EUROPEAN
COMMISSION

Brussels, XXX
SWD(2016) 24

PART 1/2

COMMISSION STAFF WORKING DOCUMENT

Review of available information

Accompanying the document

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling

{COM(2016) 51}

Table of Contents

1. INTRODUCTION: THE ROLE AND SHARE OF HEATING AND COOLING IN EU ENERGY DEMAND

Heating and cooling in buildings, businesses and industry consume around half of the energy produced and used in the European Union. With 50% (546 Mtoe) of final energy consumption in 2012, it is the EU's biggest energy sector. It is projected to remain the largest energy sector even in the long-term under both business-as-usual and decarbonisation scenarios by 2030 and 2050. Despite of its magnitude and importance in the European Union's energy markets, there is surprisingly little information about heating and cooling.

This is a sector composed of a large number and variety of actors and technologies. The bulk of heating and cooling is consumed in buildings and industry.

If we look at how this half of the EU's final energy consumption that is used for heating and cooling, is distributed among the individual sectors, we see that the share of the residential sector is 45%, that of industry 37% and that of services is 18%. The exact sectoral and end-uses' weights within the overall heating and cooling consumption change from Member State to Member State, depending on the economic structure (e.g. share of energy intensive industries) and other factors, such as climatic conditions, the efficiency of the building stock, etc.

Technologies for heat production range from small decentralised applications, such as gas and biomass boilers, micro and small cogeneration units, heat pumps and individual solar thermal panels, to large-scale industrial boilers and furnaces and large centralised generation units in district heating networks. Likewise, cooling can be produced in decentralised applications using technologies from small air-conditioning units to large chillers and heat pumps. The capacity used for thermal energy generation ranges from 1 kW or below to several hundred MW units.

Heat and cool cannot be transported economically on a long distance. Therefore, heating and cooling are produced and consumed locally. The heating or cooling market is fragmented and no single market has so far emerged either nationally or EU-wide. Instead, heat markets are local markets composed by many different technologies and economic players (vendors, installers and builders, engineering companies and energy advisors, energy utilities and energy service companies) selling the heat and cool as a commodity or service, often bundled with other services, such as facility management, water and sewage and waste treatment. Heating and cooling are closely linked with other energy markets, in particular fuel and electricity, but also with non-energy markets like, for example, water, waste, real estate and technology.

Due to their size and penetration, how heating and cooling are produced and consumed has a major impact on the EU economy and on whether the EU is able to achieve its climate and energy goals by 2020 and by 2050. The sector is key to the Europe's competitiveness, supply security, international trade position, and the well-being of EU citizens. Heating and cooling are a major factor in social integration, the spending power and the poverty level of EU citizens.

A comprehensive assessment of how energy efficiency and decarbonisation can be achieved in the heating and cooling sector is lacking. The options to reduce heat demand vary greatly across the sectors using heating and cooling. A first set of possibilities is to improve the building envelope in the residential sector, and several options exist to ensure that at different costs. In industry heat demand can be reduced by making heating and cooling processes more efficient through technologies or by recovering waste heat. However, after the heat demand is reduced, then energy efficiency needs to focus on the supply of heat, both in terms of the fuels and renewable resources consumed and the efficiency of conversion technology that is used to produce it.

In view of the strategic objectives set under the EU Energy Union framework for the EU to become a world leader on renewable energy and to apply the "energy efficiency first" principle, there is the need for the EU to fully harness the potential of the heating and cooling sector.

The EU has a number of policies and legislation affecting heating and cooling directly or indirectly. A number of Member States developed – or are in the process of developing – specific strategies addressing heating and cooling in the context of their national climate and energy policies. However, there is an insufficient understanding, as this sector has so far not been subject to a dedicated EU level assessment as a whole. This Staff Working Document is a first step to review the available information on this sector. Preliminary extracts of this review were summarized in five thematic 'Issues Papers' which have benefitted from the comments of stakeholders and Member States representatives. A dedicated Consultation Forum was convened in Brussels on 9 September 2015 and the minutes are included in Annex I.

2. PRIMARY AND FINAL ENERGY CONSUMPTION FOR HEATING AND COOLING

Heating and cooling are understood in this document as thermal energy that is produced (including from electricity) and consumed for space heating, space cooling, cooking[1] and hot water in buildings, and for processes in industry[2].

Unlike electrical energy, thermal energy is used in many qualities and temperatures, depending on the purpose and the technology. Thermal energy typically is carried through water and steam, but other materials, such as air and chemicals, can also be used as carrier. Thermal energy cannot be economically transported on longer distances (beyond 40 km) and therefore is produced and used locally.

The heating and cooling sector comprises a great variety of technologies and users. Thermal energy can be produced from conventional and renewable energy sources and through chemical processes. Thermal energy can also be produced from electricity; and electricity can, on the other hand, be produced from thermal energy. Thermal energy can be also a secondary product recovered and reused for heating and cooling purposes (e.g. residual heat from industry or even from big malls/supermarkets/retailers, which can be used for heating residential buildings).

Providing a picture of the heating and cooling sector and the uses of heat and cool across sectors is an exercise subject to the limitations of the current statistical data in this area. There is no comprehensive statistical data readily available for heating and cooling demand by end-use sectors (useful heat). Primary and/or final energy consumption for heating and cooling in Eurostat only cover derived heat sold on the market, which represents however only a portion of the total supply. Primary and final energy consumption for heating and cooling, therefore, have to be derived from primary and final energy and fuel consumption in the residential, service and industrial sectors.

The availability and reliability of data in the building sector is expected to improve in the future, thanks to The EU Building Stock Observatory[3], which will further improve the quality of data on energy uses in the residential sector, and to the forthcoming activities from Eurostat on residential energy uses and energy efficiency[4].

There are also a number of methodological issues relating to the way the contribution of certain energy sources to total energy use for heat are calculated[5]. The proportion of energy consumed for heating and cooling has to be approximated by subtracting the part of primary and final consumption used for electricity or transport; however, a considerable amount of electricity is used for space heating in buildings. Moreover, cooling data is not reported as a separate use in official statistics and consumption for cooling is included generally in final electricity consumption data, as most cooling in residential and services sectors today is

---

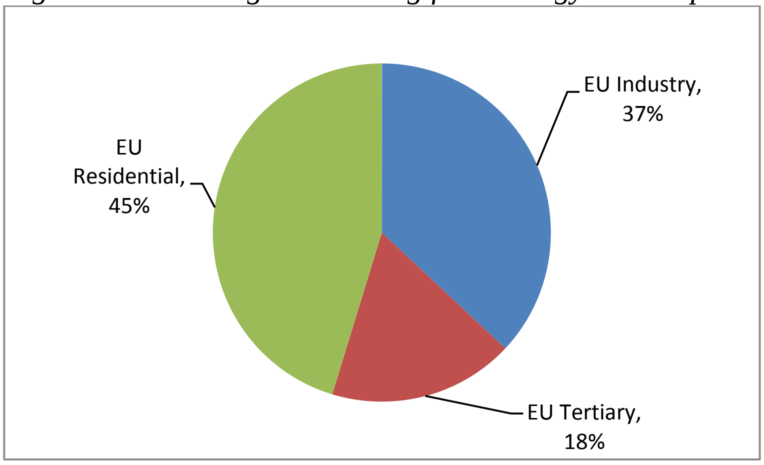
[1] The share of cooking in the overall heating and cooling consumption is included in the overall statistical analysis used in the document; however it is not further analysed as a sector because its analysis is covered in detail under the preparatory studies under the relevant Ecodesign and Energy labelling legislation.
[2] Energy used for cooling food in households (e.g. for fridges) is therefore out of the scope of this definition.
[3] BPIE et al.*;* on-going (Service tender Ref. ENER/C3/2014-543).
[4] Commission Regulation (EU) No 431/2014 of 24 April 2014 amending Regulation (EC) No 1099/2008 of the European Parliament and of the Council on energy statistics, as regards the implementation of annual statistics on energy consumption in households.
[5] IEA, (2014).

provided by individual electric air-conditioning and ventilation units or large electric absorption chillers (heat pumps).

Similarly, at global level official statistics of the International Energy Agency (IEA) acknowledge limitations and shortcomings, and identify additional specific difficulties that particularly affects heat from renewable sources. Data availability and consistency, in particular with regards to biomass use, but also related to other fuels, is recognised as a limiting factor. Such limitations of comprehensive statistical data about heating and cooling have also an impact on the forecasting of future heating and cooling needs, and on scenario modelling exercises. In this Staff Working Document, the data on heating and cooling come from the ongoing study "Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment"[6], if not specified differently. This study makes use of several statistical sources, including Eurostat, and of its own elaboration.

The total demand for heating and cooling in 2012 amounted to 546 Mtoe and represented half of the total final energy consumption in the EU (1102 Mtoe). Heating and cooling are consumed in three main sectors, namely residential, tertiary and industry, with the residential (mainly households buildings) representing the highest share. The residential sector accounted for 45% (248 Mtoe) of final energy heating and cooling consumption in 2012, followed by industry's share of 37% (202 Mtoe) and services' of 18% (96 Mtoe)[7].

Figure 2-1: Heating and cooling final energy consumption share per sector (2012)



The sectorial weight changes from country to country, depending on the economic structure and other factors, like for instance climatic conditions. The variability could be substantial. For instance, the share of industry in total heat consumption is above 45% in Spain, Finland, Portugal, Slovakia, Austria and Sweden.

If the different uses of heating and cooling across sectors are considered, it is possible to distinguish six categories: space heating, space cooling, water heating, process heating, process cooling and others, which includes cooking. The figure 2-2 provides a breakdown of the total heat consumption per use. Space heating provides for the biggest share (52%) and can be considered as a basic necessity in climates where temperatures descend below certain levels. Most of the EU belongs to such climates, although the length of time when heating is

[6] Fraunhofer et al. (2015-ongoing), Service contract regarding a study on "Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)" ENER/C2/2014-641.
[7] Agricultural sector is not included.

needed varies considerably, ranging from yearlong heating seasons to a few days a year. Space cooling counts for only 2% and it is often considered a comfort service, but in warm climates it is a necessity. If some negative effects of climate change happen, cooling may become a more wide-spread necessity or be perceived more and more as such. Process cooling (3%) is a service required in many industrial and service sectors too, e.g. the food and beverage sectors, pharmaceutical, food retail, and data centers.

Space cooling in buildings and process cooling are amongst the most dynamically growing energy uses and the provision of cooling has in fact become a vital service to modern EU society. Without cooling, the supply of seafood, dairy, meat and poultry and all frozen foods would break down, along with significant proportion of medicines, flowers, beverages and confectionery; internet data services would fail; not only comfort but economic productivity would be adversely affected in summer for people in most of southern Europe. Cooling is therefore crucial to food security and many parts of the manufacturing sector. In particular, its contribution to reduction of food waste protects also the water, chemical, processing and transportation resources invested in that food throughout its supply chain.

The German Association for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit) GIZ Proklima estimates in its Green Cooling Initiative publication (GIZ ProKlima 2014a) that globally the refrigeration and air conditioning sectors are responsible for just over 7% of global greenhouse gas (GHG) emissions when direct emission of refrigerants is combined with indirect emissions due to energy consumption. This will rise to around 13% of global emissions by 2030, with almost exponential growth of demand for space cooling in some parts of the world. One detailed model projected that global residential energy demand for cooling will exceed that for heating by 2060 (NEAA 2008).

The vast majority of cooling is provided by electrically driven plant, with only very limited use of heat driven (absorption cooling) plant. Hence, refrigeration and air conditioning accounts for about 17% of global electricity use (IIR 2014). Direct impacts on carbon emissions are through release of refrigerants (CFCs, HCFCs, HFCs) which are potent greenhouse gases when released into the atmosphere. Climate change will reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors, as confirmed and quantified by the Intergovernmental Panel on Climate Change in 2014[8]. Refrigeration demands are also projected to increase - thus refrigeration and air conditioning will have an increasingly important influence on the EU energy system, particularly due to its demand being almost entirely electrical.

Space cooling supplies present specific challenges as they are seldom measured and electricity used as input to cooling devices is not measured or reported separately. The exceptions are district cooling systems, where cold deliveries are measured for billing purposes. Electricity supply for cooling is normally just a part of all electricity delivered to a building.

The table below summarises the estimates calculated in different studies, some of which also produced forecasts or assessment of cooling demand potentials. Current demand estimates for both space cooling and refrigeration in 2009-2012 vary from 16 to 24 Mtoe per year. The

[8] IPCC estimates that global demand for residential air conditioning alone will rise from 300 TWh per year in the year 2000 to 4.000 TWh in 2050 and 10.000 TWh by 2100 (IPCC WGII 2014), with the majority of growth in developing countries.

