UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Architecture

Energy Development Sustainability: Biomass District Heating and Cooling systems in Spain and its Role in EU Climate Goals

End of Degree Project

Bachelor's Degree in the Fundamentals of Architecture

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ACADEMIC YEAR: 2022/2023

Abstract

This thesis investigates the role of biomass-powered District Heating and Cooling (DHC) systems in Spain and their contribution towards achieving the energy goals set by the European Union for 2030. With a focus on biomass as an energy source, this study examines how these systems help promote energy development sustainability and support the EU's climate objectives.

The European Union had set a target for 2020 to lower greenhouse gas (GHG) emissions by 20%, improve energy efficiency by 20% and increase shared renewable energy by 20%. The energy goals for 2020 were achieved with a 22% gross final renewable energy consumption with Spain individually accounting for 21.2%. EU’s path to climate neutrality has set milestones for 2030 and 2050. NREAP states that about a third of the energy consumption (32.5%) pertains to heating and cooling wherein Biomass-derived systems only represent 11% of the heating and cooling system in Europe. In Spain, nine out of ten of the new installations use this energy source.

A detailed analysis of five Spanish biomass district heating and cooling systems show better efficiency compared with any other thermal energy production solution with the possibility of incorporating large-scale renewable energies analysing the results to show how they help to achieve the climate goal for 2030.

Keywords: District heating and cooling system, Spain, energy development sustainability, biomass, smart cities.

Resumen

Este documento investiga los sistemas de calefacción y refrigeración urbana (DHC) en España con un enfoque en ejemplos alimentados con biomasa y cómo ayudan a lograr los objetivos energéticos de la UE en 2030, analizando su papel para lograr la sostenibilidad del desarrollo energético y lograr el cambio climático de la UE. objetivos para 2030.

La Unión Europea se había fijado como objetivo para 2020 reducir las emisiones de gases de efecto invernadero (GEI) en un 20 %, mejorar la eficiencia energética en un 20 % y aumentar la energía renovable compartida en un 20 %. Los objetivos energéticos para 2020 se alcanzaron con un consumo final bruto de energías renovables del 22%, representando España individualmente el 21,2%. El camino de la UE hacia la neutralidad climática ha establecido hitos para 2030 y 2050. NREAP afirma que alrededor de un tercio del consumo de energía (32,5 %) corresponde a la calefacción y refrigeración, mientras que los sistemas derivados de biomasa solo representan el 11 % del sistema de calefacción y refrigeración en Europa. En España, nueve de cada diez de las nuevas instalaciones utilizan esta fuente de energía.

Un análisis detallado de cinco sistemas de calefacción y refrigeración urbana con biomasa españoles muestran una mejor eficiencia en comparación con cualquier otra solución de producción de energía térmica con posibilidad de incorporar energías renovables a gran escala analizando los resultados para mostrar cómo ayudan a alcanzar el objetivo climático para 2030.

Palabras clave: Distrito de calefacción y refrigeración, España, sostenibilidad del desarrollo energético, biomasa, ciudades inteligentes.

Resum

Aquest document investiga els sistemes de calefacció i refrigeració urbana (DHC) a Espanya amb un enfocament en exemples alimentats amb biomassa i com ajuden a assolir els objectius energètics de la UE el 2030, analitzant el seu paper per assolir la sostenibilitat del desenvolupament energètic i assolir el canvi climàtic de la UE. objectius per al 2030.

La Unió Europea s'havia fixat com a objectiu per al 2020 reduir les emissions de gasos d'efecte hivernacle (GEI) un 20%, millorar l'eficiència energètica un 20% i augmentar l'energia renovable compartida un 20%. Els objectius energètics per al 2020 es van assolir amb un consum final brut d'energies renovables del 22% i Espanya representa individualment el 21,2%. El camí de la UE cap a la neutralitat climàtica ha establert fites per al 2030 i el 2050. NREAP afirma que al voltant d'un terç del consum d'energia (32,5 %) correspon a la calefacció i la refrigeració, mentre que els sistemes derivats de biomassa només representen l'11 % del sistema de calefacció i refrigeració a Europa. A Espanya, nou de cada deu de les noves instal·lacions fan servir aquesta font d'energia.

Una anàlisi detallada de cinc sistemes de calefacció i refrigeració urbana amb biomassa espanyols mostren una eficiència millor en comparació amb qualsevol altra solució de producció d'energia tèrmica amb possibilitat d'incorporar energies renovables a gran escala analitzant els resultats per mostrar com ajuden a assolir l'objectiu climàtic per al 2030.

Paraules clau: Sistema de calefacció i refrigeració de districte, Espanya, sostenibilitat del desenvolupament energètic, biomassa, ciutats intel·ligents.

Acknowledgements

As author of this thesis, I appreciate the collaborations with the Institute of Materials Technology (ITM-UPV) and the Technological Research Institute (IIT-Comillas). I give my thanks to my tutor and professors for their excellent recommendations and considerations which have undoubtedly helped to synthesize and improve my research and analytical skills.

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1. Introduction

1.1. Energy Development Sustainability

Energy has been pivotal in the history of technology and its innovation. The production and consumption of energy resources need to be sustainable to ensure its longevity. As stated by the United Nations, the most common definition of sustainable energy is that which is produced and consumed in such a way that it meets the needs of the present without compromising the ability of the future generations to meet their own needs. (Annex, 1992)

To accomplish these targets, over the past decades more focus has been laid on intelligent energy use with a growing demand for cleaner alternatives and smart cities. Sustainable energy development is interlinked with social, environmental and economic development which explains how energy resource exploitation is an after effect of economic development (Golušin et al., 2013) prominent in developing countries. For the long run, the socio-economic development of sustainable energies with low environmental implications and greenhouse gas generation is vital and renewable energy is the answer to mitigating these issues as the creation of completely renewable energy systems is the future (Lund et al., 2014).

In the past decade, industrial activities account for 56.6% of the greenhouse gases (GHG) emissions wherein 85% is produced by fossil fuels (Sen & Ganguly, 2017) leading to an energy transition with lowered fossil carbon dioxide output. A few other factors, which illustrate the urgent need for a change of energy supply at global level include excessive population growth, pollution, water scarcity, deforestation, biodiversity loss and climate change. Their manageability, increasing the shelf life of basic energy resources, reduced toxicity and pollution with a positive impact on societies often outweigh the important disadvantages. According to Lior, for large-scale energy related activities, renewable energies that are economically, socially and environmentally sustainable must be explored. (Lior, 2010) Additionally, residential and commercial buildings are the primary global energy consumers pertaining to 45% of CO2 output. This has urged countries to respond globally with policies, strategies and projects like the example of the EU to opt for climate neutrality by 2050, turning to eco-efficient, sustainable building placed in self-generated energy grids such as district heating and cooling systems (DHC).

1.2. Materials and methods

This research study follows a systematic approach with a proposed methodology, outlined in the provided illustration (figure 1), to comprehensively analyse biomass-powered district heating and cooling (DHC) systems in Spain and their contribution to achieving energy development sustainability and the EU climate goals by 2030.

The primary analysis consists of a diverse range of data sources, ensuring data quality and reliability. The initial step involves an extensive literature review, including reports, case studies, and statistical data to examine the performance and benefits of biomass and renewable energy compared to fossil fuel alternatives. Furthermore, global and EU-level studies and statistics are closely examined to gather comprehensive information on technology trends, policies, and regulatory frameworks.

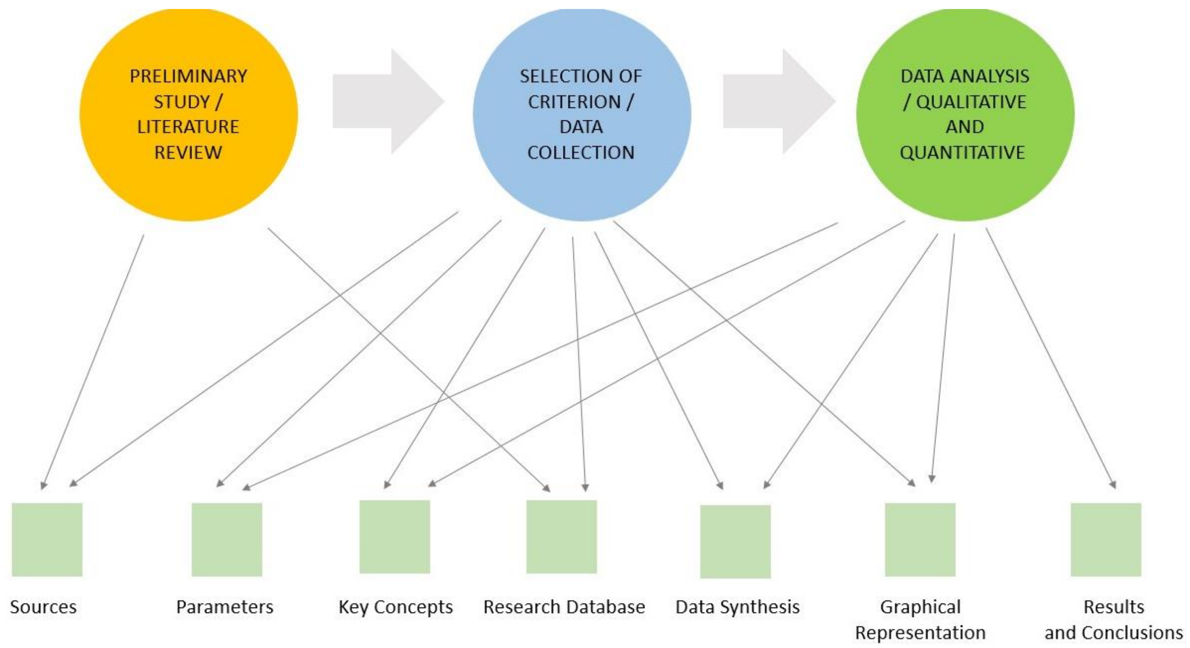


Figure 1. Methodology followed. Source: Own elaboration.

The primary sources for technical and economic data pertaining to DHC technology are European reports, case studies and literature reviews specifically relevant to the research focus. (EUROHEAT, EUROSTAT, EUROPOWER). These sources provide valuable insights into the technical aspects, economic viability, and potential advantages of biomass-powered DHC systems. To validate and enhance the available data, additional information is obtained from national statistical offices, national and European district heating and cooling associations, as well as reports featuring techno-economic data for established and emerging DHC technologies.

To examine the role of Biomass DHC as well as their compatibility with EU climate objectives, research will select five case studies from district heating and cooling networks in Spain. These case studies can be used as practical examples to provide an in-depth analysis of the aspects of engineering, economics and environment related to biomass powered DHC. Key success factors (KSF) are identified and evaluated, while policies and strategies aligned with the European and Spanish agendas are reviewed to assess their impact on biomass DHC implementation.

The research aims to provide a comprehensive understanding by synthesizing the findings from the literature review and case study analysis. Specifically, it evaluates the technical and economic aspects of biomass-powered DHC systems, including their efficiency, reliability, and potential for supporting sustainable energy development. By adopting this systematic methodology, the study endeavours to generate valuable insights into the role of biomass-powered DHC systems in Spain and their contribution to the EU's climate goals for 2030.

The research aims at contributing to knowledge and understanding of biomass district heating and cooling systems through this rigorous analysis. The objectives of this programme are to provide a solid basis for making decisions and policy development in order to enable the attainment of Sustainable Energy Transition at National and EU level.

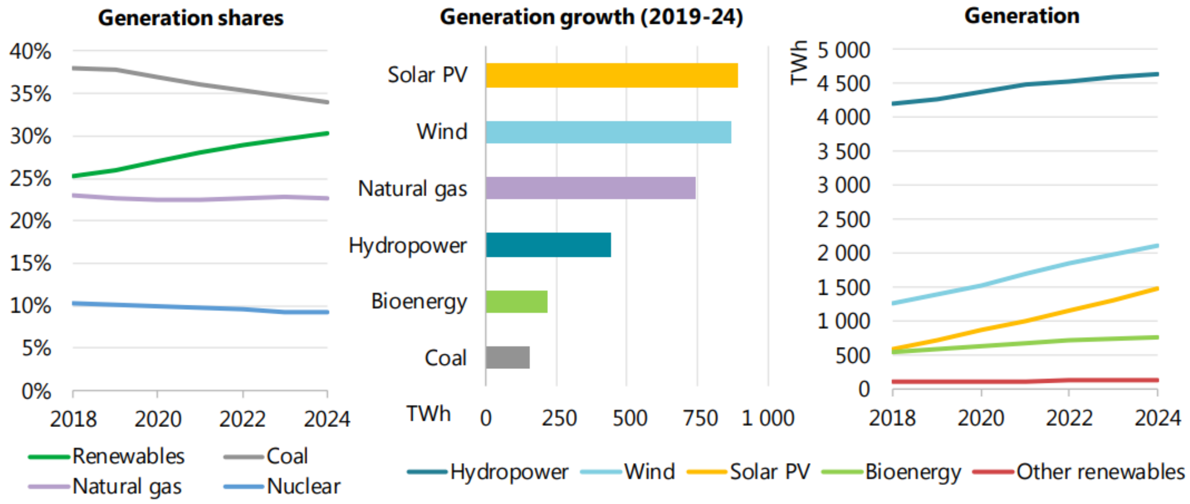
2. EU renewable energy policy and targets

Commenting on the European Union's role in establishing policies and initiatives for sustainable energy, the EU has maintained an ambitious climate neutrality front over the years. Energy efficiency, which is central to the Sustainable Development Goals (SDGs) and the current UN 2030 Agenda for Sustainable Development, is a key component of a low carbon, sustainable energy system on a global scale. With the Sustainable Development Goal 7 (SDG 7) it aims to double the energy efficiency improvement rate worldwide by 2030.

As is the case globally, the building sector is one among the highest contributors of energy consumption and environmental pollution in the EU as well, making up for about 40% of the European primary energy use and resulting in 36% of European Union’s total CO2 output. By means of the European Climate Law and Green Deal, in terms of the environmental protection in energy production increasing the biomass fuelled energy systems are the main driving force to achieve the intermediate energy goals by 2030, cutting down at least 55% greenhouse gases with respect to the 1990s. (EU Parliament & EU Council, 2009)

As the EU works toward its 2030 target, the use of biomass-derived energy (bioenergy), which currently accounts for around 60% of the union's energy needs, is likely to rise. These policies seek to create an integrated energy system, and the target scenarios demonstrate that energy based on biomass will play a significant role in achieving the long-term 2050 targets. A major end-user of bioenergy, using over 75%, is the heating and cooling industry hence its rational to support a closed energy loop system as a sustainable solution.

With the 2030 Climate Target Plan, the EU has put in place strategic plans to combat climate change, protect energy security and increase the competitiveness of European economic markets. In order to achieve Europe's Climate Neutral Continent by 2050, the main objectives of renewable energy are to cut greenhouse gas emissions by more than 55 % compared with 1990 levels by 2030 (figure 2) (EU Commission, 2021). The European Union is the largest supporter of renewable energy sources as well as the second biggest consumer. Priority shall be given to speeding up its economic development and adopting cost effective low carbon technologies.



Notes: Other renewables = solar thermal, geothermal and marine. TWh = terawatt hour

Figure 2. Evolution of energy generation - fuel, and growth percentage by renewable technology, 2019-2024. Source: International Energy Agency (IEA, 2019).

According to Golušin, sustainable energy and its implementation is a complex process as it is often a gradual process and has no definite end date, which demands a continuous improvement in terms of efficiency by studying specific indicators of each typology. (Golušin et al., 2013) Besides being environmentally friendly, the use of renewable energy sources is also capable of increasing long term global competitiveness and economic innovation, creating an additional number of green jobs as well as reducing import costs for oil and gas. The study respects the timeline of 2021-2030 of the national energy and climate plan (NECP), comparing the current state of DHC systems in Spain, primarily biomass-powered cases, and comments on its role in achieving it.

