules. Regarding district heating, it is seldom viable (see the study "Assessment of District Heating and Cooling Potential in Portugal" by DGEG, 2021).

For industry, it is not easy to find industrial consumers of heat located at or near the areas with biomass sources. Another problem hindering the growth of biomass-based CHP looming at the near future, is that other end-uses also seek to use such biomass resources, in particular fabrication of advanced biofuels that must start to replace first-generation unsustainable biofuels, according to the NECP. Nevertheless, the outlook of biomass-based CHP is favourable for the industry subsectors of pulp & paper and of wood products.

Finally, it is remarked that these analyses, policies and measures, regard essentially on-grid situations. For other contexts, like future off-grid energy communities, opportunities for fuel cell micro-CHP are prone to appear – but it is too soon for assigning a potential for these cases.