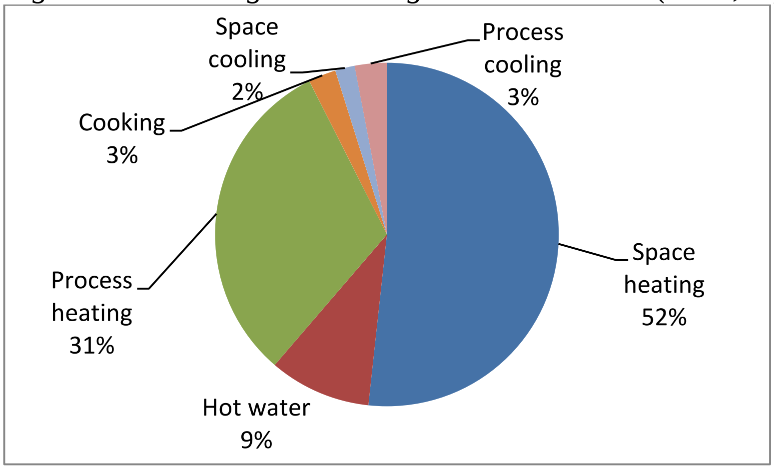
range of the potential demand goes from 100 to 174 Mtoe, demonstrating the high expected increase but, at the same time, the uncertainty attributed to the future cooling demand. Kemna (2014) estimates that the potential space cooling demand is 42.1 Mtoe, less than half of which is fulfilled. In 2020 the mainly tertiary central air conditioners would cover a load of 17.9 Mtoe (a growth of 27%) and residential room air conditioner load would almost double at 8.2 Mtoe, bringing the total cooling supply to 26.2 Mtoe (a growth of 38%). Reportedly, the tertiary sector demand would then more or less stagnate, whereas –albeit at a slower pace— residential space cooling demand would continue to increase. In 2030 the total EU space cooling load would be 30.3 Mtoe (a growth of 15% versus 2020).

Table 2-1: Estimates of cooling demand (Mtoe)

Source	**Cooling demand (space and process cooling)**	**Cooling demand "potential"**	**Space cooling demand in residential**	**Cooling demand potential in residential**	**Space cooling demand in services**	**Cooling demand potential in services**	**Cooling demand in industry**
Service contract (2015)	26.5 (2012)	n.a.	1.5	n.a.	16.7	n.a	5.4
RESCUE (2015)	24 (2010)	105	4	61	20	44	n.a
Stratego (2015)	16 (2010)	100	n.a.	4	12	n.a.	n.a
Eurac (2014)	22	174	5	117	17	57	n.a
Kemna (2014)	10.8 (2010)	42.1	4.8	30.3	14	n.a	n.a

Process heating represents the second largest share (31%) and represent an essential inputs to several industrial processes. Hot water (9%) is used both in the residential, service and industrial sectors.

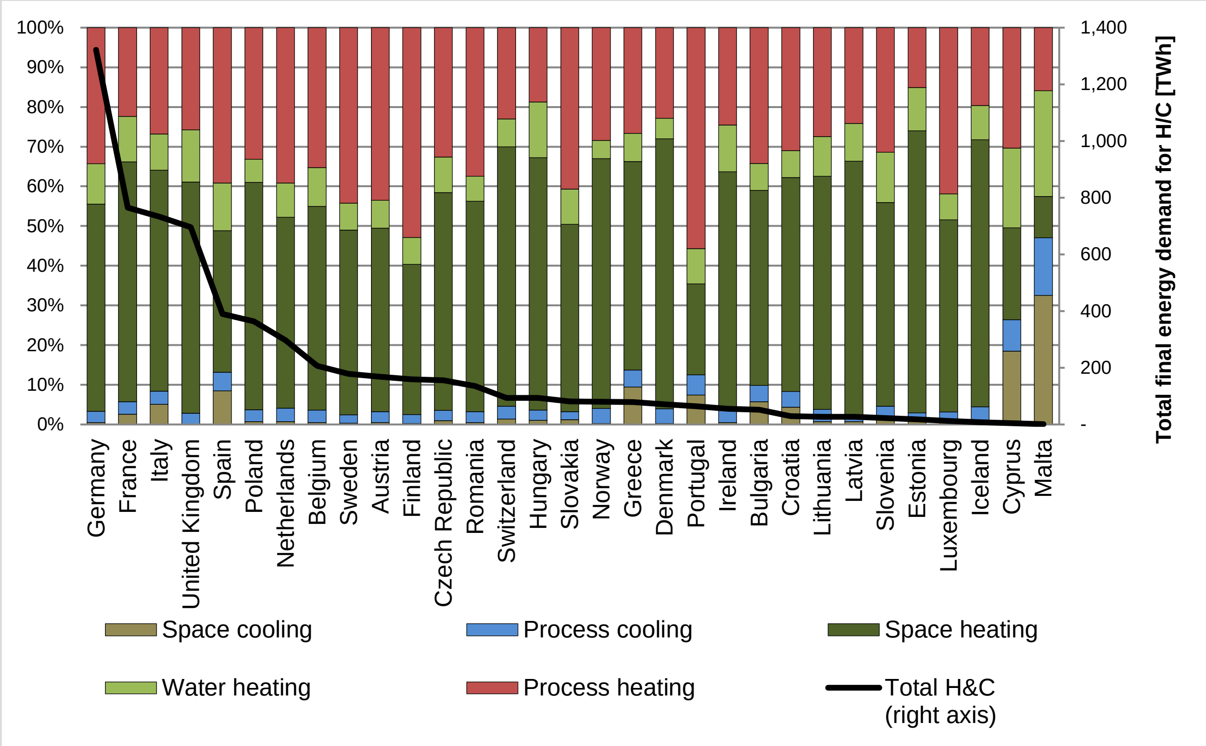
Figure 2-2: Heating and cooling end-uses in 2012 (Mtoe, %)



Also in this case, structural and climatic differences across countries result in different shares across the uses of heating and cooling. The graph below illustrates that in combination with the absolute levels of the final energy demand for heating and cooling. Included are EU28 Member States plus Norway, Switzerland and Iceland.

A comparison of final energy demand for heating and cooling by end-use reveals substantial differences across countries. For instance, the share of process heating varies from about 15% in Estonia to 56% in Portugal. Although space cooling shows clear peaks in Mediterranean countries, its share arrives at a maximum of 9% (Greece) of total final energy demand for H&C - excluding Malta and Cyprus where space cooling makes up 19% and 33%, respectively. Process cooling, on the other hand, is more evenly distributed across countries as it does not so much depend on the outdoor temperature, especially in very low temperature applications in the chemical sector such as air fractioning. Despite these differences, the general pattern is still comparable: space heating and process heating account for the major share in most countries and all end-uses are represented in each country.

Figure 2-3: Final energy demand for heating and cooling per end-uses (2012)



2.1. Buildings: current situation and trends in the residential sector[9]

Space cooling and heating are energy services required for securing a proper indoor thermal comfort. The need for heating and cooling in residential buildings is influenced by three main factors: the efficiency of the building's shell, the efficiency of the heating and cooling supply equipment and the behavior of the occupants. The climate and local weather conditions, *i.e.* outdoor temperature, have a major impact on the energy consumption of buildings and exercised a major influence on how the buildings are constructed and supplied with heat and cool, leading to widely diverging construction traditions and buildings' characteristics in the various Member States. Each factor can affect buildings' consumption significantly. For example too low and too high temperature increase the need for heating or cooling, while the demand decrease with the increase of the energy performance of the building shell or if heating and cooling is supplied through efficient technology and equipment.

[9] Buildings in the service sector will be examined in the Section 2.3.

2.1.1. Total final energy used for heating in EU's buildings in the residential sector

The demand for heating and cooling in the residential sector amounted to 248 Mtoe in 2012[10], and represented the 85% of the total final energy consumption in this sector. Therefore, only around 15% of the total energy consumed in our houses is used for non – heating and cooling uses.

Heat is used in houses to provide warmth and hot water, and to cook the food. To satisfy space heating (and hot water) requirements, supply temperatures below 100°C are sufficient (or below 120° C in conventional district heating).

Building heat demand for space heating and hot water preparation in the residential and service sectors is not directly measured and reported in EU energy statistics. It has to be calculated by using a combination of EU, international and national energy statistics, conversion efficiencies for fuels used in final consumption, and estimating how much electricity (mainly resistance heaters and heat pumps), is used for heating purposes. Increasingly, energy is used also to cool buildings, relying mostly on air conditioning and mechanical ventilation to maintain comfortable temperatures.

Such estimation has to take into account a number of factors: the heated floor area, the building thermal integrity, its size and type, climatic conditions (heating or cooling degree days), usage patterns, the number of inhabitants (m^2/person), their activity patterns and the age, of the building. Heat demand is linked to the quality of the building envelope as well as the outside temperature, with northern cities usually having a much higher level of insulation than southern cities. The final energy used for heating purposes depends strongly also on consumers' behaviour and end-users preferences, and whether proper control instruments, such as meters, meter displays and thermostatic valves allow the rational regulation of space heating and cooling comfort levels.

Different studies have estimated the total EU floor area, which is a key parameter to estimate heating and cooling demand. Europe's total useful floor area in the residential and services sector was calculated to be 25 billion m^2, of which 75% or 18.75 billion m^2 was estimated to be in the residential sector (based on 2009 data), the rest, *i.e.* 6.25 billion m^2 in the services sector BPIE (2011). Another study calculated the total heated floor area is much higher if industrial buildings are included (Kemna 2014). A further study estimated the total floor at 25.7 billion m^2, out of which 19.7 billion m^2 in the residential sector and 6 billion m^2 in the services sector (Stratego 2015).

Table 2-2: Estimate of EU28 useful floor areas (billion m^2)

Source	**Total floor area**	**Residential**	**Service sector**	**Industrial sector**
BPIE (2011)	25.0	18.7	6.2	n.a
Kemna (2014)	32.8	21.2	8.1	3.5
Stratego (2015)	25.7	19.7	6	n.a

Buildings differ greatly in their annual energy consumption. For single family buildings, the reported range extends from 585 kWh/m^2 (UK, pre-1920, detached house) to 34 kWh/ m^2

[10] In a previous assessment, Kemna (2014) calculated the total EU space heating load as 243 Mtoe, of this total, 173 Mtoe (71%) is estimated to be from boilers (defined as heating systems addressed by the Ecodesign regulation for boilers. The rest relates to buildings heated by district heating, process waste heat, the low-temperature output of large (steam) boilers and CHP installations.

(Slovenia, post-2005)[11]. 40% of the EU's building stock was built before 1960, when there were few or no requirements for energy efficiency, and only a small proportion of these have undergone major energy retrofits. The average annual energy consumption of residential buildings is 168 kWh/m^2. In another assessment, Odysee-Mure (2015) estimates that after adjustment to the EU average climate, Luxembourg and Belgium turn out to have the highest consumption, at around 2 toe/dwelling (i.e. 23000 kWh), compared to 0.8 toe (9300 kWh) in Portugal and Bulgaria. The differences are still quite large and due to a combination of actors, among which efficiency of dwellings and appliances, lifestyles (size of dwellings, appliance ownership), etc.

These values are expected to be influenced by the progressive uptake of energy performance requirements set by legislation. The Energy Performance of Buildings Directive (2010/31/EU) (EPBD), together with the Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED), set out a package of measures that create the conditions for significant and long term improvements in the energy performance of Europe's building stock.

The EPBD introduced the obligation to set minimum energy performance requirements with the view to achieving cost-optimal levels. In consideration of the diversity of climate conditions, the setting of a single level of requirements across the EU could not be envisaged. Instead, the use of cost-optimal methodology was included in the EPBD in order to facilitate the setting of similar ambition levels in Member States. 'Cost-optimality' describes the level of energy performance that leads to the lowest cost during the estimated lifecycle. The calculation includes investment costs, maintenance and operating costs, energy costs, earnings from energy produced and disposal costs (costs for deconstruction at the end of life). The objective is also that national provisions do not target specific technologies only, but instead address building systems while taking into consideration the building as a whole. The EPBD also foresees for new buildings the high-efficient alternative systems, which include district heating and combined heat and power (CHP) with renewables. The cost-optimal methodology should also help Member States to set the ambition for nearly-zero energy building (NZEB) energy performance, as this should be equal or better than the cost-optimal level in 2020.

Based on national reports on progress towards NZEBs under the EPBD, the range of values goes from targets beyond NZEB requirements (such positive energy buildings) up to 270 kWh/m^2/y. Energy performance indicators can vary remarkably from 20 kWh/m^2/y to 180 kWh/m^2/y in residential buildings, but usually targets aim at 45 kWh/m^2/y or 50 kWh/m^2/y. Values from 25 kWh/m^2/y to 270 kWh/m^2/y are reported for non-residential buildings with higher values given for hospitals.

Regarding renewable energy in buildings, the Renewable Energy Directive requires integrating renewable energy use in all new or renovated buildings and the EPBD states that the very low amount of energy in a NZEB should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

[11] BPIE (2011).