3. District Heating and Cooling system

The core principle behind the use of DHC systems is to fully utilize extra resources that would otherwise be wasted during all stages of energy production, fossil fuel or biofuel refining, and industrial processes. The recycling of heat losses from various energy exchange processes also contributes significantly. Rather than being lost, heat is recovered and commercially provided to buildings and industries to satisfy their thermal needs. Moreover, a district heating and cooling system can anchor on various renewable energy source (RES) like biomass, geothermal or solar thermal power sources (Beltran Rodriguez, 2016). Energy sources that are hard to exploit such as forms of biomass (mainly from forest residues) and geothermal energy can also be employed. Future sustainable cities will also make extensive use of combined heat and power (CHP), heat from waste-to-energy, various industrial surplus heat sources, and geothermal and solar thermal heat (figure 3). District Heating and Cooling, provides primary energy and carbon emission reduction on a wider scale for communities with the integration of small, variable heating and cooling demands.

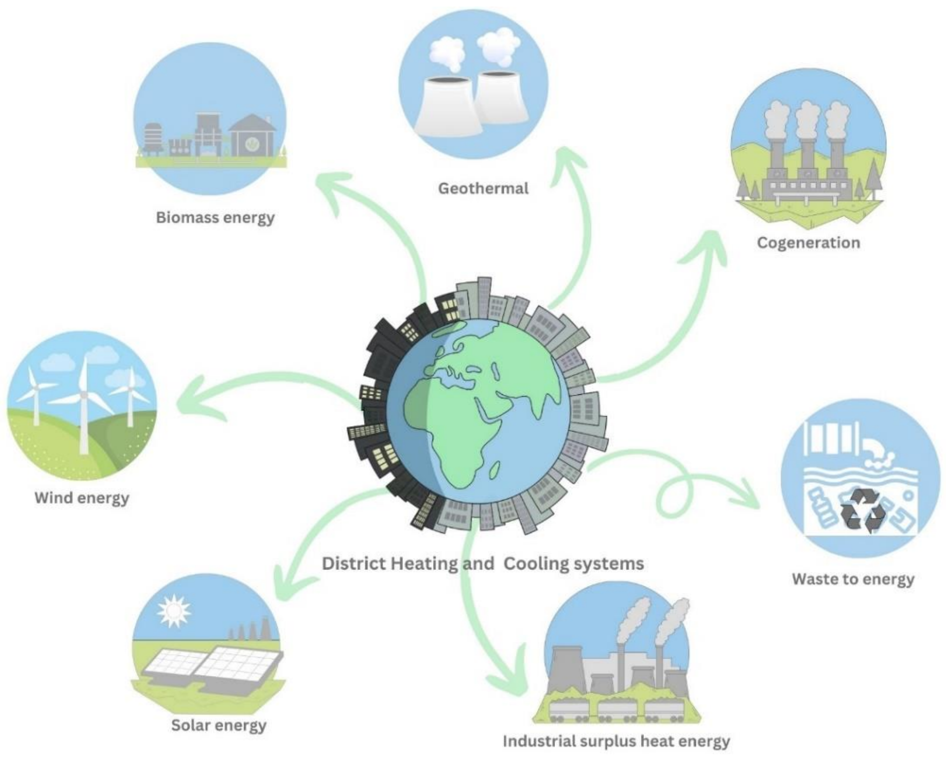


Figure 3. Energy sources for DHC systems. Source: Own elaboration.

Heating and cooling networks, also referred to as District Heating and Cooling (DHC), operate to meet the cooling and heating requirements of users who are connected to the network grid by centrally producing heat and cold that is then transmitted through a system of networks that transport the heat or cold through thermal fluids. DHC systems consists of pipe networks that connect buildings in a neighbourhood, town centre, or entire city to centralized or distributed heat-producing units to serve them. (Figure 4)

Regarding the historical aspect of DHC systems, they have been around for centuries, with the first example of a DH network dating back to the 14th century in France and the first modern European DH system in the 19th century in Germany (1893). By the dawn of the 20th century several projects were realised in Russia, Poland, the UK, the Netherlands, Czechoslovakia, France, Iceland, and Switzerland. The oil crisis in the 1970´s and the political shift in USSR in the 80s and 90s highlighted the importance of energy alternatives in the EU. The changes in the market economy influenced the energy transition for these countries. As of 2018, Iceland leads with the highest DH-citizen ratio (90%) and DH length density (6,16km/1000 citizens) followed by other Scandinavian countries for district heat supply (Bacquet et al., 2021).

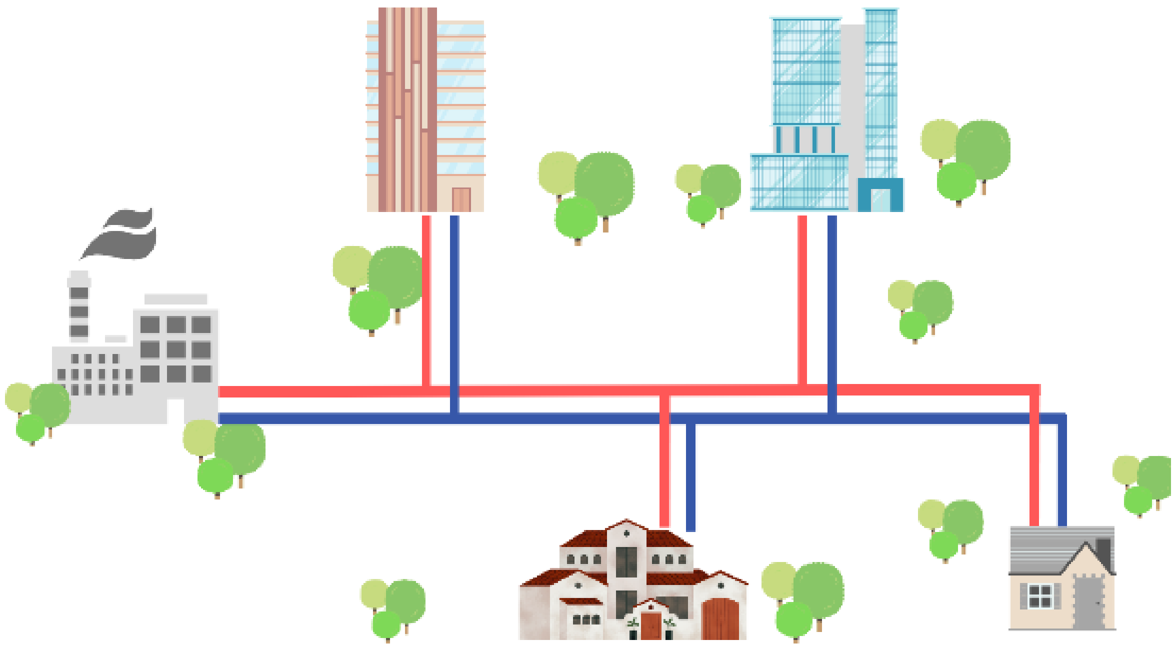


Figure 4. Schematic diagram of DHC systems. Source: Own elaboration.

According to the classification of Lund, over the years DHC systems have evolved from first generation; often powered by steam and waste incinerators to the second introduced coal and CHP, the third with an addition of biomass, geothermal and solar energy, the fourth is more RES based with low grid losses and finally the fifth generation achieves a higher efficiency with bi-directional exchange of thermal energy, thermal storage and data-driven grids (Lund et al., 2014) (figure 5).

Segregated chronologically from 2020 to 2050, the fourth generation of DHC systems is characteristic with a higher level of interaction between the producers and consumers within a smart local energy system, a higher proportion of local renewable and waste heating and cooling technologies (in addition to biomass and renewable waste) and lower operating temperatures. (Bacquet et al., 2021). The idea is to combine the use of low temperature heat sources with the operation of smart energy technologies in the heating of low energy buildings with minimal grid losses.

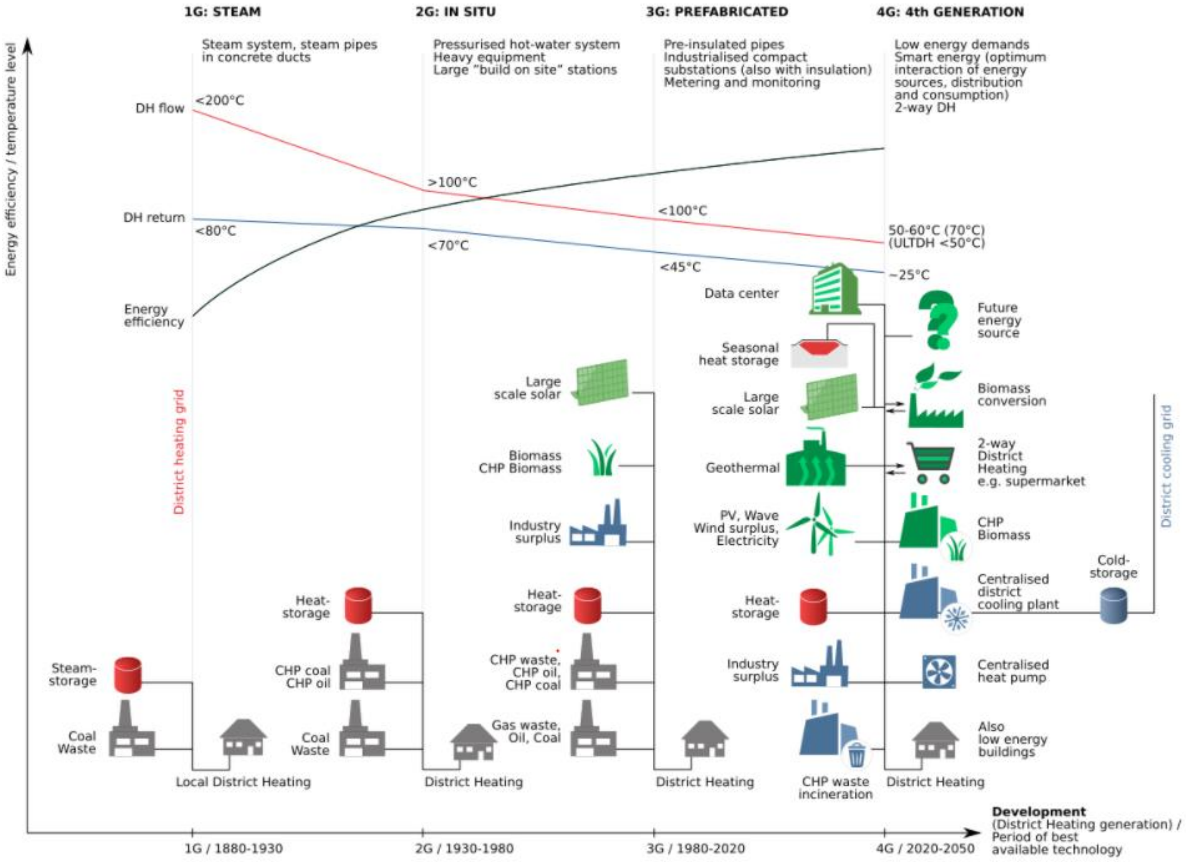


Figure 5. Generations of DH systems. Source: (Thorsen et al., 2018)

DHC systems differ based on factors such as market growth, the way local resources are used, the length of the total line, the users, and country-specific framework conditions such as the local environment and national and local laws (Bacquet et al., 2021) despite this, it has been concluded from studies globally that they have the ability to be effective prospective heat and cold supply alternatives with the necessity for an international vision and assessment for the future. (Werner, 2017)

District heating is the future of bio-fuelled power grids for planned urbanisations. The gains are huge for the investors, users and most importantly the environment. DHC systems allow the use of biomass, boost the energy efficiency of the installation, lower CO2, and greenhouse gas emissions, promote cogeneration and better global energy efficiency (Hogarsense, 2018).

The future of DHC systems show that there would be a broader energy transition wherein better efficiency, more renewables and higher flexibility result in a better energy system (AAVV, 2014). In Europe, the average heat consumption is estimated to be above the GDH limit of 50-150kWh/m2/y, varying with climatic conditions. Hence energy efficiency is vital for a greener consumption especially in buildings where DHC systems are coordinated with initiative at the municipal level. (Bacquet et al., 2021)

Cost efficiency is still a challenge when compared to other fossil fuelled resources, however the biggest share of the initial investment is in infrastructure which include pipelines and insulation as well as the needed machinery. Restriction of use is another challenger being limited to the cooler months wherein the absorption cooling technologies are growing in popularity due to their efficiency and all-year round utilisation of DHC facilities. (Bauen et al., 2009).

DH economy is classified as an economy of scope instead economy of size by Werner based on the fact that the main focus of district heating systems is currently on combining recycled heat with clean energy. This leads to a reduction in the environmental impact of conventional primary energy supply for various social heat needs, while replacing normal primary energy supplies. (Werner, 2017)

The challenge is that district heating and cooling systems are linked to local conditions in terms of demand from urban areas, as well as the sources of heat and cold. In contrast to the fossil fuel industry, which has applied generic solutions all over the world, this is a strong contrast. Since they are not well known in the current energy statistics, applicable local conditions have to be summarised and quantified at the regional, national and international level.

The challenges faced by the sector such as integration with electricity and transport, which is expected to lead to their development on a 4th generation basis need to be addressed. This future energy system will be called a Smart Energy System, in which smart networks of electricity, heating and gas are coupled together so as to create synergies between them with the ultimate aim of achieving the best possible solution for each sector and entire energy system. Most importantly, future DHC systems should not be designed for the present-day advancements but for future systems with system adaptability in mind.

From previous studies, (Lund et al., 2014; Zhang et al., 2022; Köhler et al., 2016; Lior, 2010), it has been shown that the current district heating system must undergo a radical transformation into low temperature district heating, involving networks with low power buildings and becoming an integrated part of smart energy systems.

There are extensive interfaces between the district heating and ventilation systems and a large range of additional Energy & nonenergy sectors. District heating and cooling involves a wide range of activities, from energy generation to its use, including customer relations, network management and integration, with access to cheap and reliable thermal sources and distribute it to the consumers, keeping in mind the qualitative and quantitative aspects (District Cooling, n.d.).

3.1. District Heating

District heating systems, like district cooling systems, have three components: the supply system, which includes the heating system, the delivery network, and the consumer system (figure 6). The district heating system's primary element can include a solar, geothermal, or thermal energy-powered boiler, with steam being the most common thermal carrier for big unit users (hospitals, industry, and electricity production), as well as hot water (residential, commercial). The thermal engine can be powered by gas, wood, or other fuels and can operate with variable demand (Hogarsense, 2018). The District Heating networks are ideal for biomass-powered boilers with up to 95% efficiency. Biomass is an indigenous resource that creates new economic activities and revenue (AAVV, 2014). The transmission network is the secondary element with pipelines distributing the heat energy being the highest investment of a district heating project (50% - 70%). It consists of underground thermally insulated pipes that partially prevent heat losses distribute it to various buildings. To maintain similar supply conditions the buildings are connected to the distribution network in parallel. The connection is the thermal transmission substation formed by a heat exchange system, equipped with individual measurement and control systems (Hogarsense, 2018). The consumer or the demand end of the line is the third component with in-building equipment.

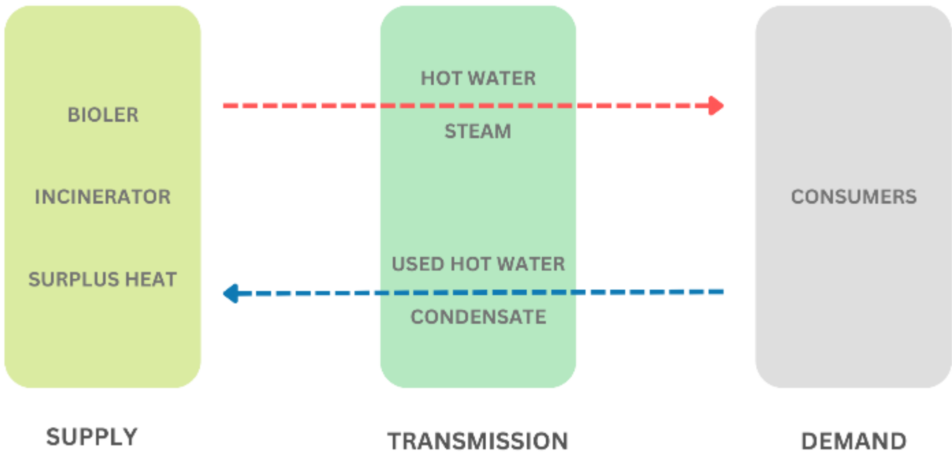


Figure 6. Generic structural diagram of DH networks. Source: Own elaboration.

DH has entered the third generation in terms of technology because of the growth of district heating networks over the years. The first generation used steam as a heat carrier. With temperature over 100ºC, pressurized hot water was employed in the second generation of systems as a heat carrier. The third generation was introduced in the 1970s, pressurised water still being the heat carrier, but the supply temperatures were often lower than 100ºC. Over the three past generations developmental focus was paid on lower distribution temperatures, material lean components and prefabrication resulting in lower manpower at construction sites. In the future the fourth generation should be based on a more flexible and lower distribution temperatures, assembly-oriented components, and materials with more flexibility.

The resulting solution should hence be more environment friendly and user oriented. In term of heat efficiency, over the course of the previous generation of DH systems, it has improved in tandem with technological advancements. As was mentioned earlier, the first generation of heating utilized steam as a carrier at 120°C, the second used boiling water primarily (95°C to 100°C), the third used hot water (70°C), the fourth developed a flow system that operated at a lower temperature (50°C to 60°C with a return of 35 to 40°C), and the fifth generation used ambient airflow (-5°C to 20°C with heat pump boost). In comparison to earlier methods, the fifth-generation system has a heating system that is simpler and more effective, resulting in lower carbon emissions because of its ground source heat pumps.

Studies have concluded from superficial analysis that DH systems have lower thresholds of heat production than demand which has led to lowering the supply temperatures, a key element of the 4GDH with interventions at the municipal and individual level of buildings. (Lund et al., 2014) Some other challenges can be legal, economic, technical, and socio-cultural barriers (Soltero et al., 2022) beyond which requires a holistic model for the evaluation and implementation of DH systems with integrated energy resources.

3.2. District Cooling

District cooling systems use natural local resources such as sea water or absorption chillers using heat to produce cooling. It is an environmentally optimised cooling system in which the chilled water is administered to the buildings with negotiable cold content loss. Like the DH systems the users are linked to the cooling production via a pipe network, thus cooling down the indoor temperature of the building (figure 7).

The chilled water is supplied to the individual buildings' own cooling systems using a heat exchanger. The water after cooling the building returns to the cooling plant at a higher temperature where is rechilled and flows in a closed loop. This results in better energy efficiency cutting down the energy consumption by 50%. A district cooling system has up to 5 to 10 times more energy efficiency than conventional machine cooling. As a result of being the combination of renewable and surplus energies, district cooling systems emit less CO2 gases and hazardous refrigerants in comparison to the alternatives. (District Cooling, n.d.)

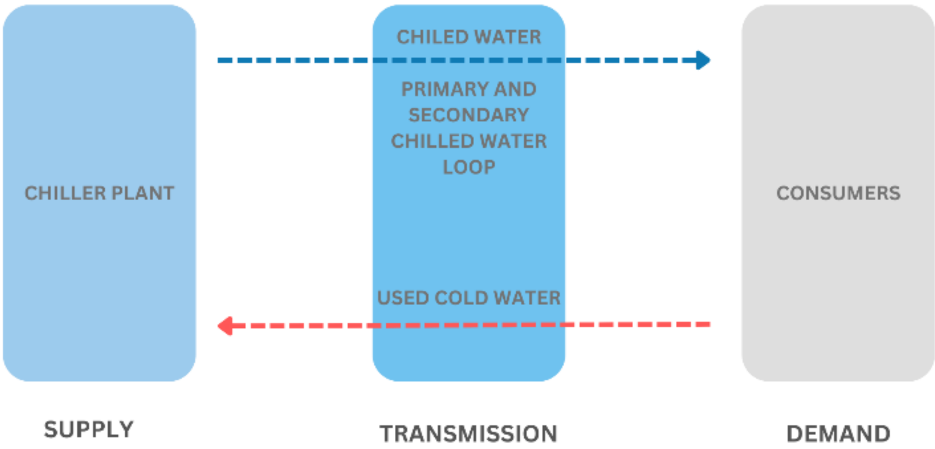


Figure 7. Generic structural diagram of District Heating networks. Source: Own elaboration.

District cooling has a similar technology generation as heating systems, beginning in the nineteenth century with first-generation pipeline refrigeration systems (centralised condensers and decentralised evaporators with refrigerant as the liquid medium) and progressing to the second generation (large mechanical chillers with cold water as the fluid medium) and then to the third generation (cold supply-based absorption chillers, mechanical chillers, natural cooling, and cold storages with water). (Lund et al., 2014)

3.3. Europe

DHC systems have already proved their effectiveness in Denmark, and Sweden. Many European cities are already aware of these benefits and integrating them into their energy strategies, but there is still a lot of potential for development.

A higher percent of DHC systems can facilitate the integration of intermittent renewable energy in the electricity mix, providing balance to the grid. (e.g., through thermal storage, or flexible CHP production) and an overall rise in the EU's security of energy supply (Fernandez et al., 2016).

The first country in Europe to install a solar powered heating network was Sweden in the 1970's, with 22 solar heating systems at the present. Another notable success story is of Denmark, with the largest district heating system in the world, in the city of Marstal which has a collector area of 18,300 m2. Odense, another city in the country has installations covering 95% of its energy demands.

Paris has the most spread-out network in Europe spanning 335km supplying energy to over a million users from its steam heating supply of 280C. The energy from the incineration of Solid Urban Waste is a huge plus. Another notable example is of Berlin, where its heating network has currently expanded to above 529 km. The Austrian city of Arbesthal serves 108 homes with a pipe length of 4.5km. Residues from sunflower cultivation is used as a fuel resource here. There are further examples in Europe where natural waste such as forest residues fuel the district heating systems such as the case of the Corsica islands in France that supplies energy to 14 buildings. (Hogarsense, 2018).

It is not known whether we are in the 3rd or 4th generation, due to a lack of data within the EU. As shown in the picture above, use of renewable energy sources is typical for 4DHG systems. Biomass, derived from renewable municipal waste as well as biomass, is the main source of Europe's RES. This shows that Europe is still at an early stage in the 4GDH as it depends heavily on alternative sources of energy.

The DHC system possesses characteristics of a natural monopoly. In the majority of European Union Member States, DH is perceived as a comprehensive service that encompasses electricity generation, grid operation, and distribution. The process of unbundling DH holds the capacity to elevate heating expenses. The market conditions exhibit significant disparities among the countries under analysis, particularly with regard to DHC implementation and the composition of their energy sources. In the residential sector in the EU 27 countries, there is a high market share of DH on heating and domestic hot water consumption within Scandinavian and Baltic countries as well as some Member States with below 1% e.g., Belgium, Ireland, Spain. The main sources of production of DH in the EU 27 are cogeneration plants, which account for 63 % of production.

In the pictures, (figure 8 and 9), Europe's largest cities with over 5000 inhabitants as of 2011 have been provided with any type of municipal heating or cooling system. They do not have a direct impact on the whole city or neighbourhood, but rather on a more specific local level with central, distribution networks and thermal transmission substations, in many cases.

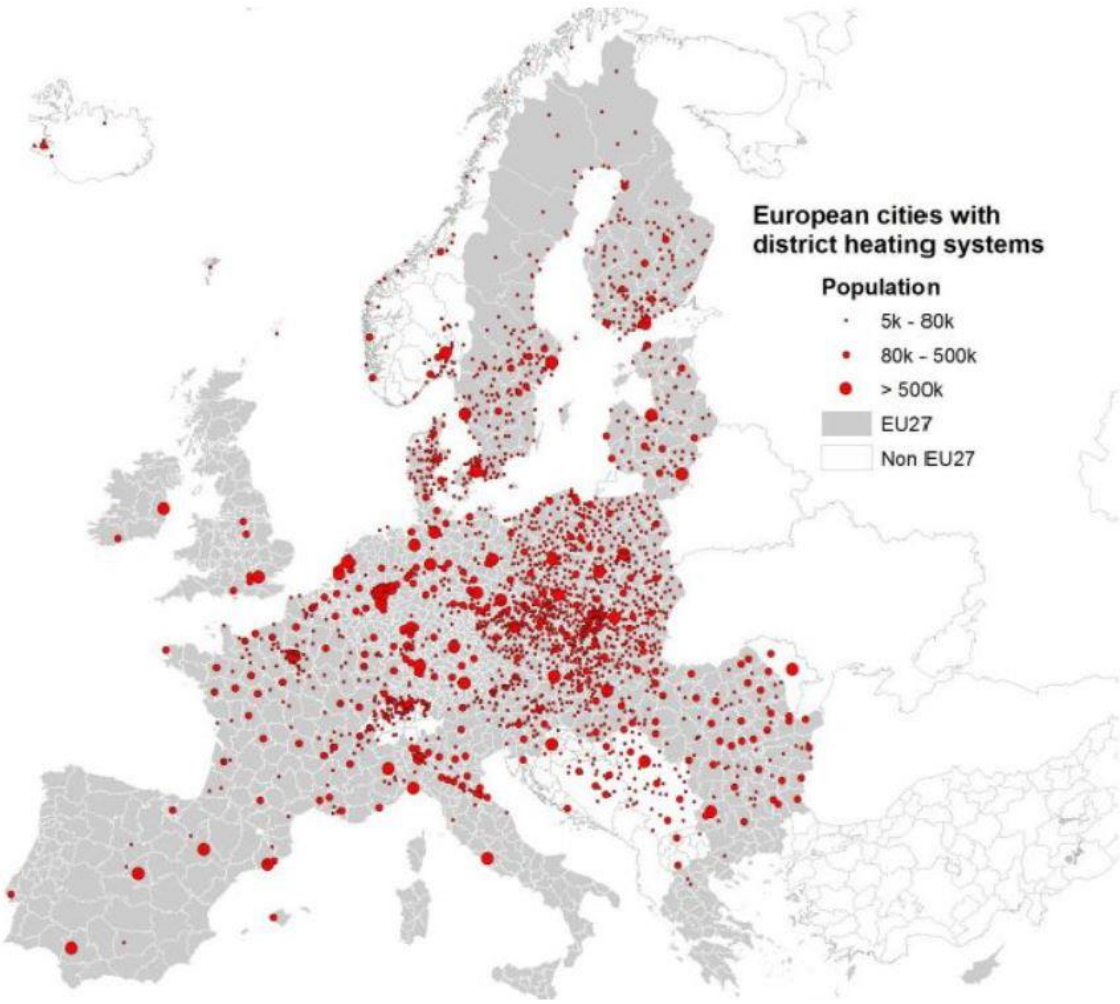
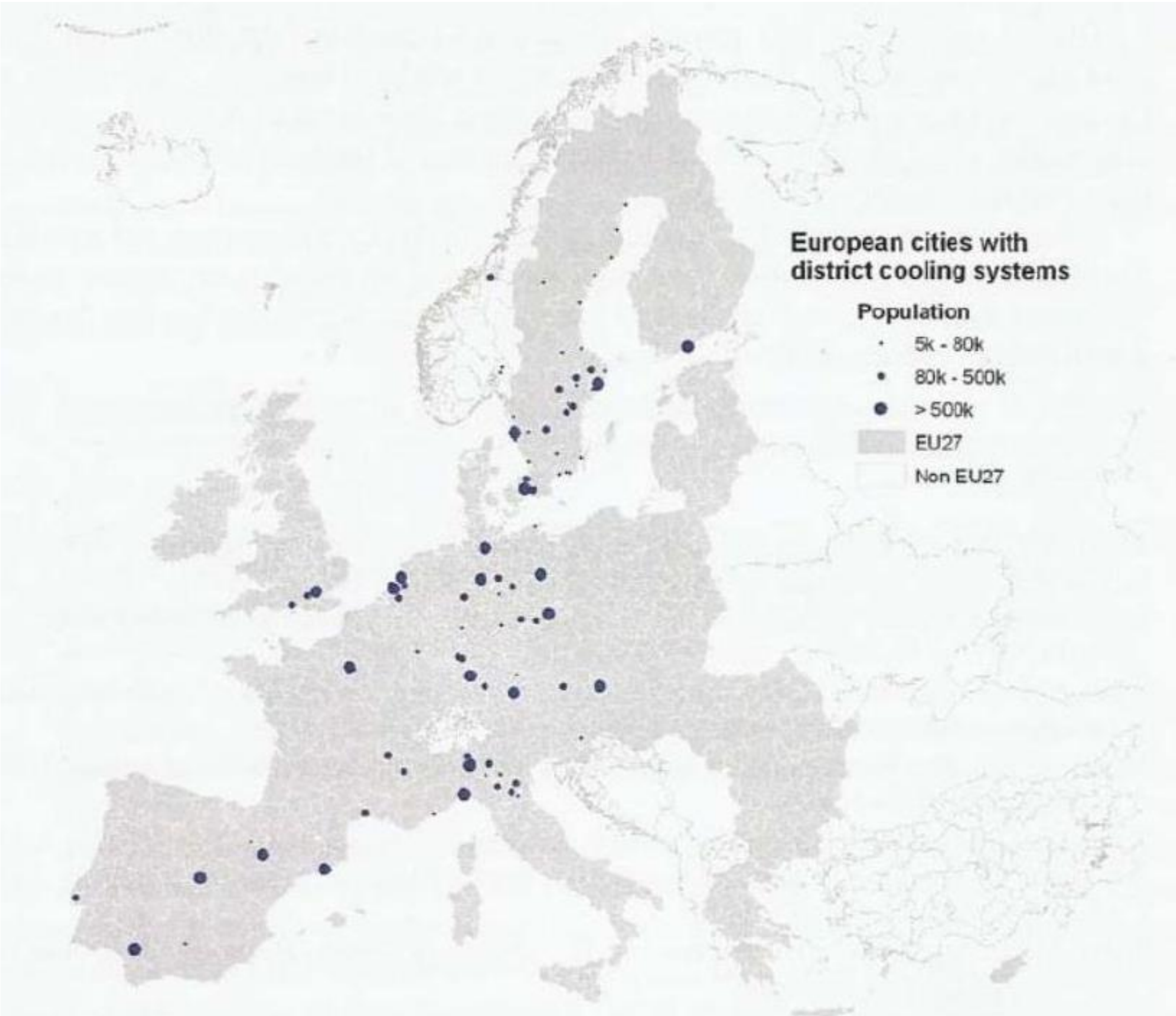


Figure 8. Map of European cities with District Heating systems. Source: Blogs udima. (Hogarsense, 2018).