Space heating

In the residential sector space heating constitutes the biggest share of energy consumption amounting to 78% of total final energy use. This average masks considerable differences depending on climate, the building type, thermal integrity, activity, etc. While the share of space heating is above 80% in colder climates, in warmer climates it is lower, around 50%. Figure 2-5 presents the amount of energy consumed in 2012 in EU28 only for space heating in the residential sector.

Figure 2-4: Thermal energy consumption per use in the residential sector (2012)

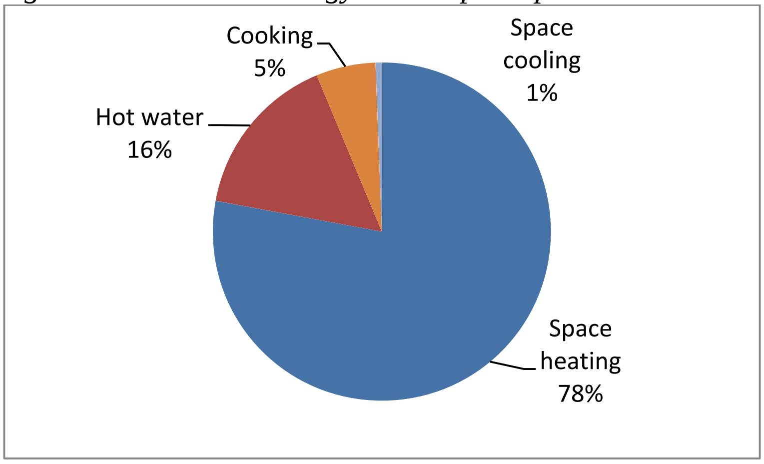
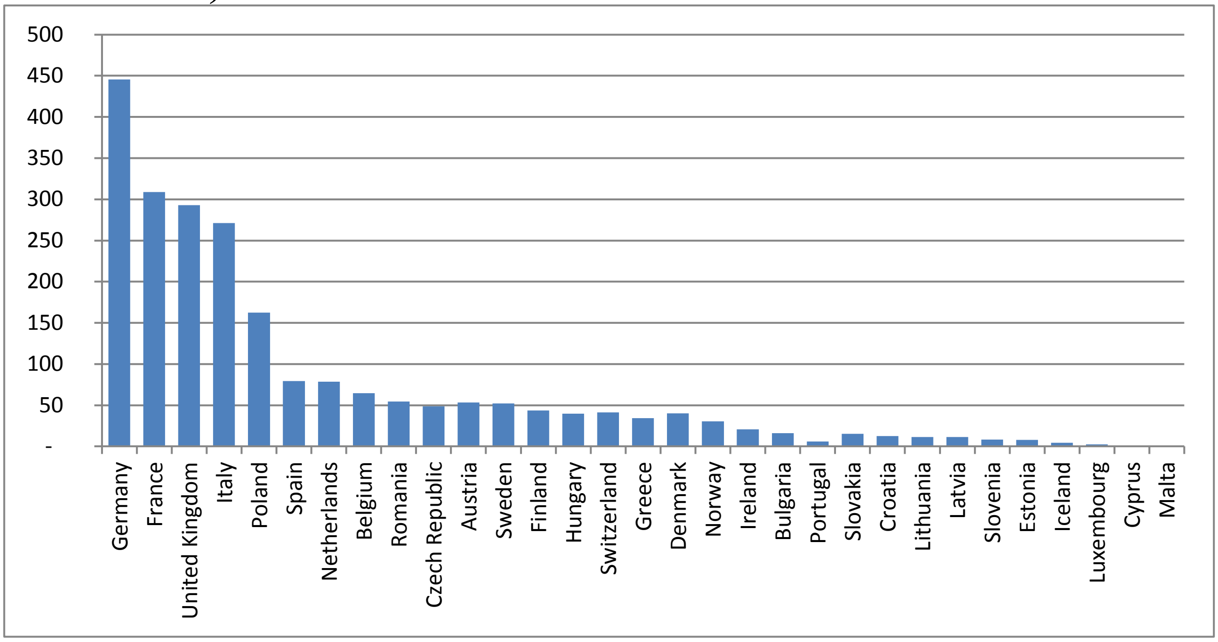


Figure 2-5: Space heating in the residential sector, 2012 (TWh, EU28 + Norway, Iceland and Switzerland)



As regards the trends over time, Odyssee-Mure estimated that since 2000 energy consumption for space heating declined by 12% and the efficiency of household space heating, measured in kWh or GJ/m^2 improved steadily, by around 2.3% per year at EU level[12]. The reasons were the deployment of more efficient new buildings and heating appliances and the renovation of existing dwellings. Energy use per square metre has

[12] Energy Efficiency Trends and Policies in the Household and Tertiary sectors, 2015, available at http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-policies-buildings.pdf.

decreased steadily in most countries since 2000, but energy efficiency improvement was partially offset by an increase in dwelling size.

Water heating

The share of hot water use in buildings is 16% of total heating and cooling demand in the residential sector (and 14% in tertiary sector). A decrease in hot water use is projected under EU decarbonisation scenarios, but other studies project on the contrary that hot water consumption would remain stable around the same levels as today[13] [14].

Cooking

Cooking consumes around 5% of heating and cooling in the residential sector.

2.1.2. Total final energy used for cooling in EU's buildings in the residential sector

Space cooling demand is estimated to be 1,6 Mtoe the EU residential sector and it is a fairly small share of total buildings' energy consumption in the European Union, but is growing fast. Several studies indicate that this is likely to increase significantly in the future mainly to satisfy unmet demand for thermal comfort[15] and partly because of more extreme weather types with warmer summers, driven by climate change. Projections even indicate 'exponential' growth in cooling under current trends.

It is nevertheless to be noted that the future development of the cooling sector is much more uncertain than the heating sector, also because the cooling demand and use is not measured; instead, cooling demand is usually included in the electricity demand of a building. Furthermore, studies have shown that the cooling demand in a building is not as stable as the heating demand, because there is great variability across households' behaviour and preferences, and people tend to be less predictable about the level of cooling they implement. New building codes with stricter requirements for the tightness of building envelopes also introduce significant cooling demands in summer.

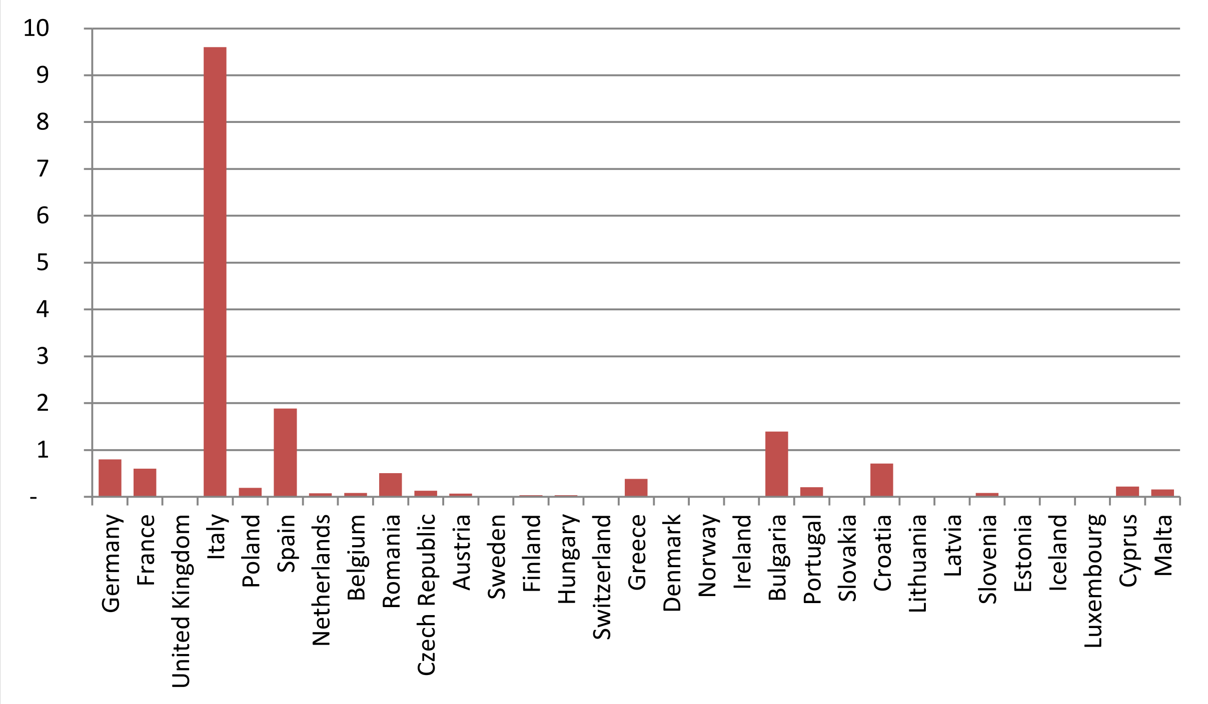
Cooling supplies are seldom measured and electricity used as input to cooling devices is not measured or reported separately. The exceptions are district cooling systems, where cold deliveries are measured for billing purposes. Therefore, the electricity supply for cooling is normally just a part of all electricity delivered to a building when cooling is applied. Unlike heating, cooling is today not considered a necessity throughout Europe, but only a comfort factor in some Member States. Therefore, cooling supplies are almost always lower than full cooling demands, since all cooling demands are not met and, in some Member States, most consumers accept higher indoor temperatures during warm summers.

[13] "Ecodesign Impact Assessment" Study estimated the total energy consumption for water heating was 581 TWh in 2010 (175 in dedicated water heaters and 406 TWh in combination heaters).

[14] IEE Stratego Project No: IEE/13/650. The Project is co-funded by the EU Intelligent Energy Europe programme. The project mapped cooling demand in Europe and summarised the existing (widely diverging) cooling demand projections in the literature.

[15] IEE Stratego Project No: IEE/13/650.

Figure 2-6: Cooling demand in 2012, EU28 (Twh)



Also in the case of cooling, the picture is varied across countries depending from their climatic conditions and economic structure. As it can be seen from the figure above, Italy is by far the country with the highest consumption, followed by Spain, Bulgaria, France and Germany.

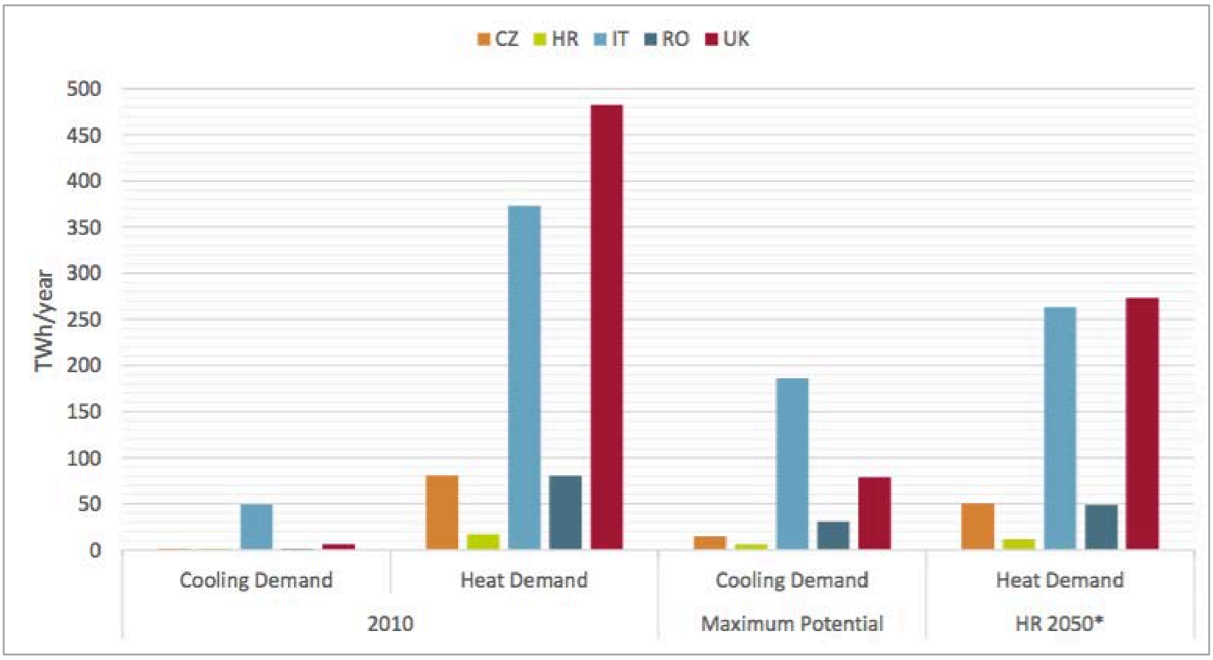
According to the EU Intelligent Energy Europe project RESCUE[16], in 2010 around 40% of service building sector floor area and 7% of residential sector in Europe were equipped with some type of active cooling systems. In the residential sector the share of cooling in energy consumption is around 1%, while in the tertiary sector this share can be as much as 30% (BPIE; 2011).