Note: Cooling (Includes cooling systems of DHC or independent cooling systems)

Figure 9. Map of European cities with District Cooling systems. Source: Blogs udima. (Hogarsense, 2018).*

In the EU, there is a wide energy imbalance between the biomass generated and consumed (Ericsson & Nilsson, 2006) which must be addressed and acted upon to increase the sustainable future paths. Better use of energy resources, also referred to as conservation, is the first step in any future path. This necessitates the reduction of superfluous waste, enhancement of energy conversion efficiency, substitution of lower-energy-intensive products and processes, increased recycling of environmentally friendly goods, and adoption of a lifestyle characterized by reduced energy consumption. The conservation efforts should be conducted in a manner that does not compromise the fundamental needs and comforts of individuals, while also avoiding any substantial detrimental effects on productivity. Attaining these objectives requires the establishment of a unanimous agreement concerning the intensified targets and associated policies.

It is very important that actions are quickly taken in order to significantly enhance the involvement and cooperation between countries around the world with a view to reduction of greenhouse gas emissions and additional negative environmental effects associated with energy use. In this area, significant research, development and testing has to be carried out due to the continued impracticality of mass carbon sequestration.

For the purpose of preventing damage to land, water resources and agriculture as well as for avoiding unnecessary competition with food production, it is necessary to apply a detailed sustainability analysis in biomass energy use.

Another aspect to consider is the unsteady availability of resources which could be combatted by planning ahead of time. Even while food crops, grassy plants, woody plants, forestry or agricultural wastes, oil-rich algae, and the organic portion of municipal and industrial wastes are popular biomass energy sources, they might not always be accessible. A diversity in the energy resources will be an advantage in terms of adaptability and efficiency.

The world's largest contributor to greenhouse gas emissions is buildings. It is highly encouraged to develop economical, environmentally friendly buildings that not only reduce their negative environmental impact but also help to heal and improve the environment. A more comprehensive method is to build housing units that minimise their indirect energy use and emissions by limiting the need for transport and other resources of residents.

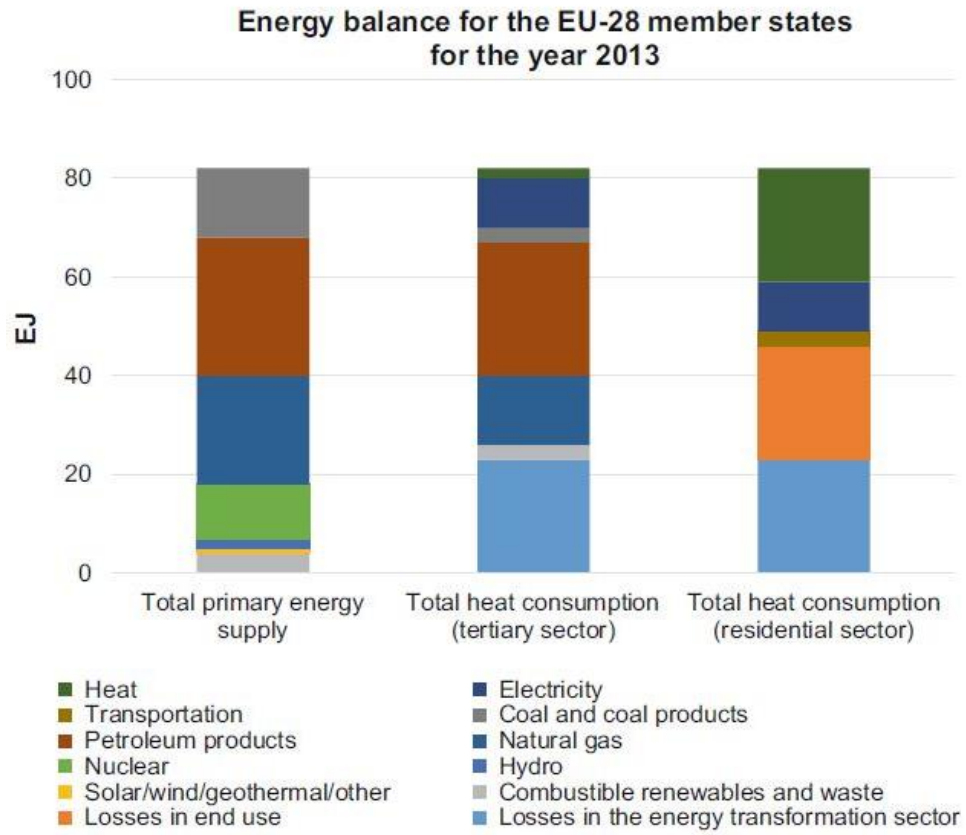


Figure 10. Energy balance for the EU members - 2013. Source: (Colmenar-Santos et al., 2017)

The challenges encountered in the field of energy development, paradoxically, present avenues for significant opportunities. Furthermore, these challenges also create favourable circumstances for small enterprises and nations, unburdened by the inherent inertia that plagues larger organizations. One notable hindrance is the absence of a political system that promotes swift and efficient implementation of research and solutions. Therefore, it is crucial to seek and educate the public to garner popular support for rational approaches, thereby mitigating this obstacle. There is a great need for much time spent in many of the innovation solutions, with the necessity for rapid action without falling behind in innovation. (Lior, 2010; Moretti et al., 2016)

According to the annual energy balances by the EUROSTAT, conventional thermal power plants located in the EU-28 waste more energy in the form of residual heat that could better be used in the cogeneration plants fir the DHC networks, figure 10. Based on the graphs, in the future the most optimal solution would be to pace these cogeneration plants in the surroundings of the city.

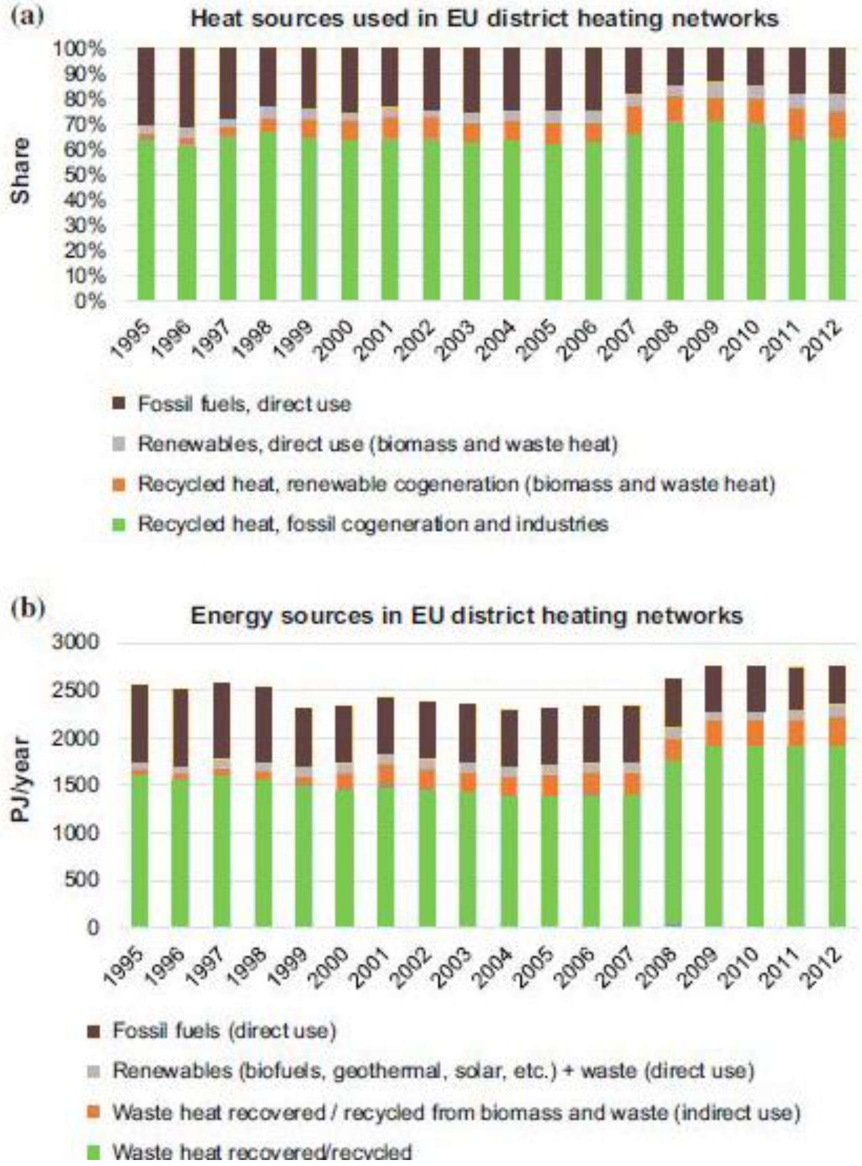


Figure 11. Energy share and generations (a) for each district heating source (b) in the EU-28.
Source: (Colmenar-Santos et al., 2017)

Upon examining the provided data in figure 11 regarding district heating networks, it is evident that there has been a significant increase in the utilization of residual waste energy over the past decade. It is crucial to acknowledge that due to variations in energy availability throughout the year and the temperature of reject heat, it is not possible to satisfy all thermal demands solely through the utilization of residual heat from thermal power plants. Consequently, there is a need to establish comprehensive district heating and cooling networks that incorporate waste energy from conventional thermal power plants across the European Union-28.

3.4. Spain

The first introduction of District Heating and Colling systems in Spain was in the 1930s in Madrid. A more recent installation in this city was in 1998 with collaboration if the City Council, EREN, and IDEA. The system has two boilers of 5,200kW and 700kW, fuelled by biomass from forest residue.

A more elaborate centralized biomass powered heating system was planned out in Segovia, which supplied energy demands of a seventies neighbourhood of a 1000 residential block, a school, sports centre, and a cultural centre. Other more important facilities in the recent years include the Forum 22@ District Heating and Cooling network in Barcelona in 2004, the Thermal power plant for the Expo-Zaragoza 2008 and the Thermal power plant for the Agri-food city of Tudela, Navarra. In 2017, the largest DH network in Spain was opened in Mostoles and later in 2011, the installation of the Thermal power plant in the Ciudad de la Justicia in Madrid and the Ciudad Medio Ambiente Thermal power plant in Soria (Hogarsense, 2018).

The data of the percentage of the DHC network distribution in Spain as per 2019, is shown in figure 12. The District Heating and cooling network consensus 2015, which covers both grids and micrgrids, sets out the inventory of the DC networks in Spain. It identifies 270 networks with 247 surveyed, showing progress compared to previous years; 2012 in 46 surveyed networks, with the 2013 surveying 139 increasing to 202 in 2014.The surveyed networks in 2015 cover an area of 7 million m2 or 93,000 homes representing a total of 310 km of networks and saving emissions of 156,000ton/yr of CO2 and an average of 81% of fossil fuel consumptions (Beltran-Rodriguez, 2016).

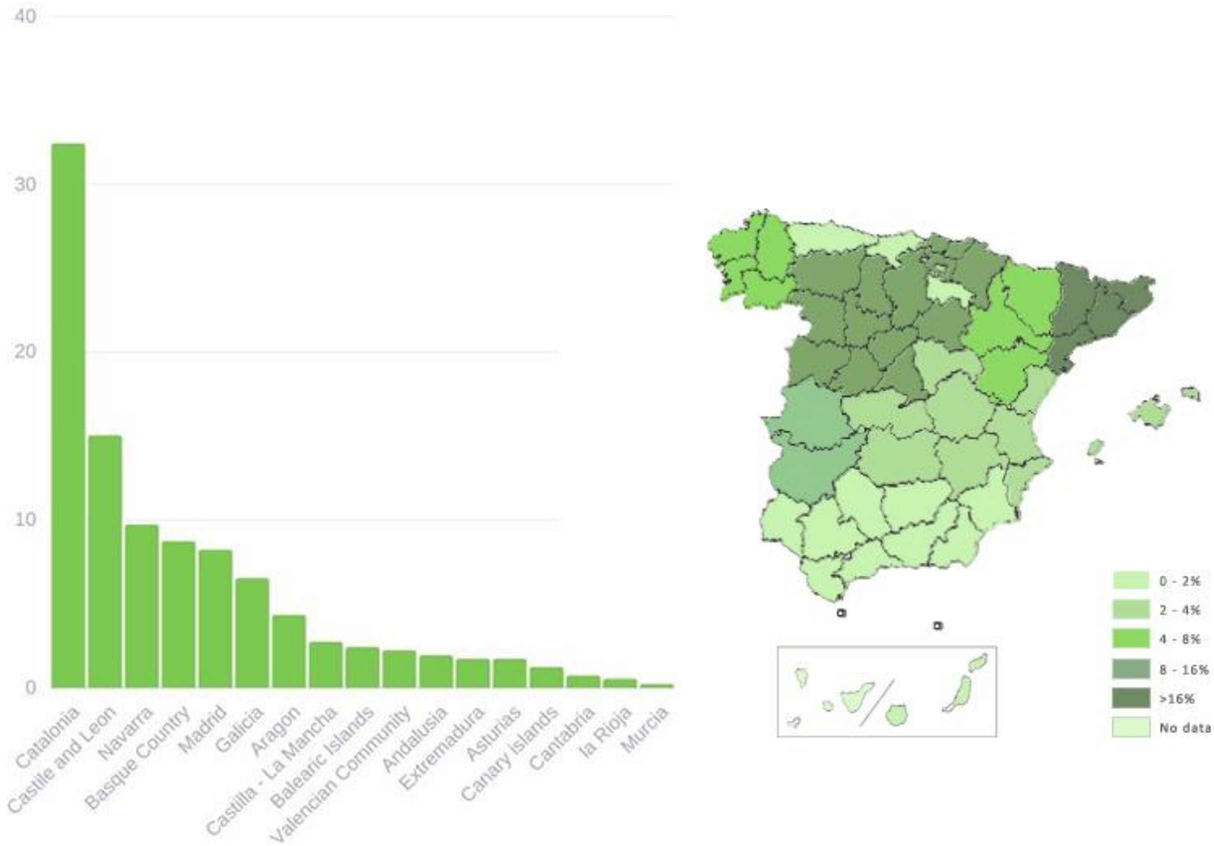


Figure 12. Regional percentage of DHC installations in Spain - 2019. Source: Own elaboration

Currently in Spain the development of DHC systems is pacing upwards mainly to comply with the EU policy targets in the coming decades. Catalonia and particularly Barcelona has a strong commitment to the impetus that DHC Networks need, with the tertiary section being the biggest client. It is the autonomous community with the largest number of networks, with 34%, with Castilla and Leon that has 13% of the networks second. The other communities fail to achieve even a 10%, however Navarra with 9.42% occupies the third place. The networks installed in 2019 have been surveyed to save 303,343 tons of CO2 emissions (Balboa-Fernández et al., 2020).

In terms of installed capacity, Catalonia leads the rankings with 424MW, accounting for 37.3% of the total surveyed capacity. Madrid holds the second position with 301MW installed, representing 26.4% of the total capacity, while Navarra ranks third with 117MW, comprising 10.3% of the total capacity. The tertiary sector, responsible for 69% of electricity consumption, is followed by the residential sector, which consumes 23% of electricity, and the industrial sector, accounting for 8% of electricity consumption (refer to figure 13).

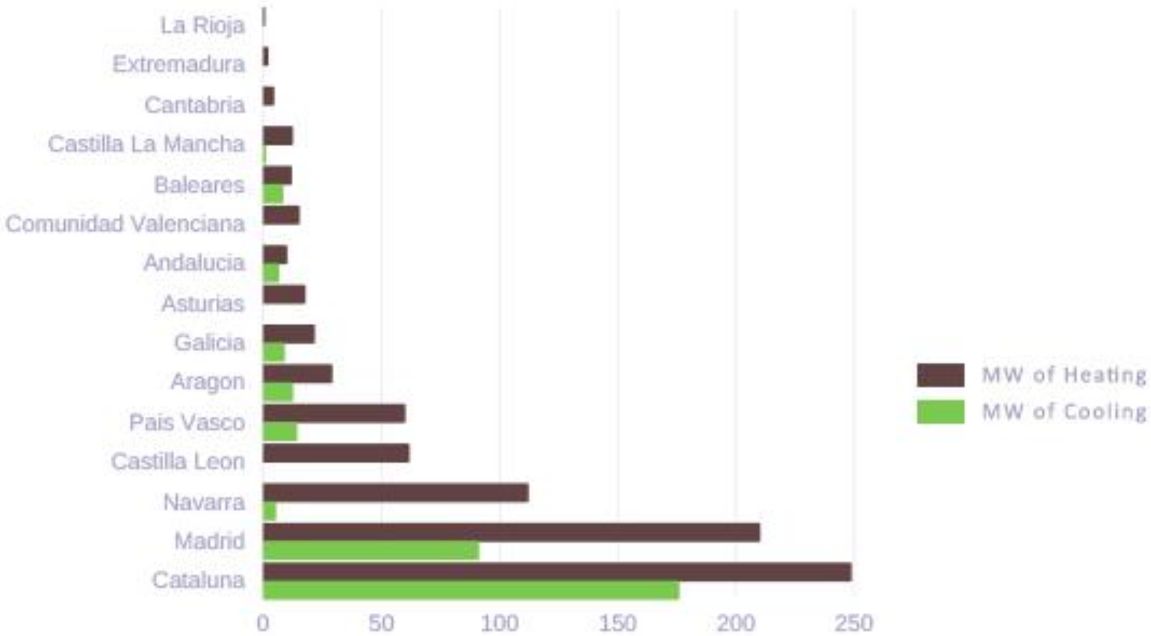


Figure 13. Installed Capacity by Autonomous Community and grid type. Source: Own elaboration based on ADHAC.

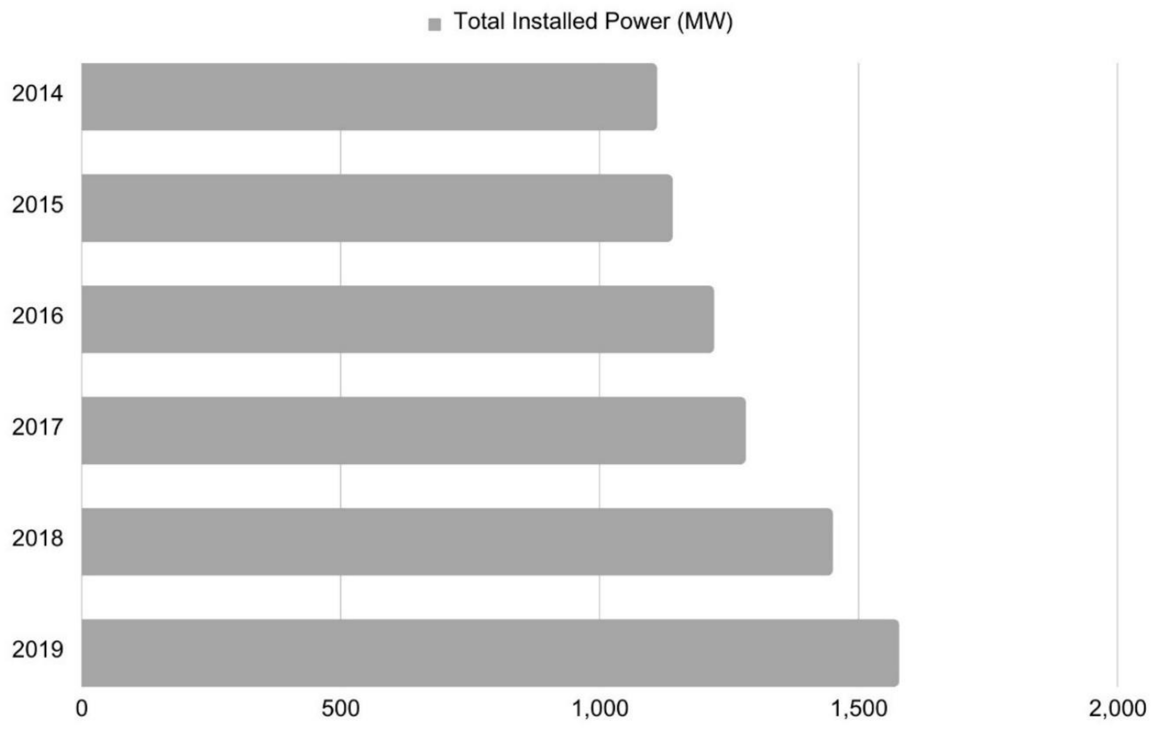
With respect to the networks, heating networks are higher with 89% of the total an only 1% cooling networks and 10% combined heating and cooling network. However, the heating and cooling networks have the largest installed capacity with a total of 1,138.94MW (37%). In short, the installed capacity is mainly used for the supply of heating given that the total installed capacity is 72%. So, 814.44MW is allotted for the supply of heating and 324.50 MW to the production and supply of cooling.

The network's clients are distributed as follows:

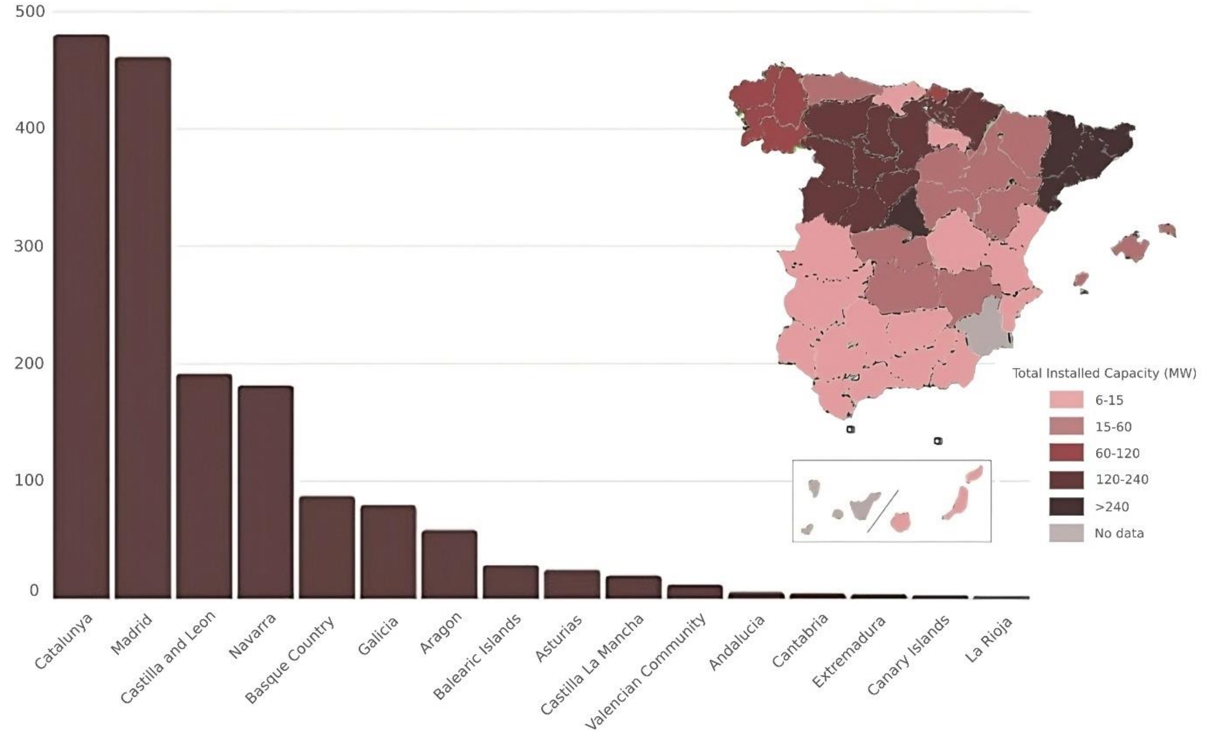
- Tertiary sector: 156 networks - 63.2%
- Households: 48 networks – 19.4%
- Industry: 13 networks – 5.3%
- Households+ Tertiary: 15 networks – 6.1%
- Industry + Tertiary: 7 networks – 2.8%
- Households + Industry: 4 networks – 1.6%
- Households + Tertiary + Industry: 4 networks – 1.6%

About the ownership of the networks, 50.2% are publicly owned; 42.8% private owned and 6.7% with mixed ownership. Regarding the networks surveyed; 174 consume renewable energy; 3 consume natural gas; 25 a mix of different fuels; 11 runs off diesel and 3 consume electricity. An analysis of the installed capacity show that the networks that consume natural gas represent almost 49% of the installed capacity with networks supplied with renewable counting to 29%, electricity accounting for 19% and diesel at 3%.

Spain's building stock is well-suited to utility scale DHC networks because the country has significant amount of community housing, in comparison to other European counterparts and this type of housing is mainly located in urban municipalities. Spain has a long way to go before reaching the figures of Austria, Germany, Finland, and Denmark (Beltran-Rodriguez, 2016).



(a)



(b)

Figure 14. Regional evolution of total (a) installed power and (b) installed capacity. Source: Own elaboration based on ADHAC.

As seen in figure13 a, b, the DHC network percentile in Spain as per 2019, has increased by 20,5% since 2013. The vast majority of the 414 networks provide heat (374), 36 networks supply both heat and cold energy whilst just 4 networks solely supply cold energy (Balboa-Fernández et al., 2020).

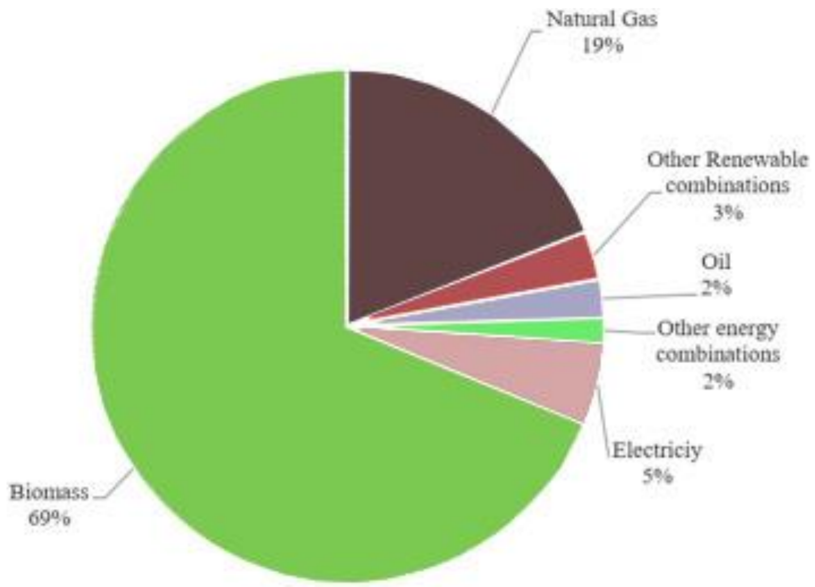


Figure 15. Power sources for DHC systems - 2019. Source: Own elaboration based on ADHAC.

Figure 15, shows that for DHC networks, biomass and natural gas accounted for 66 % and 19% of the total energy resources available as at 2019. Energy resources such as electricity, diesel, geothermal, cogeneration, waste heat, LPG, biogas and solar hot water are consumed on a small scale (Balboa-Fernández et al., 2020).

In spite of advances made in recent decades, there have still not been major facilities for DHC across Europe. On the other hand, it is also very profitable for private networks to be installed in densely populated areas with intelligent heat meters and familiar buildings fitted with internet of things or big data analysis. One of the main obstacles is that Spain does not have statistics on demand for heat, which could help avoid a lot of misinformation from users when selecting an adequate heating and hot water system. The Spanish Government, which is currently in the process of drawing up new legislation on climate change and energy transition, has presented a provisional proposal for an Integrated National Energy and Climate Plan. One of the main targets for 2050 is to decarbonise the economy (Balboa-Fernández et al., 2020).

According to the analysed data and results, it can be concluded that a massive promotion of DHC in Spain has been achieved from 2013 onwards with visible improvements in installed capacity by Catalonia, Madrid, Castilla y Leon and Navarra. Biomass, natural gas or a combination of these is the most common fuel used. Systems aimed at heating energy, e.g., the use of cogeneration, solar energy and biomass, have a technically and economically significant potential.

Spain's Renewable Energy Cycle still remains below that of the EU as a whole. Replacing existing energy resources with more environmentally friendly ones, raising the bar on thermal storage, use of intelligent meters, largescale data processing, better service networks and substation performance, while coping with a lack of heat statistics and prices can achieve energy independence in the future. (Balboa-Fernández et al., 2020).

3.5. Biomass powered Heating and Cooling system

In consideration of Spain's overall percentage of energy output, although renewable thermal sources including biomass contribute to a small share, in 2014 biomass and biogas constituted around 2% of the total energy generation as well as 13.65% of the heat consumed in the heating and cooling sector (Hogarsense, 2018).

Biomass is the main renewable energy source across Europe in terms of final energy consumption. Biomass applications are also the most widely disseminated and used renewable energy sources in the residential sector. The Eurostat database indicates that, in 2012 and 2013, the total annual energy consumption of solid biomass other than biogas or renewable municipal waste. However, the available statistics do not provide sufficient information on biomass capacities particularly in the housing industry. In national statistics, the overall energy use of biomass end equipment is usually assessed by looking at household equipment surveys with a multiplied ratio of wood consumption per user profile. (Köhler et al., 2016)

Figure 16. Main source of biomass: Forest residue. Source: (Paredes-Sánchez et al., 2021)

In biomass-powered heating systems, biomass is burned in boilers or furnaces, producing heat that can be used for space heating or water heating in residential, commercial, or industrial buildings. A biomass furnace is a sealed vessel in which the water or any substance shall be heated. In order to use in different processes and heating applications, heated or vaporized fluid is discharged from the boiler. There are two main types of household use: hot water and centralised heating. During combustion, energy is released in the form of hot water, steam or air and it's transferred to a network of pipes or ducts for heating purposes.

The same is true of biomass powered cooling systems, which use absorption or adsorption chillers that are able to drive the refrigeration cycle with heat generated from biomass combustion. This cycle will cool the water and another heat transfer fluid which then circulates through a building's heating systems to supply air conditioning or refrigeration in different types of applications.

Reductions in fuel dependence, greenhouse gas emissions and the use of biomass resources at local level are among the advantages of using biomass for heating and cooling. By using agriculture and forestry residues (figure 16) and/or dedicated energies crops, biomass is a renewable energy source that can be sustainably managed and harvested to contribute to circular economy.

In view of the continuing development of renewables in Spain, Biomass District Heat and Air conditioning systems have attracted a lot of attention lately. While District Heating and Cooling systems have been in operation in Spain since the 1930s, the implementation of biomass-based DHC networks can be traced back to the late 1990s when the City Council, in collaboration with EREN (Ente Regional de la Energía de Castilla y León) and IDEA (Institute for the Diversification and Saving of Energy), initiated projects to harness the potential of biomass for heating and cooling purposes.

One notable example of biomass DHC systems in Spain is the project in Segovia. In this project, a comprehensive centralized biomass-powered heating system was planned and implemented to cater to the energy demands of a residential block consisting of approximately 1,000 units, as well as a school, sports center, and a cultural center that were constructed in the 1970s. This initiative demonstrated the feasibility and effectiveness of biomass DHC systems in providing sustainable heating and cooling solutions for large-scale residential and public buildings (Hogarsense, 2018).