At a more detailed level for five EU countries, the EU Intelligent Energy Europe project STRATEGO[17] has estimated that annual space cooling demands for Italy are currently 13% of concurrent heat demand in primary energy terms but could rise to 70% of heat demands by 2050, after heat efficiency measures take effect and all currently foreseen space cooling demands are met (referred to as the STRATEGO maximum potential cooling demand) (STRATEGO 2015). The space cooling demands for the UK would rise from 1% today to 29% in 2050; those for Romania rise more steeply from 2% now to 63% of the heat demand in 2050. The demand figures are shown in the Figure below. These figures do not include any refrigeration demands.

[16] RESCUE (2014), EU district cooling market and trends, 2014. Report prepared by Capital Cooling under the framework of the RESCUE project co-funded by the IEE programme of the EU.

[17] STRATEGO (2015), Enhanced heating and cooling plans for 2010 and 2050, co-founded by the Intelligent Europe Programme, Project number IEE/13/650.

Figure 2-7: Current and future potential cooling (air conditioning) demand in the five STRATEGO project countries for both residential and services (TWh, primary energy).



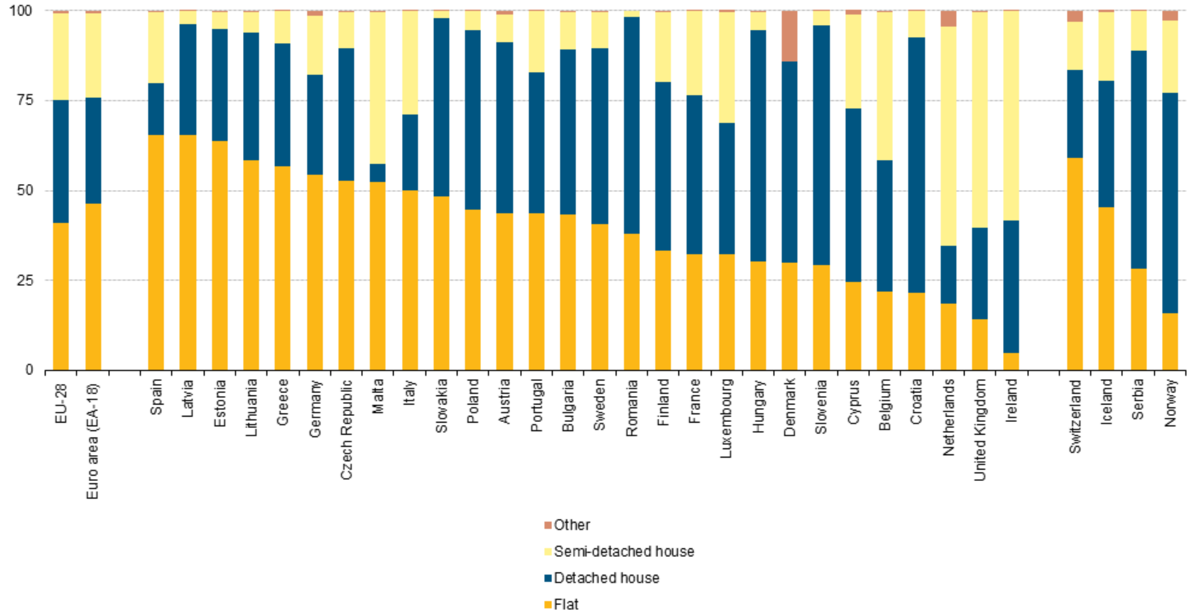
CZ = Czech Republic, HR = Croatia, IT = Italy, RO = Romania, UK = United Kingdom. Source: STRATEGO 2015. The HR 2050 is the heat roadmap 2050 scenario that includes energy savings.

2.1.3. Further distinctions concerning residential buildings performance and types

Type of dwelling

Heating and cooling demand in buildings also depends on the building type (single family house, multi-apartment buildings) and region types (urban, non-urban). In 2013, 41 % of the EU-28 population lived in flats, just over one third (34 %) in detached houses and 24 % in semi-detached houses. The share of persons living in flats was highest across the EU Member States in Spain (65 %), Latvia (65 %) and Estonia (64 %). The share of people living in detached houses peaked in Croatia (71 %), Slovenia (67 %), Hungary (64 %), Romania (60 %) and Denmark (56 %). The highest propensities to live in semi-detached houses were reported in the Netherlands (61 %), the United Kingdom (60 %) and Ireland (58 %).

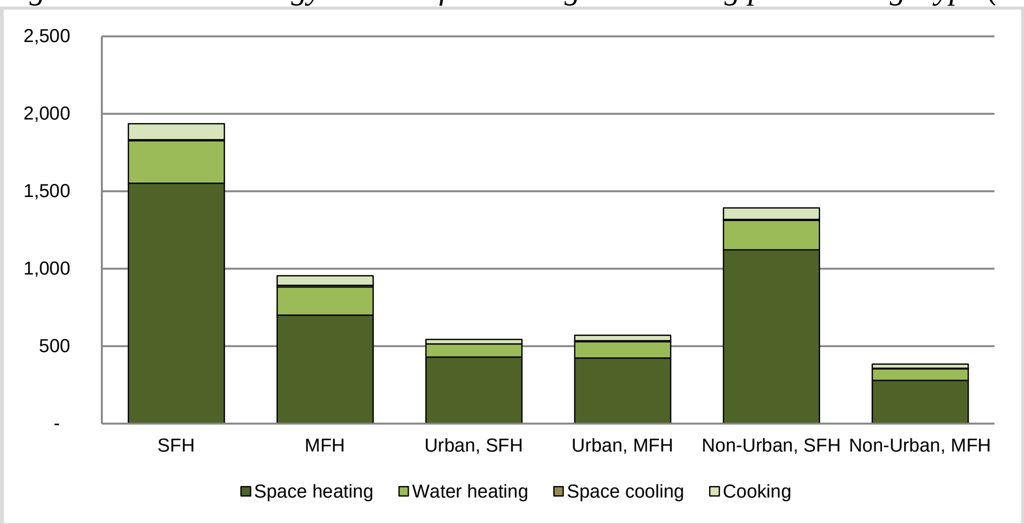
Figure 2-8: Distribution of population by dwelling type, 2013 (% of population)



Source: Eurostat (online data code: ilc_lvho01)

The heating and cooling energy demand of all single family houses is more than twice as high as that of all multi-family houses. The regional disaggregation reveals that more than half of the heating and cooling demand is consumed in single family houses in non-urban areas. Heating and cooling demand in urban areas is equally distributed among single and multi-family houses.

Figure 2-9: Final energy demand for heating and cooling per buildings type (TWh, 2012)



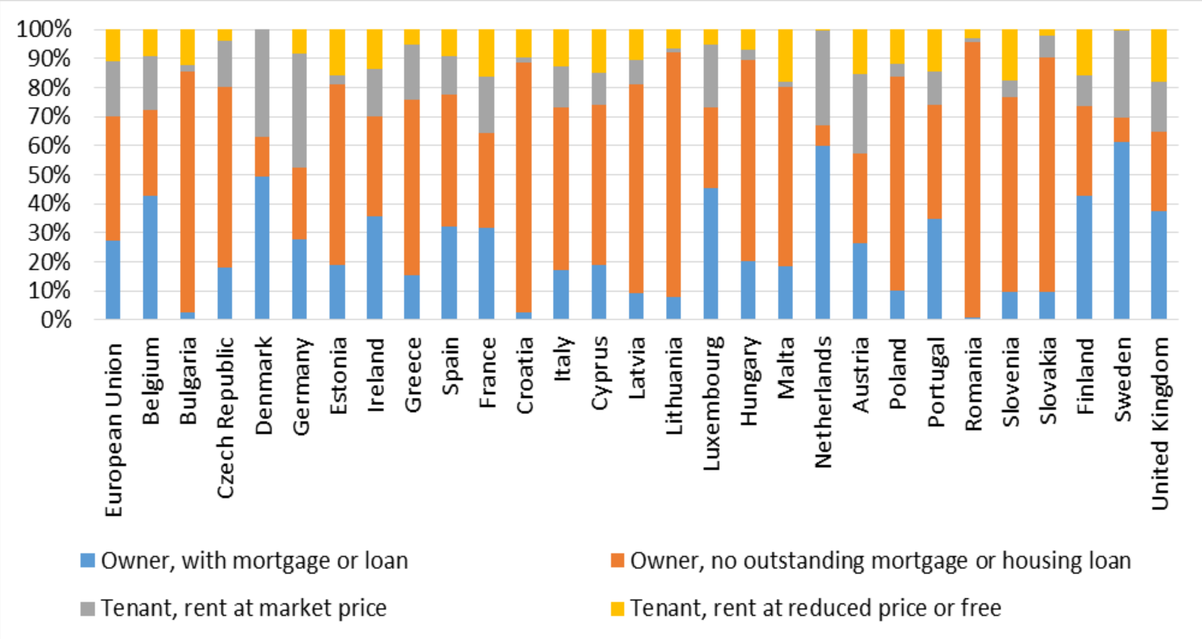
Tenure status

In 2013 over one quarter (28%) of the EU-28 population lived in an owner-occupied home for which there was an outstanding loan or mortgage, while more than two fifths (43%) of the population lived in an owner-occupied home without a loan or mortgage. As such, seven out of every 10 (70%) persons in the EU28 lived in owner-occupied dwellings, while 19% were tenants with a market price rent, and 11% tenants in reduced-rent or free accommodation (social housing).

More than half of the population in each EU Member State lived in owner-occupied dwellings in 2013, ranging from 53 % in Germany up to 96% in Romania. In Sweden (62 %) and the Netherlands (60 %) more than half of the population lived in owner-occupied dwellings with an outstanding loan or mortgage.

The share of persons living in rented dwellings with a market price rent in 2013 was less than 10 % in ten of the EU Member States. By contrast, close to two fifths of the population in Germany and Denmark lived in rented dwellings with a market price rent, as did close to one third of the population in the Netherlands, more than one quarter in Sweden and Austria, and more than one fifth in Luxembourg. The share of the population living in a dwelling with a reduced price rent or occupying a dwelling free of charge was less than 20 % in all EU Member States.

Figure 2-10: Population by tenure status, 2013 (% of population)



Source: Eurostat

2.2. Industry: current situation and trends in the industrial sectors

Industry accounts for one fourth of the EU's total final energy consumption in 2012, of which the majority (73%, amounting to 202 Mtoe) is used for heating and cooling. The 27% of final energy demand not used for heating and cooling is mainly used for mechanical applications driven by electricity.

Like the residential sector, industry's heating and cooling (heat) consumption is not directly reported in Eurostat energy statistics. Industry’s primary, final and useful heat consumption must be derived from overall primary (conventional and renewable energy sources) and final consumption (fuels, derived heat, renewable energies, electricity) in the various industrial sectors and estimated taking into account the efficiencies of specific conversion technologies and industrial processes, as well as organisational and behavioural patterns in industrial companies. The challenge in establishing useful heat consumption, *i.e.* actual heat used in industrial processes and industrial buildings, is even more significant, because actual delivered heat is rarely measured (except for a few district heating systems). The calculation of final, primary and useful energy requires the knowledge of the cross-cutting technologies used in most industrial sectors, and of the efficiency of specific processes which differ sector by sector, even sub-sector by sub-sector, and down to the plant level. Examples of cross-cutting heat technologies are steam systems (large boilers) generating process steam in a wide range of industrial processes such as drying, fractionation, component separation or heating, e.g. in the pulp and paper, the chemical food and beverage and refinery sectors.

Industry is very diverse. Processes are specific to sectors and even sub-sectors and require different temperatures ranging up to 2000°C and above. Process heating can be divided into low, medium and high temperatures. The definition of low, medium and high temperature is specific to each sector and different thresholds are used[18]. A possible distinction is of temperatures below 200° C, between 200°C and 500°C and above 500°C[19]. A large number of processes in industry uses heat at medium and low temperatures like, for example, the production of plastics (temperature 180 – 290°C) and drying technologies (160 – 180°C). At lower temperatures, heating and drying processes are used in many industries such as dairy, breweries, chemicals, food industry, slaughterhouses, production of paint, textile industry and the mineral oil industry.

Temperature levels are one important variable when assessing the potentials for substitution of fossil fuels with renewable sources for heat supply in industry, since not all renewable energy sources are capable of reaching temperatures above 200°C, and this constitutes a technical limit to the decarbonisation of heating through renewable sources.