In addition, development of biomass DHC installations in Spain is supported by the national policy promoting renewable energy sources. Spain has set ambitious targets and biomass is recognised as a key element in achieving those objectives, with the aim of increasing the proportion of renewables in its energy mix. (Bacquet et al., 2021)

The evolution of biomass in Spain has progressed in recently, as reflected by the estimation of energy production from this renewable source (figure 17). Biomass energy has experienced a substantial growth trajectory in Spain, becoming one of the most important renewable energy sectors in the country. The estimation suggests that biomass currently represents around 16% of the total renewable energy production in Spain. This growth can be attributed to several factors, including supportive government policies, increased investment in biomass infrastructure, and technological advancements in biomass conversion technologies. (Bigordà, 2017).

Additionally, Biomass DHC systems provide localized economic benefits by supporting the local forestry and agriculture sectors and creating jobs in rural areas. However, despite their advantages, there are also challenges associated with the implementation of these systems. Even though biomass is capable of becoming a new source of energy, the high cost and lack of suitable infrastructure hinder its commercialisation. Therefore, in order to optimise system operation, it is possible to determine which options are most suitable at each application by taking into account a broad range of energy sources. (Power et al., 2021) The availability and accessibility of biomass feedstock can be inconsistent, posing logistical challenges for reliable supply chains. Moreover, the upfront costs of establishing biomass infrastructure and the need for skilled labour in maintenance and operation can be significant. Nonetheless, with effective policies, technological advancements, and collaboration between stakeholders, the Biomass DHC sector in Spain has the potential to grow.

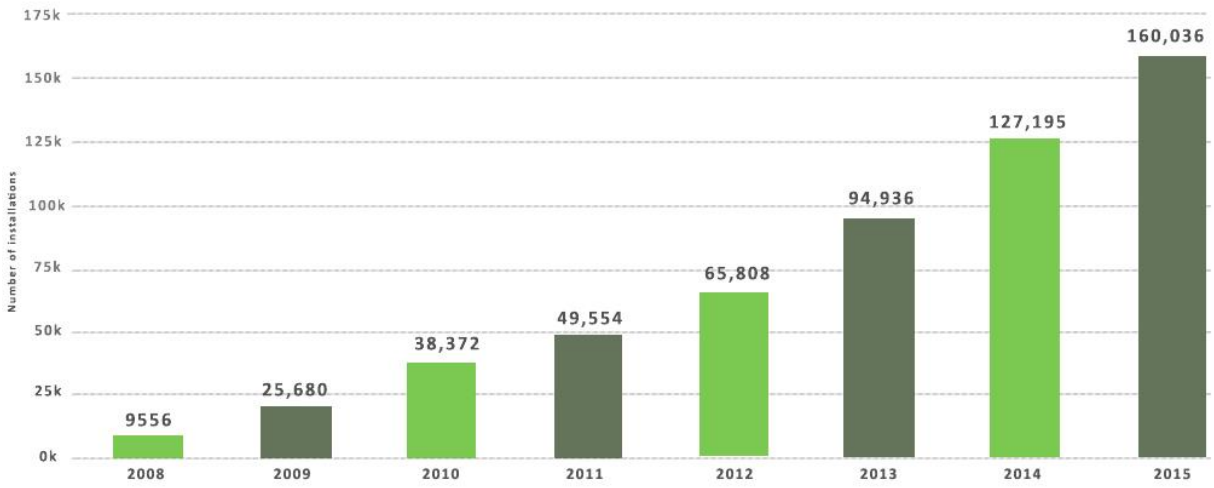


Figure 17. Evolution of the number of Biomass installations in Spain, 2008. Source: Own elaboration based on (Bigordà, 2017).

The shift to closer temperature configurations, e.g., lower temperatures for heating districts and higher temperatures for cooling districts, will make district energy systems more important in the circular economy. (Zhang et al., 2022) Biomass, besides being a low carbon energy resource is a versatile and sustainable energy source, capable of generating both heat and electricity.

With an estimated energy production of 1,500 MW, biomass has become a significant contributor to Spain's renewable energy mix, providing reliable and clean energy for various sectors, including residential, commercial, and industrial. In conclusion, the DHC system has economic, environmental and social benefits. The evolution of biomass, which is envisaged to play a vital role in achieving the country's energy transition objectives and emission reduction targets, will be further prioritised by Spain as it still prioritises expanding its power generation capacity from renewables. (Bigordà, 2017).

4. Case study

In particular, this case study intends to carry out thorough evaluations and comparisons of five district heat and air conditioning units in Spain with a special focus on their energy sustainability. The analysis aims to identify key success factors (KSF) that influence the establishment of efficient and low-carbon DHC systems.

In line with the Sustainable Development Principles, this study is aimed at developing a comprehensive framework for research on DHCs. The work of Kveselis, which stresses the need to consider sustainability principles when studying and developing DHC systems, is used in this research. By adopting this approach, the study aims to contribute to the knowledge and understanding of sustainable DHC practices, providing valuable insights for future research and policy development in the field. (Kveselis et al., 2017).

Despite the increased adoption of district heating and cooling systems in Spain since 2013, renewable sources still account for a relatively small proportion of the overall energy output. Through a meticulous review of available data, the research seeks to identify DHC innovations that are replicable, ideal, and economically viable, with a specific focus on biomass-powered DHC systems.

To evaluate the efficiency and environmental impact of the selected DHC systems, the following indicators have been chosen:

- Assessment of the energy sources
- Analysis of energy efficiency
- CO2 emissions and global environmental footprint (Moretti et al., 2016)
- Adaptability to changing energy demands and sources
- Assess economic viability
- Comparison with alternatives

By analysing these key factors, the research aims to provide valuable insights into the sustainability and effectiveness of DHC systems in Spain. Furthermore, the identification of key success factors will contribute to the development of best practices and guidelines for future DHC projects, both in Spain and internationally, particularly those powered by biomass, and contribute to the broader understanding of sustainable energy practices.

The analysed group consists of five cases with a view to evaluating the aspects relating to different scale, climatic conditions and energy systems that have been defined on the basis of main criteria and methodological series, analysis parameters and an initial context overview and study. The selected district heating and cooling (DHC) systems and locations are shown on the map below (figure 18), followed by the basic data of each of the cases. The essential data of the selected DHC networks are included in tables in the respective subsections.

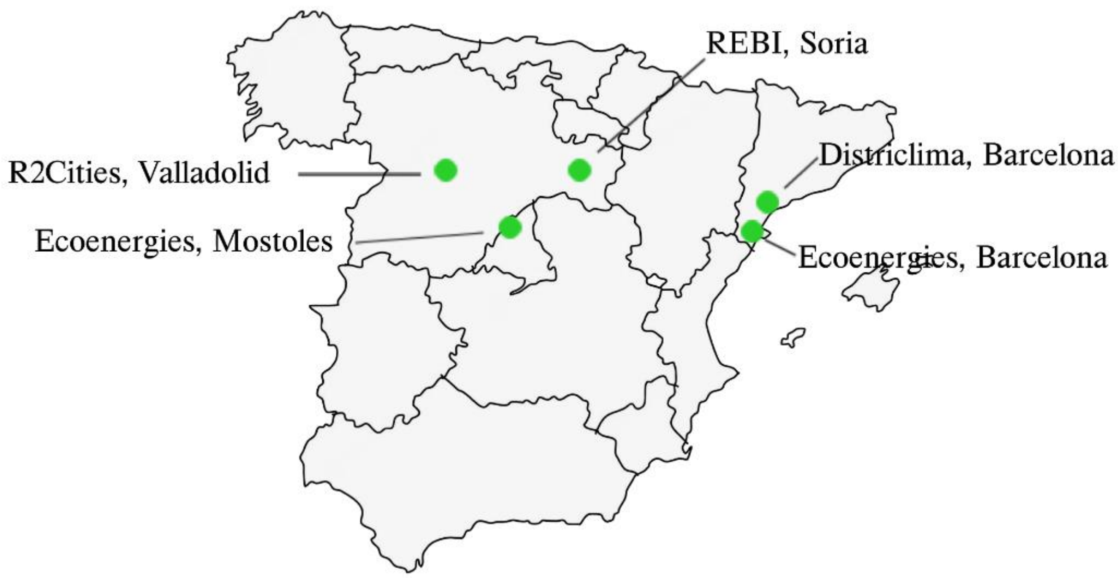


Figure 18. The five cases of District Heating and Cooling networks analysed in Spain. Source: Own elaboration

A variety of District Heating and Cooling System are included in these cases, with the main focus mainly on district heating system. As stated by the International Energy Agency, this emphasis is in line with the recognition that heat is the world's largest energy end use demand, accounting for around 50% of global total energy consumption in 2018. (IEA, 2019) Moreover, according to projections, by 2070 the energy demand for air conditioning in buildings is projected to exceed that of heating (Isaac & van Vuuren, 2009). These factors make it clear that the study of DHC systems have a key role to play in satisfying both current and future heating and cooling needs. The case study focuses on the economic, environmental and social aspects of district heating and cooling systems.

The environmental aspect of the analysis will focus on assessing the carbon footprint and overall environmental impact of biomass DHC systems. This evaluation will consider factors such as greenhouse gas emissions, air quality, the utilization of renewable biomass resources and the comparison with other resources. The study will explore how biomass DHC systems contribute to reducing carbon emissions and advancing Spain's sustainability goals. In analysing the economic dimension, the study will evaluate the long-term economic viability of biomass DHC systems. Additionally, the study will explore the potential for job creation and local economic benefits associated with biomass DHC implementation. In terms of the social dimension, the study will examine the societal implications and benefits of biomass DHC systems as well as the perception of biomass as a renewable energy source, discussed in the upcoming parts of this research.

It is necessary to consider that a DHC consists of a broad and complex variety of facilities, distribution system, and infrastructures in a centralized location. The cases are varied in terms of the majority being District Heating systems with a higher concentration of DHC systems in the north of Spain (Barcelona, Mostoles, Valladolid, Soria). The aim of this study is to produce a complete picture of the total location and performance of biomass DHC systems in Spain's energy landscape through an examination of these diverse cases.

4.1. Overview

District heating and cooling (DHC) systems offer a centralized approach to supplying heating and cooling needs to multiple buildings or areas, promoting energy efficiency and sustainability. In Spain, several cities have implemented DHC systems, such as DISTRICLIMA in Barcelona, Eco energies in Barcelona, WEDISTRICT in Valladolid, REBI Heating network in Soria, and Ecoenergies in Mostoles. While these systems share the goal of providing efficient heating and cooling, there are notable similarities and differences among them.

All five DHC systems emphasize the use of renewable energy sources to meet heating and cooling demands. Biomass sources is used as the main energy source in three of the cases (Eco Energies, WEDISTRICT, and REBI Heating Network) while some cases utilize renewable energy sources like solar panels and waste-to-energy plants. These networks supply heating, cooling, and/or hot water to multiple buildings. covering vast areas. Energy efficiency is achieved by applying measures such as heat condensing pumps and remote management systems. Each system incorporates centralized power plants that produce heat or cooling for distribution through its pipe network. This centralization enables efficient energy production notably in DISTRICLIMA (Barcelona) and reduces individual building emissions. They focus on reducing carbon emissions, promoting energy conservation, and utilizing sustainable energy sources.

The energy sources vary from waste-to-energy steam, sea water refrigeration, biomass and photovoltaic panels. The comparison has some difficulties due to the lack of specific details and recent data as well as the non-uniformity of the cases analysed, which vary from 53,400 m2 to 15,000,000 m2 and different heating and cooling capacities, ranging from 2 MW to 73 MW as well as the number of buildings on the grid. DISTRICLIMA in Barcelona serves 80 buildings over 760,000 m2, while REBI Heating network in Soria supplies heating and hot water to homes in a specific area of Soria. The length of the distribution grid also varies. DISTRICLIMA in Barcelona has a network spanning 14 km, while Ecoenergies in Mostoles has a 4 km pipe network. The cooling and heating capacities differ across the systems.

For instance, DISTRICLIMA in Barcelona has cooling power of 35.9 MW and heating power of 51 MW, while Ecoenergies in Mostoles operates with three biomass boilers and estimated energy savings of 15% for its users.

The study of these case helps us to understand the varied approaches to district heating and cooling systems in Spain, showcasing different technologies, energy sources, and scale of implementation in urban areas. Each network has its own characteristics based on specific needs and geographical location of the respective cities or districts. In the following sections we see their analysis based on several key success factors (KSF), as these cases show the diverse approaches taken to achieve efficient heating and cooling. We look at the comparative analysis of these cases with respect to our topic of study focusing on the heating and cooling energies produced by these networks and the energy recipients of these grids. By adopting these sustainable practices, these cities contribute to reducing greenhouse gas emissions and promoting a greener future for Spain's energy infrastructure.

(a) DISTRICLIMA, Barcelona

DISTRICLIMA S.A., operating in Barcelona since 2004, focuses on providing district heating and cooling services in the Forum and Technological District 22 areas. The central plant utilizes steam generated from the Municipal Waste Treatment Facility, which condenses in seawater (figure 19). The district heating and cooling network spans 14 km, serving 80 buildings with a total area coverage of over 760,000 m2. The heating capacity is 51 MW, while the cooling capacity is 73 MW, including a cumulative cooling capacity of 40 MW and an ice accumulation capacity of 80 MW (EU Commission, 2021; Beltran Rodriguez, 2016; DISTRICLIMA, 2009).

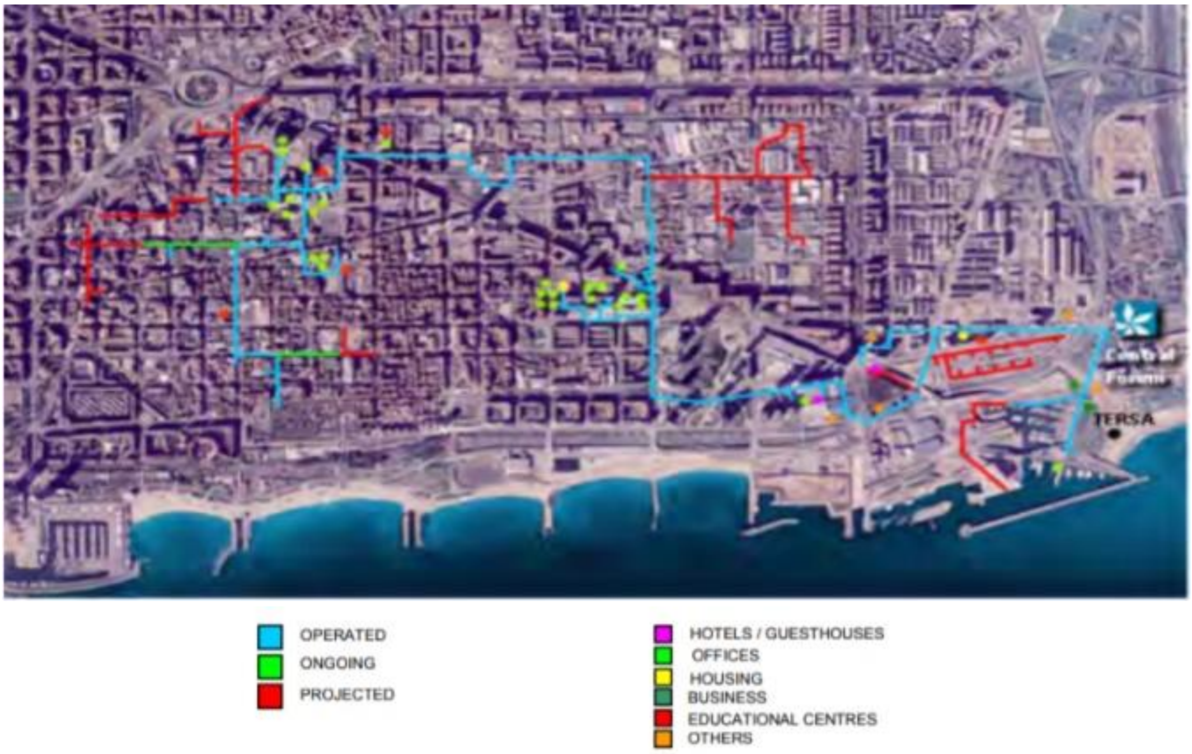


Figure 19. DISTRICLIMA's distribution network. Source: DISTRICLIMA (DISTRICLIMA, 2009).

In the 22@ area, the Forum Power Plant supplies 39 buildings, including office spaces, hotels, hospitals, shopping malls, and private residences. The air-conditioned area covers 360,000 m2, with contracted heating and cooling capacities of 30 MW and 45.7 MW, respectively. The network extends over a distance of 10.8 km, and the heating temperatures range from 90 ºC to 60 ºC, while the cooling temperatures range from 5.5 ºC to 14 ºC. The installed heating capacity consists of 20.4 MW from steam exchangers and an additional 20 MW backup boiler, while the installed cooling capacity comprises 29.2 MW and a 10.4 MW chilled water tank with a capacity of 5,000 m3 (figure 20).

The Forum Plant boasts three key energy efficiency factors. Firstly, it produces all heat and half of the cooling from steam generated by the Tersa Waste-to-Energy Plant. Secondly, it employs a seawater refrigeration system for cold production, which enables high yields without the need for refrigeration towers. Lastly, it utilizes a chilled water tank with a capacity of 5,000 m3, allowing for the accumulation of 50 MWh of cold and facilitating the sustained use of renewable cooling even during periods of low demand.

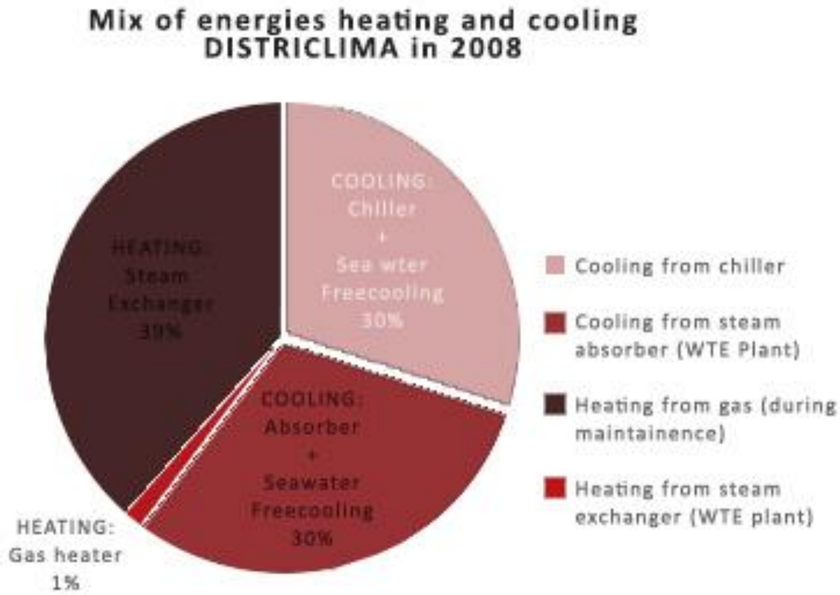


Figure 20. DISTRICLIMA Barcelona´s heating and cooling sources. Source: DISTRICLIMA (DISTRICLIMA, 2009).

In terms of cooling production, the Forum Plant features two 4.5 MW absorption cooling machines utilizing waste-to-energy steam with speed regulators, capable of achieving a coefficient of performance (COP) exceeding 10 in winter. Additionally, the plant includes a 5,000 m3 chilled water tank. For the refrigeration system, there are three 12.5 MW titanium seawater/refrigerated water exchangers and a seawater pumping station with a capacity of 5,000 m3/h. Heating production is facilitated by four 5 MW 90 ºC steam/water exchangers and a 20 MW gas steam boiler, which serves as a backup for the waste-to-energy steam (AAVV, 2014).

DISTRICLIMA in Barcelona operates a district heating and cooling system that incorporates biomass-powered facilities, such as the Municipal Waste Treatment Facility, to provide sustainable and efficient heating and cooling services to a significant number of buildings in the Forum and Technological District 22 areas. The company's infrastructure and energy efficiency measures, including the utilization of seawater for cooling and the incorporation of chilled water storage, contribute to the reduction of environmental impacts and the promotion of renewable energy use in the region.

(b) Ecoenergies, Barcelona

Eco energies Barcelona is a notable example of a district heating and cooling (DHC) network located in the Barcelona Zona Franca area. Originally planned for a residential development of 18,000 houses and industrial areas, this project faced challenges due to economic crisis but ultimately became a successful endeavour. The DHC network (figure 21), serves as a prime illustration of the potential for such systems in cities with warmer climates, where district energy supply is less prevalent compared to Northern countries.

Figure 21. Phases of District Heating and Cooling Network Expansion in Barcelona. Source: Ecoenergies. (Elcacho, 2014)

Comprising three power plants strategically positioned within the network, Eco energies Barcelona, also known as the DHC network for the south of Barcelona, covers a vast geographical area of 15,000,000 m2 upon completion. The network provides heating, air conditioning, and domestic hot water to connected buildings through environmentally friendly methods (Veolia, n.d.). The plant incorporates advanced features such as 3rd generation heating and cooling facilities, an ice pool utilizing glycol water at -10ºC, heat condensing pumps, and photovoltaic solar panels. It is equipped with branches for heat, positive cold, and negative cold distribution. Biomass, primarily sourced from parks and gardens (13,000 tons) and forestry (17,000 tons), along with energy crops, serves as the main fuel source (Elcacho, 2014).

At present, Eco energies Barcelona has a capacity to supply an area of 1,200,000 m2 with 2.9 MW of power. However, the project has ambitious plans to expand its capacity to 6 MW using 3rd generation technologies, with 1.3 MW derived from biomass. These targets are set for a 30-year period, showcasing the network's long-term commitment to sustainable energy solutions. The DHC network effectively manages the heating and cooling requirements of Barcelona Sur and L'Hospitalet regions (Beltran Rodriguez, 2016; DISTRICLIMA, 2009).

(c) WE District, FASA, Valladolid

Valladolid, a province that is committed to renewable energy, is leading the way in the implementation of a biomass and heating cooling district network in the district of FASA. The network has been in operation since 2018 and today provides energy to six buildings, namely four public buildings of various dimensions and two housing estates with an area of over 53,400 m2. The network operates with a peak capacity of 6.96MW, powered by two biomass boilers with a capacity of 3.48MW each (Valladolid, n.d.).

Figure 22. DH system in Valladolid. Source: R2Cities (R2Cities ES, n.d.)

The DHC network in Valladolid (figure 22), extends through the streets, branching out from its central location to reach each building efficiently. Spanning approximately 11.30 kilometres, the network incorporates the latest generation leak detection and breakdown systems, ensuring continuous monitoring and remote management capabilities. The total planned consumption for the entire network is estimated to be 22,069,734 kWh per year, with an expected annual consumption of 7,886 tons of biomass chips for District Heating (Valladolid, n.d.).

This biomass-powered DHC network in Valladolid, as exemplified in the FASA district, highlights the province's commitment to sustainable energy solutions and showcases the successful integration of renewable resources in meeting the heating and cooling needs of multiple buildings. The WE

District project in FASA, Valladolid, serves as a notable example of how biomass-based DHC systems contribute to reducing carbon emissions and promoting environmentally-friendly heating and cooling solutions.

(d) REBI Heating network, Soria

The REBI heating network in Soria holds the distinction of being the first Spanish city to pioneer the concept of a zero-carbon city. With a thermal power of 2MW and a network spanning 28km, it effectively supplies heating and sanitary hot water to residential areas in central and north Soria (figure 23).

Figure 23. DH network in Soria. Source: REBI (GESDINET, 2019)

The primary energy source for this network is biomass, specifically utilizing forest residue as fuel. This biomass-based power generation plant, resembling the one in Valladolid, was commissioned in December 2014 and occupies a sizable 800 m2 building located in the north-eastern part of the city. It is estimated that the network's annual consumption amounts to approximately 28,000,000 kWh. Notably, buildings connected to the REBI heating network in Soria can enjoy substantial savings of at least 15% on their heating bills. The establishment of the REBI heating network showcases Soria's commitment to sustainable energy solutions and serves as an exemplar for other cities in Spain and beyond. (SLU, 2019; GESDINET, 2019)

(e) Ecoenergies, Mostoles

Ecoenergies in Mostoles stands out as Spain's largest and most ambitious biomass-powered District Heating and Cooling (DHC) network. It serves a densely populated area, providing centralized heating and sanitary hot water (figure 24), to meet the demands of thousands of homes. The network's first phase involved the connection of 3,000 homes, with plans to expand and reach a total of 6,000 homes in successive phases. The heating network in Mostoles comprises a 4km pipeline, equipped with three biomass boilers and 13 exchange substations. The power plant responsible for generating heat utilizes forestry biomass in the form of wood chips, consuming approximately 5,934 tons of biomass annually. The sourcing of wood chips is facilitated by nearby woodlands, ensuring a sustainable and local fuel supply. Users of the Mostoles Ecoenergies grid can benefit from estimated energy cost savings of about 15% compared to conventional heating options (VEOLIA, 2019).

Ecoenergies in Mostoles exemplifies the potential of biomass-powered DHC systems in promoting energy efficiency and sustainability. By utilizing locally sourced biomass, the network reduces reliance on fossil fuels and contributes to greenhouse gas emissions reduction. The centralized approach of DHC systems optimizes resource utilization and minimizes energy losses, resulting in cost savings and environmental benefits. The implementation of Ecoenergies demonstrates the commitment of Mostoles to a cleaner and more sustainable energy future.

Figure 24. Mostoles Biomass powered DHC network. Source: Ecoenergies. (VEOLIA, 2019)

It is worth noting that while Ecoenergies in Mostoles represents a significant achievement in biomass-powered DHC, other Spanish cities have also implemented their own DHC systems, each with its unique characteristics and objectives. These include DISTRICLIMA in Barcelona, Eco energies in Barcelona, WEDISTRICT in Valladolid, and the REBI Heating network in Soria. Despite variations, these systems collectively contribute to Spain's sustainable energy goals, showcasing the country's commitment to efficient and environmentally friendly heating and cooling solutions.

4.2. Key factors analysed

(a) Energy sources

A wide variety of energy sources (table 1), are used in the analysis of DHC schemes in Spain, and account is taken of a strong emphasis to be placed on renewables and lower carbon options. In three cases, namely Ecoenergies, WEDISTRICT and the REBI heating system biomass has been shown to be a common renewable energy source. It highlights the potential of biomass, derived from parks and forestry residues or energy crops as a sustainable source of power for DHC systems. (Ecoenergies, Zona Franca, Barcelona; WEDISTRICT, FASA, Valladolid; REBI Heating system, Soria).

Case studies	Type of network	Year of commissioning	Low-carbon energy sources
Forum 22@ District Heating and Cooling network, DISTRICLIMA Barcelona	District heating and cooling	2004	Steam, gas
Ecoenergies, Zona Franca, Barcelona	District heating and cooling	2009	Biomass from park and forestry residue, natural gas, residual cold energy
WEDISTRICT, FASA, Valladolid	District heating	2018	Biomass
REBI Heating system, Soria	District heating	2014	Biomass
Mostoles District Heating	District heating	2017	Gas, Natural gas, Biomass (forestry origin wood chip)

Table 1. Capacity, production and energy sources of the DHC systems studied. Source: Own elaboration

Additionally, to meet the needs of these systems for heat and cooling, besides biomass, other energy sources like steam, gas, natural gas or residual cold are used. This diversified mix of energy sources plays a crucial role in reducing carbon emissions and promoting sustainable energy consumption in the respective areas (Forum 22@ District Heating and Cooling network, DISTRICLIMA Barcelona; Mostoles District Heating).

Various factors, such as the need to improve energy efficiency, flexibility in supply and independence of energy sources like industrial waste heat or cogeneration plants, influence the implementation of DCH systems in

Spain. These systems are intended for diverse sectors, with the main users of DHC power supply coming from homes, industries and higher education. (Werner, 2017) While Spain differs from other EU countries in the distribution of electricity to DHC installations, it is important to note that the tertiary sector has the highest supply of electricity in Spain. (2019)

The cost and lack of adequate infrastructure hinder biomass in its mass commercialisation, even if it has the potential to become a new source of energy. For this reason, the use of a wide range of energy sources allows it to determine which option is most appropriate for each application in order to optimise system performance. (Power et al., 2021)

The DHC system in Spain contributes to reducing the use of fossil fuels through primarily relying on wind and solar energy. This also has the effect of reducing energy consumption, improving energy efficiency and decreasing CO2 emissions. The positive environmental impact of DHCs in Spain is underlined by their annual CO2 emissions reduction of 305,945 tonnes as well as a 79% drop in fossil fuel consumption. (Paredes-Sánchez et al., 2021)

Overall, the energy sources employed in DHC systems in Spain demonstrate a concerted effort to integrate renewable and low-carbon options. The ability of district heating to increase Europe's energy independence and reduce CO2 emissions is highlighted by the fact that, in 2021, 43% of European district heat will come from renewable and waste heat sources. (Euroheat, 2023) These systems play a crucial role in advancing Spain's transition towards a more sustainable and efficient energy landscape, showcasing the country's commitment to reducing carbon emissions and promoting renewable energy utilization in the heating and cooling sector.

(b) Energy efficiency

The results (table 2), from the case studies analyzed show notable emphasis on the use of renewable and low carbon energy sources in the DHC systems on Spain and the country´s commitment to optimising energy consumption and reducing environmental footprint.

Case studies	Maximum heat power produced (MW)	Maximum cold power produced (MW)	Energy recipients
Forum 22@ District Heating and Cooling network, DISTRICLIMA Barcelona	Installed heating capacity: 20.4 MW (steam exchangers) + 20 MW backup boiler;	Installed cooling capacity: 29.2 MW +10.4 MW (5,000 m^3 chilled water tank)	80 buildings
Ecoenergies, Zona Franca, Barcelona	Maximum heat power • Conventional: 110MW • From biomass: 10 MW.	Maximum cold power • Conventional: 68,5 MW • Industrial: 12 MW • Recovered from the Plant Port: 30 MW • Ice accretion: 320 MWh	18,000 houses
WEDISTRICT, FASA, Valladolid	14 MW thermal potential	-*	6 buildings, 4 public buildings of varied sizes and 2 housing communities, covering in total an area of 53,400m2
REBI Heating system, Soria	21 MW thermal potential	-*	31 buildings
Mostoles District Heating	Gas-20MW, Natural gas-6.6MW, Biomass-1.1MW	-*	3000 residential homes (target 6,000 homes)

- *Lack of data*

Table 2. Energy efficiency based on the maximum heat and cold power and the energy recipients of the DHC systems studied. Source: Own elaboration

The utilization of biomass as a renewable energy source in the Ecoenergies, WEDISTRICT, and REBI Heating system exemplifies the potential of this resource in DHC systems (Ecoenergies, Zona Franca, Barcelona; WEDISTRICT, FASA, Valladolid; REBI Heating system, Soria). Biomass, derived from park and forestry residue or energy crops, offers a sustainable alternative for heat generation, contributing to the reduction of greenhouse gas emissions and reliance on fossil fuels. The cases studied vary in the power generated depending on the sources, scale and layout of the systems.