Process cooling qualities again have sector specific definitions. One distribution distinguishes between temperatures below –30°C, between –30°C and 0°C and between 0°C and 15°C. Industrial process cooling is produced from electrical refrigeration[20]. Cooling is needed in the industrial processes for the production of food and for process cooling. Process cooling also covers a wide range of industries where the materials first have to be heated and then cooled.

Overall, it has been estimated that, in 2012, out of the total thermal energy use, 60% of industry's energy consumption is for high temperature process heat (over 500°C), while medium or low temperature (below 500°C) represents 39% of heat demand[21]. Heat demand above 500°C is provided by industrial furnaces, while heat demands below 500°C are mostly provided by steam boilers and CHP units. Space heating is 14% and 4% is used for process

[18]At least the melting temperature of iron (1538°C) needs to be reached when producing iron and various steel types. In brick production the bricks are fired at temperatures of up to 900-1200 °C[18]. In cement production, a temperature of 1400 – 1500 °C is used to form clinker from different minerals. The most common fuels used are petcoke and coal. Oil and natural gas are used to a lesser extent due to higher costs. For the production of glass, temperatures can reach 1200°C when producing fused quartz glass. However, it is possible to lower the transition temperature for the glass by adding different substances.

[19] Other classifications are possible. For example (JRC 2012) used the following temperature bands; low temperature below 200°C, medium temperature between 200°C and 600°C, high temperature above 600°C.

[20] In a different breakdown, Euroheat & Power also considers three temperature intervals in the industrial sector. The lower range of temperatures, below 100°C, corresponds to such processes as washing, rinsing, food preparation, space heating and hot water preparation in industrial facilities. The medium range of temperatures, between 100°C and 400°C, corresponds to processes of drying or evaporation. This energy is normally provided by steam. The higher range of temperatures, over 400°C, is used for material transformation processes, such as reduction of metal ores, cracking and distillation, calcination, electric induction, etc. These temperatures are used for process heating e.g. within the production of iron and steel and the production of bricks and cement, refined petroleum products and chemicals, etc.

[21] An earlier estimate concluded that 57% of industry's energy consumption is for high temperature process heat (over 600°C), medium temperature (between 200°C and 600°C) represents 18% of heat demand, while 15% is low temperature heat (below 200°) and 10% is space heating (JRC 2012).

cooling, of which half is used for temperatures between 0 and 15°C. In total, industry consumed 37% of the total heating and cooling demand in Europe.

Figure 2-11: EU28 final energy consumption in industry per end-use (2012)

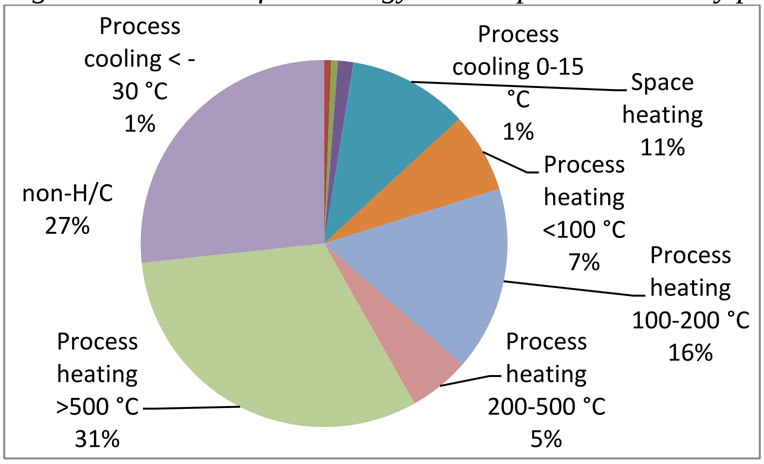
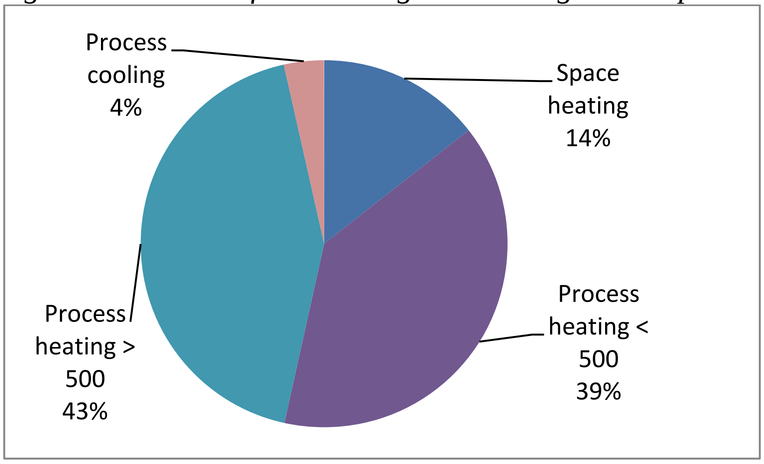


Figure 2-12: EU28 final heating and cooling consumption in industry per end-use (2012)

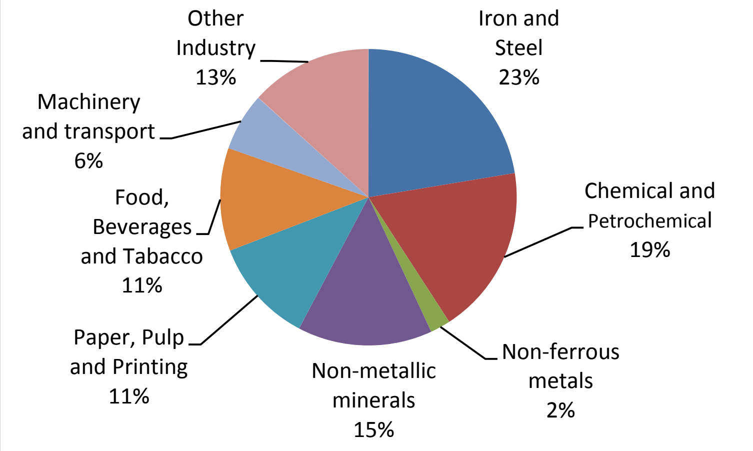


The share of energy consumed in the form of thermal energy varies sector-by sector. In some sectors, thermal energy needs constitute more than two thirds of overall energy consumed, e.g. in non-metallic minerals, while in others on the contrary electricity driven processes and motors dominate, such as in non-ferrous metals and machinery, as shown in Figure 2-14.

The figure below represents the sectoral breakdown of heating and cooling consumption in energy intensive industries[22].

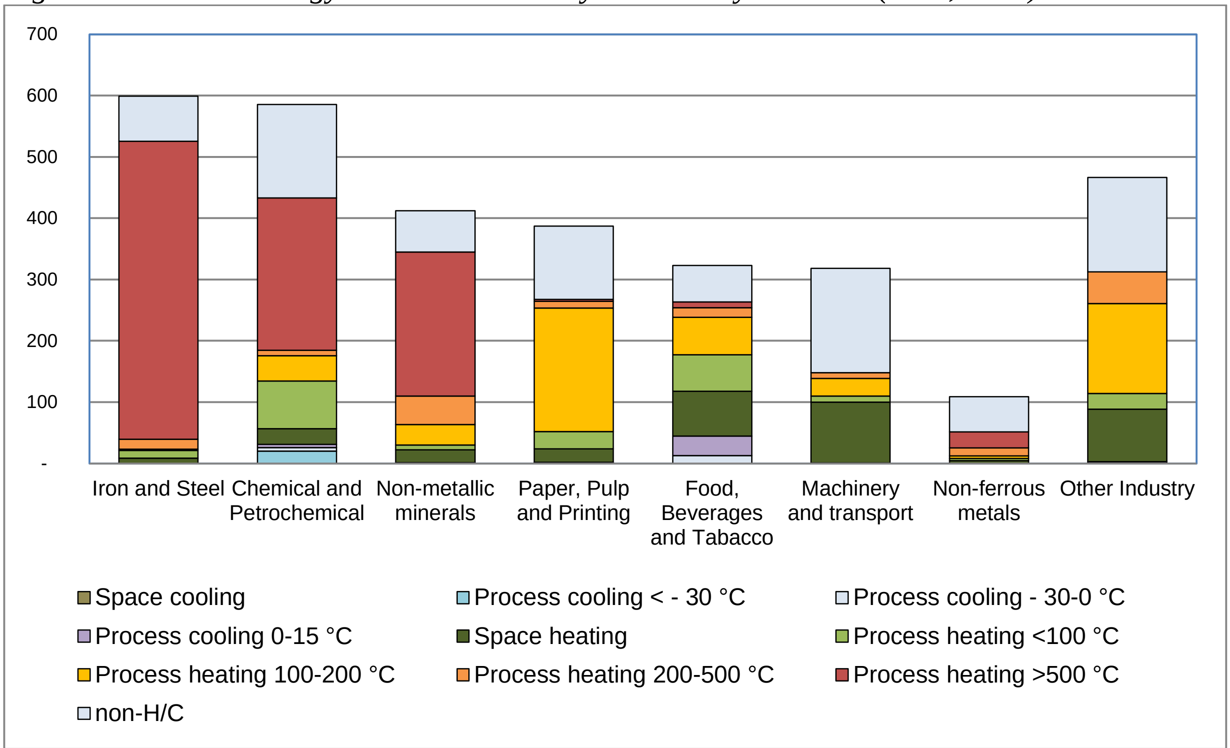
[22] The energy intensive industries included here are: i) iron and steel, ii) non-ferrous metal, iii) chemical, iv) non-metallic mineral products and v) pulp and paper; vi) food, drink and tobacco, vii) textile, leather and clothing, viii) ore extraction, ix) engineering and other metal industries. There are various ways to classify energy intensive industries, e.g. some classification does not classify food and drink or the textile industry as energy intensive.

Figure 2-13: EU 28 heating and cooling consumption in industry per sector (2012)



The following figure combines the two sets of information and illustrates the demand disaggregated per end-uses across the different industrial sectors.

Figure 2-14: Final energy demand in industry in EU28 by end-uses (TWh, 2012)



High temperature process heating is mostly needed in the iron and steel, the chemical and the non-metallic minerals (cement and glass) industries. Also non-ferrous metals (main demand in aluminium) has a high share of process heat >500°C, although in lower total numbers. Process heat in the form of steam between 100 and 200°C is mostly needed in the pulp and paper industry and the “others” sub-sectors, but to some extent in all sub-sectors. Space heating has high shares in the light industries (machinery, food and tobacco and others). Process cooling is mainly used in the chemicals industry (mostly for air fractioning at very low temperatures) and in the food industry.

Another study (ICF 2015) has calculated the specific share of process heat, process cooling and electricity in energy intensive industries. According to this study, the highest share of process heat is registered in refineries, while it is the food and beverage industry which consumes the highest share of cooling.

Table 2-3: Energy consumption in energy intensive sectors broken down to process heat, process cool and electricity[23]

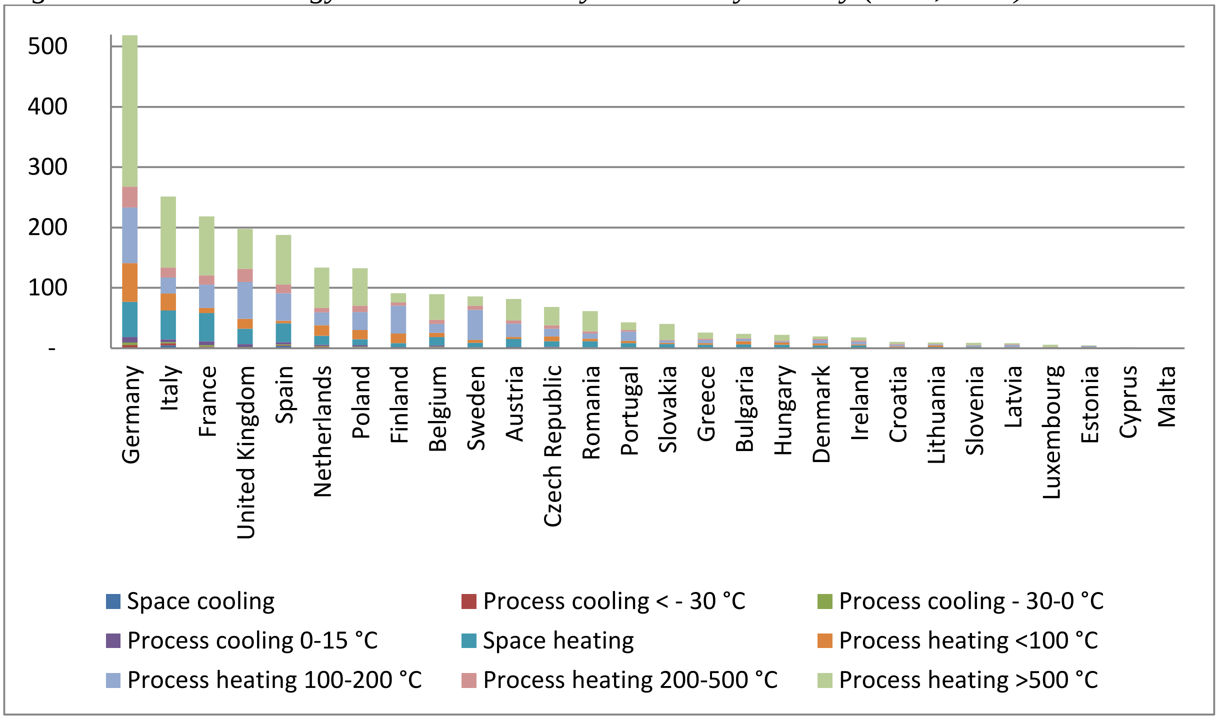
	Final energy consumption in 2013 [ktoe]	Process heat [%]	Process cooling [%]	Electricity [%]
Chemical and Pharmaceutical	51,485	58%	0.6%	30%
Iron & Steel	50,815	75%	0.4%	19%
Refineries	44,657	84%	0.6%	7%
Pulp & Paper	34,265	59%	0.3%	31%
Non-metallic Mineral	34,249	74%	0.2%	17%
Food & Beverage	28,353	62%	10.0%	34%
Machinery	19,282	40%	1.0%	53%
Non-ferrous Metal	9,381	36%	-	57%

Source: ICF, 2015

For what concerns cooling and refrigeration in specific, the estimated electricity demand for process cooling amounted to 7 Mtoe in 2012. The top six countries with higher cooling use are Germany (19%), Italy (15%), France (12%), Spain (10%), UK (7%), and the Netherlands (6%).These countries represent 68% of total process and space cooling in the EU28+3 countries.

[23] The percentages presented here are with reference to the total final energy demand of the respective sector. Process heat % excludes electrical heating and HVAC. Electricity % includes electrical heating and HVAC (note that non-ferrous metal has very high electrical heating consumption). Process cooling includes cooling towers, chillers and refrigeration. It excludes HVAC. The energy consumption includes non-energy uses, as there are no sufficient statistical data to separate energy use from non-energy use data.

Figure 2-15: Final energy demand in industry in EU28 by country (TWh, 2012)

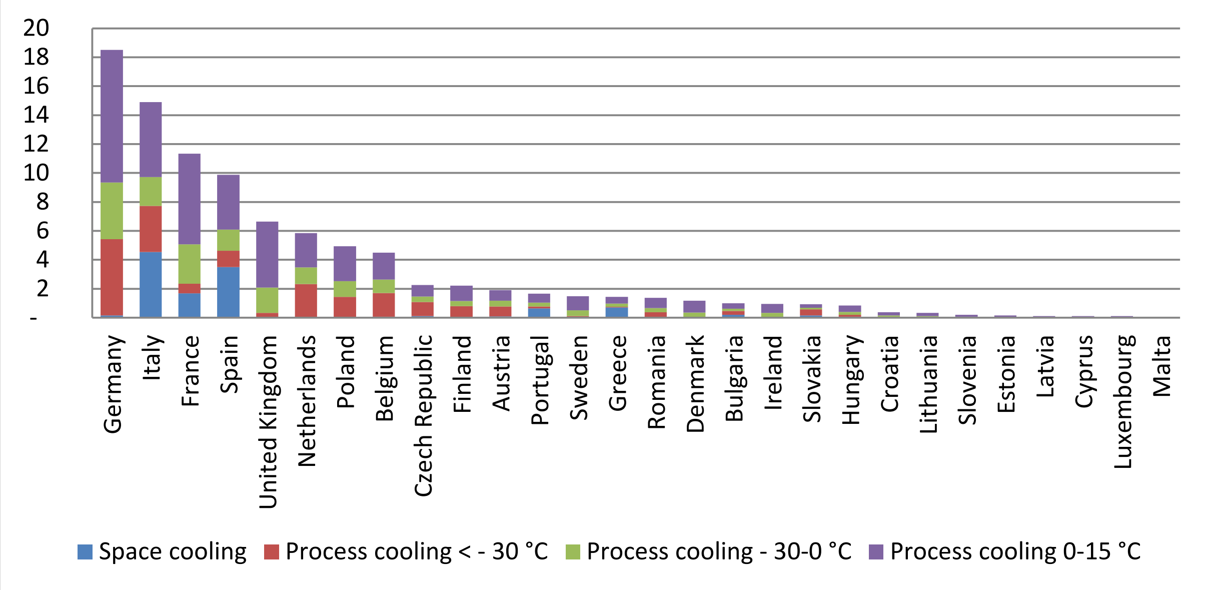


Process cooling between 0°C and 15°C amounts to 53% of the total process cooling demand in Europe and this highlights the importance of the industrial food cool supply along its supply chain. Additional requirements for the food industry with respect to freshness, reduction or complete avoidance of the use of additives, sustainability, increased quality, and hygiene increase the importance of process cooling technologies in the processing of foodstuffs. The cooling processes in this industry, mostly for high temperature cooling (>0°C) and deep freezing temperature levels, are found in industrial producing plants, creameries and dairy production, breweries, milk production and slaughter-houses. The storage of products before production and after production of foodstuffs in cold storage houses is central for process cooling. Centralised cooling technologies for storage are found across Europe with relevant capacity sizes.

The demand for process cooling between 0°C and -30°C is employed for processes of deep cooling in different food processes (see above) and chemical industries. The use of cooling is very diverse in the chemical industry and includes the cooling down of different types of fluids as well as gases, and the direct cooling of processes. At this temperature level different cooling machines are used in auxiliary processes or in integrated cooling machines in laboratories. In addition, freeze-drying processes require deep freeze temperatures relevant for pharmaceuticals and medicine production. This is particularly needed for the storage of final products and climate chambers also relevant in bio-technology.

Process cooling at very low temperatures below -30°C down to about -190°C is only needed for the refrigeration in some processes and for certain products of the chemical industry (air fractioning, gas liquefaction in basic chemicals). A small proportion is also used in research and development processes or military uses.

Figure 2-16: Final energy demand for cooling in industry by country and temperature level (EU28, TWh, 2012)



2.3. Heating and cooling in the tertiary sector

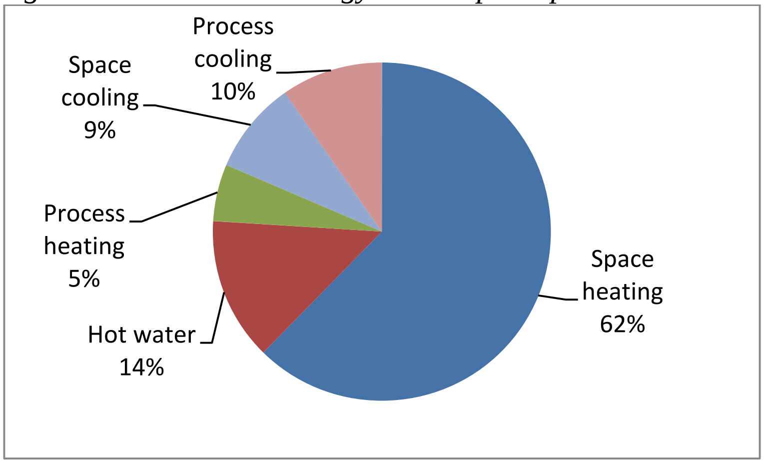
The tertiary sector is also very diverse, with markedly different structures of energy consumption depending on the subsector. Compared to residential buildings in the tertiary sector lighting, ventilation, air-conditioning and process cooling often constitute important end-energy uses and therefore electricity consumption share in non-residential buildings is higher than in the residential sector[24] . However space heating and hot water still generally remain the biggest end-uses.

It is estimated that the average annual energy consumption in the non-residential (tertiary and industry) sector buildings is 280kWh/m^2 (covering all end-uses), and around 52% or 145 kWh/m^2 of this is used for heating. This is at least 40% larger than the equivalent value for the residential buildings (BPIE 2011).

Overall, the service sector consumed in 2012 152 Mtoe of final energy, out of which 63% (96 Mtoe) was used for heating and cooling. As for the different end-uses, space heating makes still the biggest share (62%), while cooling needs altogether consume 19% of the overall heating and cooling needs.

[24] Ibidem.

Figure 2-17: Thermal energy consumption per use in the tertiary sector (2012)



The service sector contributes significantly to the EU's economic activity. Key service sectors and their associated sub-sectors are listed in the table below.

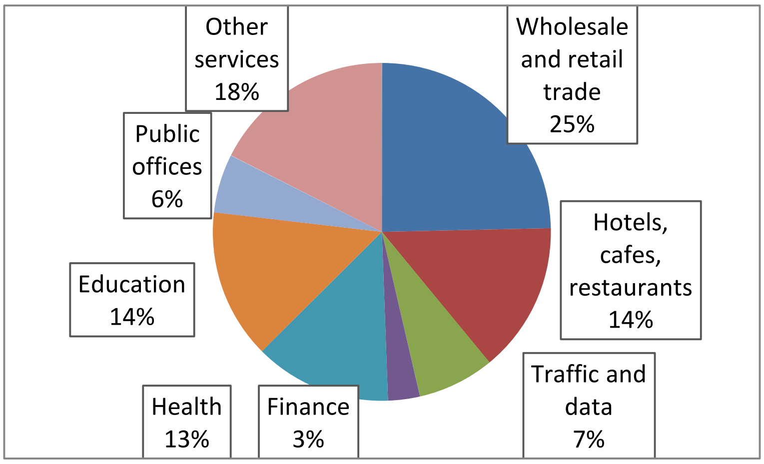
Table 2-4: Service sector grouping and sub-sectors

	EUROSTAT Sector grouping	NACE Code	Sub-sector components
1	Wholesale and retail sale	G46-47	Wholesale and retail sale of textiles and clothing, food, beverages and tobacco, households goods
2	Information and communications	J62-63	Computer programming, data processing, data hosting and related activities
3	Financial and insurance activities	K64-65	Financial services, insurance, reinsurance and pension funds
4	Accommodation and Food service activities	I55-56	Hotels, holiday accommodation, restaurant and other food serving activities

Source: ICF

If we look at the final energy consumed for heating and cooling across the tertiary sub-sectors, it becomes evident that overall the biggest consumer is the wholesale and retail trade sector, which makes 25% of consumption.

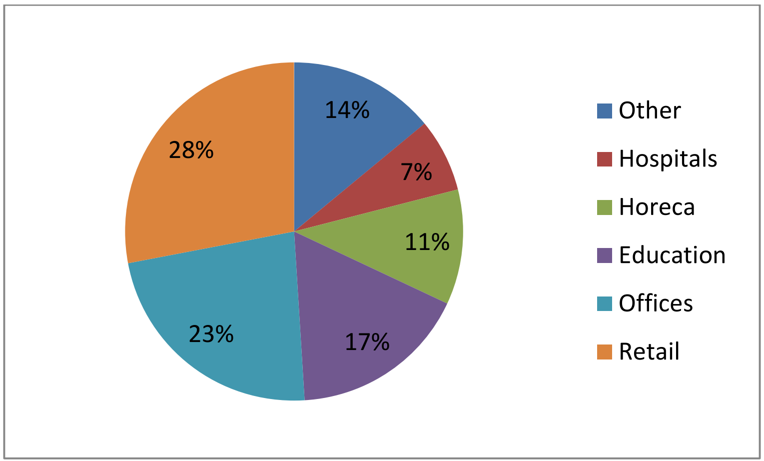
Figure 2-18: EU 28 heating and cooling consumption in services per sector (2012)



As for the 'traffic and data transmission' sector, another study has estimated that the electricity consumed in data centres accounts for between 25% and 60% of operating costs, and up to 30% of turnover (Intellect 2013a) with cooling accounting for an average of between 35% and 40% of the electricity bill[25].