Implementation of DHC systems aligns with the EU climate goals as it uses energy efficiency techniques, allowing the utilization of locally available and environmentally friendly resources thus lowering dependence on traditional energy sources, such as fossil fuels, these systems promote greater energy independence, lower carbon emissions, and increased overall efficiency. For instance, the Forum 22@ District Heating and Cooling network in Barcelona utilizes steam from a municipal waste incinerator for heat production, effectively repurposing a by product that would otherwise go to waste (DISTRICLIMA, 2009). By maximizing the utilization of waste heat and optimizing energy distribution, this approach not only reduces energy waste but also enhances the overall energy efficiency of the system.

In addition, how innovative techniques for the circular economy can be employed is demonstrated by using residual cold energy and installing heat exchanger units and photovoltaic solar panels on Ecoenergies in Zona Franca, Barcelona (Ecoenergies, Zona Franca, Barcelona). By the heat recovery from the waste plant which would have otherwise been in a landfill and energy generation the DHC network can become a more integrated and sustainable system.

The phased approach, as seen in the construction of the Marina power generation plant, and the expansion to new areas, demonstrates a strategic vision to optimize energy delivery and meet the growing demand while minimizing energy losses (DISTRICLIMA Barcelona). The expansion plans of the analysed DHC systems further reinforce the commitment to energy efficiency.

(c) Carbon emissions

This section examines the CO2 emissions of five representative DHC systems in Spain (table 3), and compares their environmental impacts, assessing their energy efficiency and emissions reduction strategies. The results of the analysis of CO2 emissions of the DHC networks represented highlights the importance of scale, coverage area, and optimized design in achieving sustainable systems.

District heating and cooling networks analysed Parameters analysed	Forum 22@ District Heating and Cooling network, DISTRICLIMA Barcelona	Ecoenergies, Zona Franca, Barcelona	R2Cities, FASA, Valladolid	REBI Heating system, Soria	Mostoles District Heating
Type of network	District heating and cooling	District heating and cooling	District heating	District heating	District heating
Total pipe length	85 km	17 km	4.4 km	28 km	4 km
Area of distribution	1.6 million m2	2.5 million m2	55,000 m2	1.326.450 m2	217.567 m2
CO_2 emissions annually (tn/yr)	21.000	13.400	7,886	22,000	6,621

Table 3. Carbon emissions in the production, transmission and distribution of energy of the DHC systems studied. Source: Own elaboration

The analysis reveals varying levels of energy efficiency. The centralized nature of DHC systems allows for more efficient energy generation and distribution, leading to lower overall emissions. The Forum 22@ and Ecoenergies networks exhibit commendable efficiency, considering their large coverage areas. The R2Cities system demonstrates efficient operations within a smaller network, while the REBI Heating system serves a larger area, resulting in higher annual CO2 emissions of 22,000 tons, however, considering the larger area served, the system still manages emissions effectively. The Mostoles District Heating system's optimized design for the specific area it serves contributes to its impressive efficiency.

By reducing reliance on individual heating and cooling units, DHC systems lower emissions and improve air quality, benefiting human health. These systems optimize resource utilization by efficiently distributing heat and cold, minimizing energy waste. Moreover, the environmental impact on ecosystems is minimised through use of renewable energy sources such as biomass and recovered energy.

Sustainable building practices, such as good waste handling, dust control measures, noise reduction strategies and compliance with the environment requirements, should be adopted to minimise adverse effects on DHC systems' construction phase. It is also vital to include criteria for the life cycle assessment (LCA) of industry equipment, in order to limit impacts on the environment associated with manufacturing phases. (Guillén-Lambea et al., 2021).

Overall, DHC systems have the potential to significantly lower CO2 emissions from the initial phases of energy production to transmission to distribution. These systems have a critical role to play in the transition towards a more sustainable and low carbon future by integrating renewable energy sources, using waste heat as well as optimising energy efficiency.

(d) System adaptability

District Heating and Cooling (DHC) systems in Spain demonstrate good adaptability to changing energy demands and sources due to several key factors discussed in this sub-section showing their potential to meet evolving energy needs while transitioning to sustainable and low-carbon energy sources.

The flexibility and resilience of DHC systems are enhanced by the geographical location, good weather conditions, a wide range of available energy sources, infrastructure developments as well as an enabling regulatory framework. A diverse energy mix, which also includes renewables like sun and biomass, is a benefit for Spain. This diversity offers opportunities for sustainable heat generation in DHC systems. Solar energy can be utilized for both heat production and cooling through solar thermal collectors and absorption chillers, respectively. Biomass, including forestry residue and energy crops, can be harnessed as a renewable energy source for heat production in DHC systems (Holmgren & Elmegaard, 2019).

Policies and incentives promote energy efficiency, renewable energy integration, and decarbonization. These regulations facilitate the adaptation of DHC systems to changing energy demands and sources, providing a conducive environment for their development and expansion (Lake et al., 2017).

Successful case studies, such as the Forum 22@ network in Barcelona, serve as practical examples of the adaptability of DHC systems in Spain. The Forum 22@ network demonstrates how DHC systems can effectively meet the heating and cooling needs of a large urban area while reducing carbon emissions. These success stories validate the viability and scalability of DHC systems in the Spanish context (Rezaie & Rosen, 2012). In order to achieve the sustainability goals, DHC systems are expected to be of great importance. In order to respond to the objectives, set by the 21st Conference of Parties, DHC systems are capable of making efficient adaptations to changing energy needs for a new Sustainable Energy Model which can be derived from Renewable Energy sources, optimising energy efficiency and using existing infrastructure. (Fernández et al., 2021)

(e) Economic viability

In the process of growing DHC networks in Spain, they have showed to promote economic growth by providing job opportunities and establishing stable and affordable energy supplies. (Euroheat, 2023) **DHC systems achieve economic viability by fostering local industries, new business opportunities and investments.** The functioning the District Heating and Cooling networks require workforce, besides encouraging the growth of related sectors such as low carbon source providers, equipment manufacturers, and energy service companies.

There are many different types of skilled laborers, technicians, and experts needed, from the early planning and design stages to the construction, operation, and maintenance phases. This job creation helps to lower unemployment rates, raise living standards, and improve the general socioeconomic wellbeing of the communities where DHC systems are used.

By promoting energy security and reducing dependency on imported fuels, DHC systems offer a diversified and resilient energy supply. This stability helps to mitigate energy price fluctuations, ensuring affordable energy for consumers and businesses. The reduced reliance on individual heating and cooling units also allows for economies of scale, making DHC systems more cost-effective in the long run. By providing affordable and efficient energy services, DHC systems help to alleviate energy poverty, making energy more accessible to a broader segment of the population.

These systems not only contribute to regional and national economic growth but also help to foster sustainable and inclusive development. DHC systems play a crucial role benefiting both the economy and society. Existing European projects are likely to expand to accommodate future urban developments. An increasing ambition to achieve 40 % of greenhouse gas emissions reductions by 2030, which should be taken into account in a more comprehensive review. On the other hand, the Spanish Government has been working on a Climate Change and Energy Transition Law and has presented a proposal for an Integrated National Energy and Climate Plan with ambitious 2050 targets for a practically decarbonised economy. (Euroheat, 2023)

(f) Comparison with alternatives

Although it was in the 1990s that fossil fuels, such as coal, oil or natural gas, were the main source for DHC systems because of their availability and capacity to be used, recent years have seen an increasing shift towards renewable energy sources. Air pollution, rapid emission rates and depletion of the ozone layer are also detrimental to fossil fuels. In order to reduce the negative impact on the environment, technological progress has made waste heat production an important technique. (Jouhara & Sayegh, 2018)

Various studies have been carried out to evaluate the impact of low carbon district heating and cooling on energy alternatives. (Lindroos et al., 2021; Fahlén & Ahlgren, 2009; Sdringola et al., 2018). According to the statistics of Europower, in the future DHC networks will expand to possibly power over half of the total spatial and water heating in the residential and commercial sectors. (Euroheat, 2023). Results indicate that a combination of heat and power plants (CHP) along with DHC could be a promising long-term solution. (Moretti et al., 2016)

Biomass based District Heating and Cooling has advantages such as fuel diversity and carbon neutrality over other energy alternatives. (Bauen et al., 2009) They offer economic and environmental benefits by being climate friendly and offsetting emissions with the carbon absorbed during the growth generating power that could be harnessed as heating, energy and cooling simultaneously. (Sdringola et al., 2018; Fahlén & Ahlgren, 2009) The use of biomass, which is the world's most important contributor to renewables and provides an essential role for responding to climate change by shifting towards cleaner energy sources as well as limiting dependence on imports in order to create a stable and sustainable energy future. (Lindroos et al., 2021). By converting huge amounts of existing residues and wastes, biomass has a significant potential to expand in the decades to follow combined with the innovations in technology. (Bauen et al., 2009)

5. DHC model and its role in achieving the EU climate goals for 2030

The District Heating and Cooling (DHC) model plays a significant role in helping achieve the EU climate goals for 2030. The DHC approach contributes to the EU's climate objectives as follows:

- **Energy Efficiency**: DHC systems enable the efficient generation and distribution of heat and cooling, resulting in reduced energy waste compared to individual heating and cooling units. By optimizing energy efficiency, DHC helps decrease greenhouse gas emissions and improve overall energy performance.
- **Integration of renewables**: DHC network provides a great opportunity for the integration of different Renewable Energy sources like Biomass, Solar-Thermal, Geothermal and Waste Heat Recovery. These low carbon sources of energy represent a significant CO2 emission reduction in the DHC systems, which reduce their reliance on crude oil.

- **Decentralised Energy Production:** the integration of decentralised energy production, e.g., CHP plants or renewable energy installations, could be supported by DHC networks. In addition, these decentralised energy sources contribute to a more sustainable and diversified energy mix that reduces the dependency on centralised power generation as well as improving energy resilience.
- **Waste Heat Recovery:** DHC systems can capture and utilize waste heat from various sources, including industrial processes, power generation, and data centres. By harnessing this otherwise wasted heat, DHC networks maximize energy efficiency and reduce the environmental impact associated with heat generation.
- **Building Renovation and Energy Transition:** The use of DHC systems and building refurbishment programmes are frequently mutually beneficial. Energy efficiency measures can be effectively combined with the conversion to lower carbon heat and cold solutions through connections between renovated buildings and a DHC network.

The widespread implementation of DHC systems is essential to achieve the EU's 2030 climate objectives, which include a significant reduction in greenhouse gas emissions. They provide a sustainable and efficient solution for meeting heating and cooling demands while significantly reducing CO2 emissions. In the near future, the industry is expected to expand and promote the decarbonization and with a more efficient energy conversion of the relevant heat markets in Europe by further decarbonizing its supply sources. (Euroheat, 2023) In order to accelerate energy transition and support a greener future, the EU recognises the importance of DHC systems and is promoting their introduction by means of policy frameworks and financial incentives. Appropriate installation of district heating and cooling systems, supported by EU climate legislation, will contribute to the achievement of the decarbonisation targets set out under the European Green Deal in this area. (Bacquet et al., 2021)

6. Conclusion

An analysis of the results in European district heating and cooling has been carried out, particularly focusing on a limited case study for five individual cases around the country.In particular, an investigation has been carried out into the role of biomass driven DHC networks and their contribution to future DHC systems which result in the following main conclusions:

1. Biomass-powered DHC systems in Spain have the potential to contribute significantly to the country's energy goals and EU climate objectives.
2. Biomass represents 11% of the heating and cooling systems in Europe, with nine out of ten new installations in Spain utilizing biomass as an energy source.
3. Biomass DHC systems in Spain can incorporate large-scale renewable energies and enhance their contribution to the climate goal for 2030.
4. The implementation of biomass DHC systems, such as Ecoenergies in Mostoles, reduces greenhouse gas emissions and promotes energy independence and security.
5. Biomass DHC systems contribute to local economic development by creating jobs and supporting the growth of the biomass supply chain.
6. Spain's substantial potential for developing biomass DHC systems can meet the growing demand for cooling while minimizing environmental impacts.
7. DHC networks, including biomass-powered systems, play a vital role in reducing carbon emissions, advancing energy resilience, and fostering economic prosperity.
8. Biomass DHC systems have a low environmental impact compared to other heating and cooling alternatives.
9. Challenges related to energy conversion management, environmental impact, and information transparency should be addressed for the future development of DHC systems.
10. A comprehensive and holistic approach to evaluating biomass DHC systems is crucial, considering factors such as energy efficiency, cost, infrastructure, and environmental impact.

11. The integration of renewable and low-carbon options in DHC systems contributes to energy sustainability, reducing CO_2 emissions and fossil fuel consumption.
12. The initiatives of DHC systems, such as DISTRICLIMA and Ecoenergies, demonstrate Spain's commitment to sustainable and innovative energy solutions.

Additionally, the thesis demonstrated the role of biomass district heating and cooling systems in helping Spain and the EU achieve their climate goals. **These systems achieve a significant reduction of greenhouse gas emissions compared with traditional methods by exploiting biomass as an energy source. The research showed that these systems have a positive impact on efforts to decarbonise, and their potential for meeting EU targets in the area of energy efficiency has been identified.**

Overall, the paper concludes that biomass district heating and cooling systems in Spain play a significant role in achieving the EU's energy goals and **promoting energy development sustainability. The analysis of case studies showcases the efficiency and contribution of these systems in reducing greenhouse gas emissions and advancing Spain's transition to a more sustainable energy landscape.**

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8. Annex

8.1. *Abbreviations*

4GDH	*Fourth Generation DH systems*
5GDH	*Fifth Generation DH systems*
CED	*Cumulative Energy Demand*
COP	*Coefficient Of Performance*
COP21	*UN Climate Change Conference*
CHP	*Combined Heat and Power*
DHC	*District Heating and Cooling*
DH	*District Heating*
DC	*District Cooling*
EREN	*Ente Regional de la Energía de Castilla y León*
EU	*European Union*
GHG	*Greenhouse gases*
GWP	*Global Warming Potential*
IDEA	*Institute for the Diversification and Saving of Energy*
IEA	*International Energy Agency*
KSF	*Key success factors*
LCA	*Life Cycle Assessment*
NECP	*National Energy and Climate Plan*
RES	*Renewable Energy Sources*

8.2. *Interrelation of the Thesis and SDGs*

Biomass district heating and cooling systems involve the use of organic matter to produce energy for heating and cooling in buildings. This renewable energy source is considered cleaner and more sustainable than traditional fossil fuels, such as oil or gas, which emit greenhouse gases and contribute to climate change.

By increasing implementation of biomass-powered district heating and cooling systems, Spain can reduce its dependence on fossil fuels and promote renewable energy sources. This aligns with the ***SDG 7 goal of ensuring access to affordable, reliable, sustainable and modern energy for all.***

The implementation of district heating and cooling systems with biomass in Spain can generate ***employment opportunities and stimulate economic growth, which is in line with the objectives of SDG 8.*** *The operation of these systems requires skilled workers, and the development of the biomass supply chain can create new business opportunities and boost local economies.*

In addition, ***biomass district heating and cooling systems can contribute to the development of sustainable infrastructures and innovative technologies, which is aligned with the objectives of SDG 9.*** *The use of these systems requires the development of new infrastructure, such as pipelines and storage facilities, and the use of innovative technologies to optimize energy production and consumption.*

In addition, its use can have positive impacts at the urban and global scale interrelated with several other SDGs, such as ***SDG 13 (Climate action)****,* ***SDG 11 (Sustainable cities and communities)*** *and* ***SDG 12 (Responsible consumption and production)****, reducing the greenhouse gases. gas emissions, mitigate climate change (SDG 13), the use of sustainable energy sources can help create green cities and communities (SDG 11) and promote responsible consumption and production (SDG 12).*

In conclusion, the analysis of the sustainability of energy development through the implementation of urban heating and cooling systems with biomass in Spain is linked to several SDGs.