Within the EU, non-residential buildings (which includes the sectors presented in the table above) accounts for 25% of the total European building stock. Buildings in the retail and wholesale space comprise 28% of the non-residential stock, while office buildings (which include financial and insurance) are the second biggest category, with 23%. The accommodation and food service sector (Horeca) accounts for 11% of EU non-residential building stock.[26]

Figure 2-19: Services share in the buildings stock in m^2 - % (2009)



Source: BPIE; 2011

Hospitals are, on average, the most energy intensive buildings with continuous occupancy, but since their share is only 7% of non-residential buildings, their total consumption is small. This is also the case for hotels and restaurants, which are equally energy intensive, but constitute only 11% of non-residential buildings. While these two categories represent the highest energy intensive type in specific terms, offices (23% of total), wholesale and retail trade buildings (28% of total), on the other hand, represent more than 50% of energy use. Education (17% of total) and sports facilities (4% of total) account for a further 18% of the energy use while other buildings account for some 6%.[27]

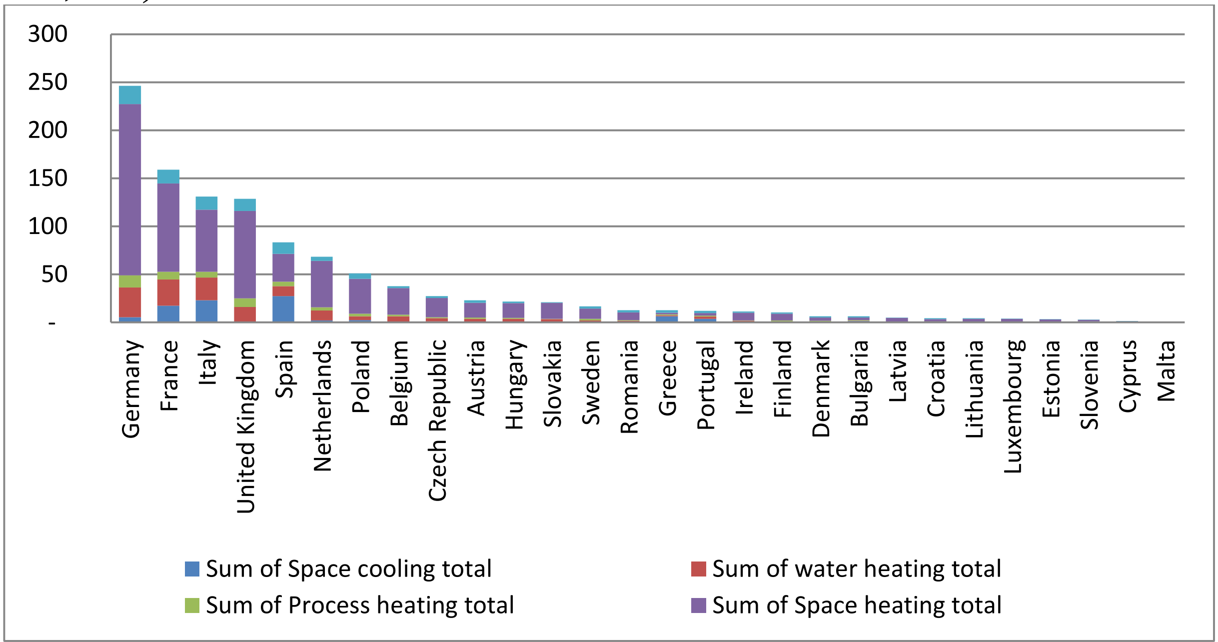
In the biggest sector (wholesale and retail), the average share of energy consumption for a food retailer is largely driven by refrigeration – which accounts for 50% of the energy use. Stringent European food regulations coupled with consumer demand for convenience and fresh products are key contributing factors. Additionally, these stores require refrigeration for fresh and frozen products 365 days a year for 24 hours a day to ensure product quality. Lighting is the second largest energy consumer accounting for 25% in an average store followed by HVAC (20%) and electrical appliances and other internal processes (5%)[28].

[25] Tait Consulting (2015).
[26] BPIE (2011) Europe's buildings under the microscope.
[27] Ibidem.
[28] JRC (2013) Best Environmental Management Practice in the Retail Trade Sector.

For non-food retailers, energy consumption is unclear, since energy use depends on the products being sold in the store. Heating and air-conditioning remains however a significant contributor since comfortable temperatures for consumers are maintained by retailers to ensure a ‘pleasant shopping atmosphere’, and this varies both regionally and seasonally across the EU. In warehouses, energy consumption can vary significantly according to the types of goods stored as well as the climate of the region they are located in. An analysis in the UK showed that heating represents almost 60% of the energy consumed (ICF; 2015).

Office buildings are the second largest consumers of energy among non-residential buildings in Europe. Due to tightly packed areas, such as trading floors, the financial and insurance sector occupies office space at high densities[29].
In terms of cross-country comparison, the following figure shows that the highest amount of energy for heating and cooling in the service sector is consumed in Germany, France, Italy, UK and Spain.

Figure 2-20: Final energy demand for heating cooling in the tertiary by country (EU28, TWh, 2012)

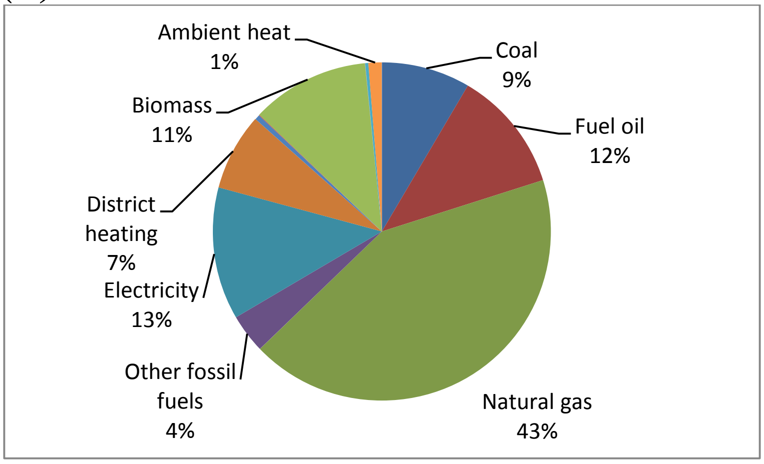


[29] In the UK, an average employee working in this industry occupies 9.7m^2 of workspace. In 2012, this sector employed approximately 3.15 million people in Europe. Assuming that each person worked in an office, the office space used by the sector was approximately 30.6 million m^2 of space. Studies have found that on average, the annual unit consumption of energy per m$_2$ in an EU non-residential building is 295kWh/m^2.

3. FUEL MIX IN HEATING AND COOLING

Europe's energy system is dominated by fossil fuels. The heating and cooling sector represented 50% of the overall final energy demand in EU28 in 2012. In terms of final energy demand, direct fossil fuels use represented 68%[30].

Figure 3-1: Final energy consumption for heating and cooling per energy carrier, 2012 (%)[31]

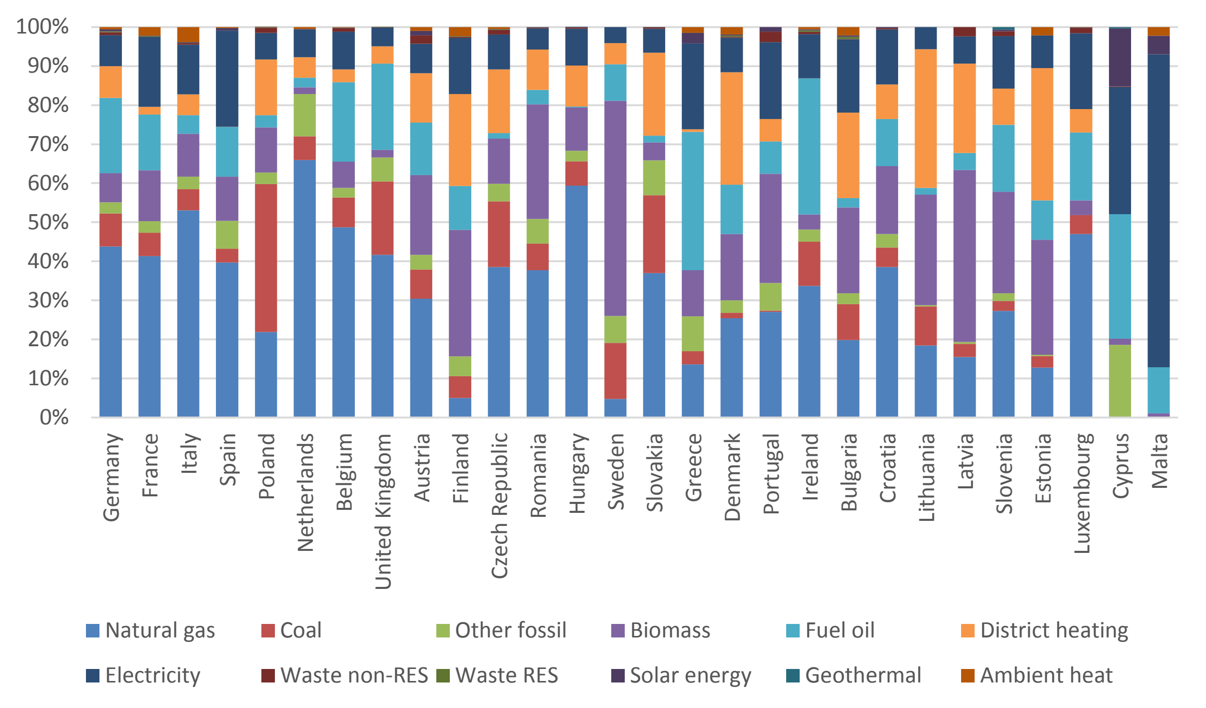


Natural gas was the largest energy source for heating and cooling in 2012, with a share of 43%. Overall, the direct use of natural gas for heating and cooling represented 59% of the total gas onsumption in Europe in 2012. It was followed by electricity (13%), fuel oil (12%), biomass (11%), coal (9%) and district heat (7%). The figure below represents the share of the different energy carriers across EU28 in 2012.

[30] This overall share does not take into account the energy carrier used to produce electricity and in district heating.

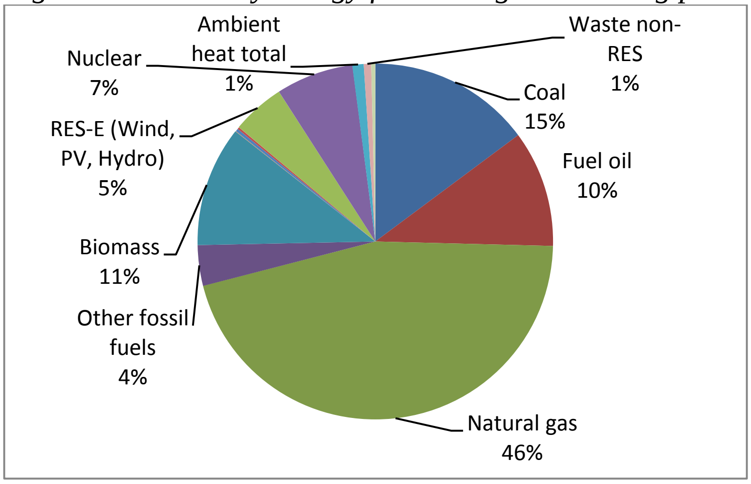
[31] The following sources remain each below 1%: solar, geothermal, renewable waste, non-renewable waste, other.

Figure 3-2: Final energy consumption for heating and cooling per energy carrier per country, 2012 (%)



If the energy carrier used to produce electricity and district heating is taken into account, the total (direct and indirect) share of fossil fuels employed for heating and cooling is higher, and this can be seen from the primary energy data presented below.

Figure 3-3: Primary energy for heating and cooling per energy carrier, 2012 (%)



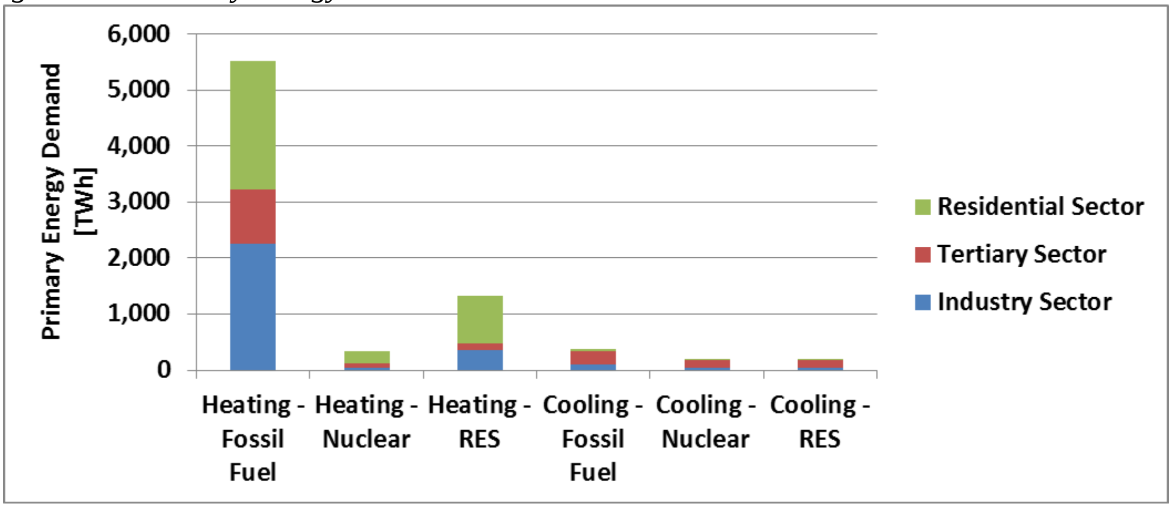
About 684 Mtoe of primary energy demand were used for heating and cooling purposes in the EU28. Thereof, 46% was natural gas, which is the individual most important energy carrier for the supply of heating and cooling in the EU28. It is followed by coal (about 15%), biomass (about 11%), fuel oil (10%), nuclear energy (7%) and some renewable energy sources (wind, PV and hydro, about 5%)[32]. Other renewables like solar (thermal) energy, ambient heat and geothermal energy in sum accounted for 1.5%. Across all energy carriers,

[32] Both nuclear energy and renewable energy are used for electricity generation which in turn is used for heating and cooling.

renewables accounted for 18% of primary energy supply for heating and cooling, whereas fossil fuels accounted for the major share of 75%. The share of heat sources in the EU is similar to what happens at global level. In fact, according to IEA statistics, three-quarters of global energy use for heat is currently met with fossil fuels.

While the penetration of renewable energy has gone the farthest in the electricity sector (26% of electricity production), in the heating and cooling sector it reaches only 18% of primary energy.

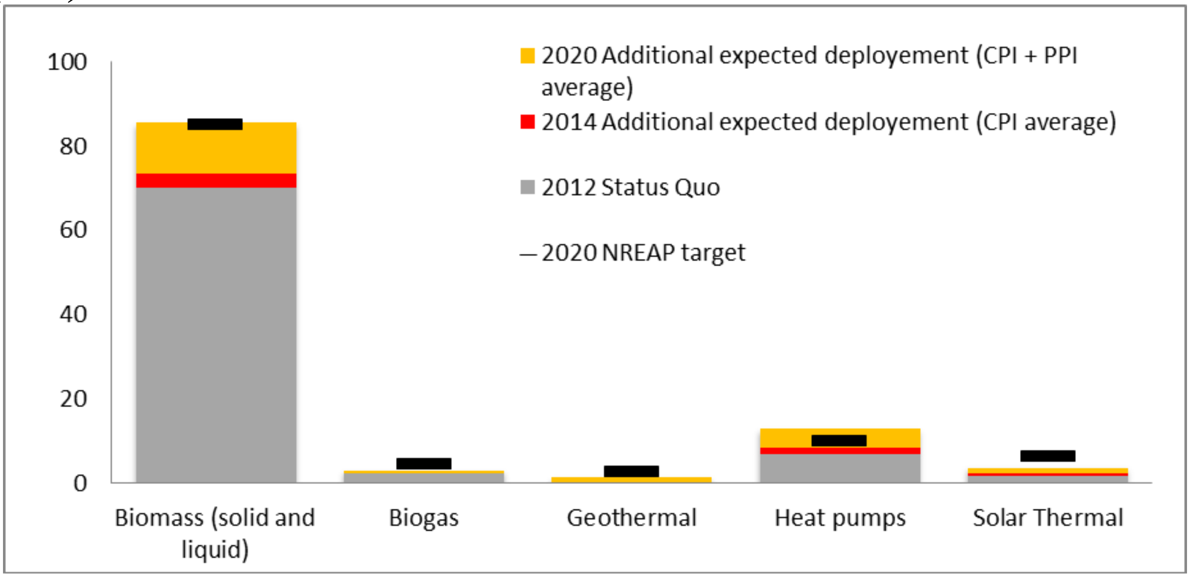
Figure 3-4: Primary energy demand in EU-28SIN in 2012



Renewable energy is growing due to the EU renewable energy target for 2020 and the policies to reach it. Its share was estimated to have reached 16.6 % of final energy in 2014 overall in the European Union[33]. As regards heating and cooling, biomass is the leading renewable energy carrier representing around 90%[34], while other renewable energy sources, such as geothermal, solar thermal and biogas remained below 1%[35].

[33] COM(2015) 239 Final.
[34] Biomass was calculated to provide 14% (73,6 Mtoe).
[35] Data on final energy consumption for renewable heating and cooling are also reported in Eurostat, following the requirements of the Renewable Energy Directive (2009/28/EC).

Figure 3-5: Technology-specific RES deployment for heating and cooling at EU level (Mtoe)[36]



As regards future potentials for renewables in the heating and cooling sector, Member States plan to generate nearly 21 % of their heating needs from renewables by 2020[37]. Biomass is the source for which the highest increase is foreseen, with an additional 140 TWh (12 Mtoe) to be employed by 2020. The second largest increase is attributed to heat pumps, which are expected to provide an additional 65 TWh (5,6 Mtoe) of renewable heating and cooling in 2020 (Figure 3-5).

The share of biogas was estimated to reach 3% of all renewable heat sources and below 1% of the whole heating and cooling sector in 2014[38]. According to the Progress Reports, only Germany and Cyprus were slightly above 1%. As for heat pumps, their share is estimated to reach 10% of all renewable heat sources and 1.6% of the whole heating and cooling sector in 2014[39]. According to the 2012 Progress Reports, heat pumps covered a substantial share of heating demand in Sweden (8.4%), Italy (4.6%) and Malta (3.4%). Solar thermal energy was estimated to reach around 3% of all renewable heating and cooling sources and below 1% of the whole heating and cooling sector in 2014[40].

At EU level, the share of geothermal energy was estimated to reach 1% of all renewable energy sources and below 1% of the whole heating and cooling sector in 2014[41]. Geothermal heat reaches noticeable heat market shares only in a few Member States (e.g. Bulgaria, Hungary, and Slovenia), while the largest volumes are found in France.

The averages values for the EU mask, however, considerable variations in Member States. All Member States have adopted a sector specific renewable energy target for heating and cooling in their National Renewable Energy Action Plans. Most Member States are on track to achieve their 2020 target; some are switching faster than planned. This trend is particularly visible in the Baltic and Nordic Member States, where the share of renewable energy in heat

[36] Green-X (Ecofys/TU Wien, 2014). CPI (Consumer Price Index), PPI (Producer Price Index).
[37] According to the National Renewable Energy Action Plans.
[38] Green-X (Ecofys/TU Wien, 2014).
[39] Ibidem.
[40] Ibidem.
[41] Ibidem.

consumption is also highest among all Member States (ranging from 67% in Sweden to 43% in Estonia). These are also the Member States where the use of district heating and CHP, including based on renewables, is the highest.

Table 3-1: Share of renewable energy in heating and cooling (%)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
EU28	9.9	10.3	10.9	11.9	12.0	13.7	14.1	15.0	16.1	16.5
Belgium	2.8	3.4	3.7	4.5	5.0	6.2	6.1	6.3	7.7	8.1
Bulgaria	14.1	14.3	14.8	13.9	17.3	21.7	24.4	24.9	27.5	29.2
Czech Republic	8.4	9.1	9.6	11.4	11.1	11.8	12.6	13.2	14.1	15.3
Denmark	19.9	22.1	23.0	27.0	28.1	29.5	30.7	32.0	33.5	34.8
Germany	6.3	6.8	6.9	8.3	7.4	9.2	9.7	10.4	10.4	10.6
Estonia	33.2	32.2	30.7	32.7	35.5	41.8	43.3	44.1	43.1	43.1
Ireland	2.9	3.5	3.6	3.9	3.6	4.3	4.5	5.1	5.4	5.7
Greece	12.8	12.8	12.5	14.4	14.3	16.4	17.8	19.4	23.4	26.5
Spain	9.5	9.4	11.4	11.3	11.7	13.3	12.6	13.6	14.1	14.9
France	12.3	12.4	12.1	12.9	13.4	15.2	16.4	16.3	17.3	18.3
Croatia	11.7	10.8	11.4	10.5	10.4	11.6	13.0	15.6	18.3	18.1
Italy	4.3	4.6	5.8	5.9	6.4	8.7	10.4	12.2	16.9	18.0
Cyprus	9.3	10.0	10.4	13.1	14.5	16.3	18.2	19.2	20.7	21.7
Latvia	42.5	42.7	42.6	42.4	42.9	47.9	40.7	44.8	47.4	49.7
Lithuania	30.4	30.1	29.7	29.8	32.8	34.4	33.2	33.7	35.5	37.7
Luxembourg	1.8	3.6	3.6	4.4	4.6	4.7	4.8	4.8	5.0	5.6
Hungary	6.5	6.0	7.5	8.9	8.3	10.5	11.0	12.3	13.4	13.5
Malta	1.1	2.2	2.6	3.2	3.6	1.8	8.4	8.1	16.7	23.7
Netherlands	1.9	2.1	2.4	2.5	2.6	3.0	2.7	3.2	3.4	3.6
Austria	20.2	22.6	23.5	26.2	26.8	28.6	30.5	30.7	32.4	33.5
Poland	10.2	10.1	10.2	10.4	10.9	11.6	11.7	13.0	13.3	13.9
Portugal	32.5	32.1	34.2	35.0	37.5	38.0	33.9	35.2	34.0	34.5
Romania	17.6	18.0	17.6	19.4	23.2	26.4	27.2	24.3	25.7	26.2
Slovenia	18.4	18.9	18.6	20.4	19.2	25.0	25.7	28.4	30.2	31.7
Slovakia	5.0	5.0	4.4	6.2	6.1	8.1	7.8	9.1	8.7	7.5
Finland	39.5	39.2	41.4	41.6	43.4	43.5	44.4	46.2	48.4	50.9
Sweden	46.6	51.8	56.2	58.6	60.9	63.5	60.9	62.5	65.7	67.2
United Kingdom	0.8	0.8	0.9	1.1	1.3	1.6	1.8	2.2	2.3	2.6
Norway	25.7	29.0	28.6	29.5	31.1	32.1	32.6	34.2	33.8	31.8

Source: Eurostat

The increased use of renewable energy will be accelerated, in particular in Central and Eastern Europe, also with the support of the €6 billion from the European Structural and Investment Funds allocated to renewable energy over the 2014-2020 period.

Additional use of renewable energy in 2013 compared to the level in 2005 enabled the EU to cut its demand for fossil fuels by 116 Mtoe. The electricity sector accounted for 71% of this, while the heating and cooling sector contributed 19%. Most of the replaced fuel was coal

(47%) and natural gas (30%).[42] Avoided imported fuel costs due to increased use of renewable energy are more than €30 billion per year[43].

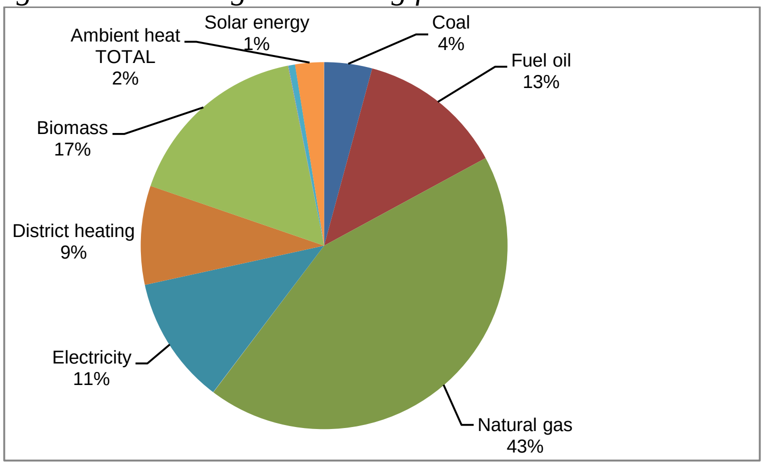
3.1. Fuel mix in buildings

Like energy consumption, the fuels used for heating of buildings are not reported, but must be derived from primary and final energy statistics, processed using a number of factors.

Natural gas is the dominant fuel for heating and cooling. Its overall share is 43% in the residential sector and is followed by oil products and electricity with 13% and 11% respectively. The share of coal and coal products is 4%, which raises concerns about the pollution and consequent negative health effects especially in urban and dense areas. Biomass represents 17%, while solar is 1% and geothermal is around 0.1%. The share of district heating is 9%[44].

These overall averages cover large differences in regional and national fuel mixes. In the residential sector, gas is the most common fuel in all EU regions – with the exceptions of few countries like Bulgaria, where it represents only 3% and the main energy carriers for heating and cooling is biomass, followed by electricity and coal. Similarly, in Estonia, natural gas represents only 6% and heat is supplied mainly through district heating and biomass. The highest use of coal in the residential sector is found in Central and Eastern Europe, with Poland supplying 44% of heating from coal, and also in Ireland (19%). As for renewable energy sources, solar heat reaches the highest share in the southern countries, like in Cyprus (26,1%), Greece (4,3%) and Spain (1,6%).

Figure 3-6: Heating and cooling fuel mix in the residential sector, 2012



District heating supplies about half of the national heat consumption of the residential sector in some northern Member States (42,2% in Sweden, 41,9% in Denmark, 36.7% in Lithuania, 36.2% in Estonia and, 32.7% in Finland), and accounts for a significant national heat market share in most of the countries in Eastern Europe.

3.2. Fuel mix in the industry and tertiary sector

The energy dense fossil fuels and related technologies dominate the supply of medium and high temperature heat for industries, which seek supply solutions adapted to provide high

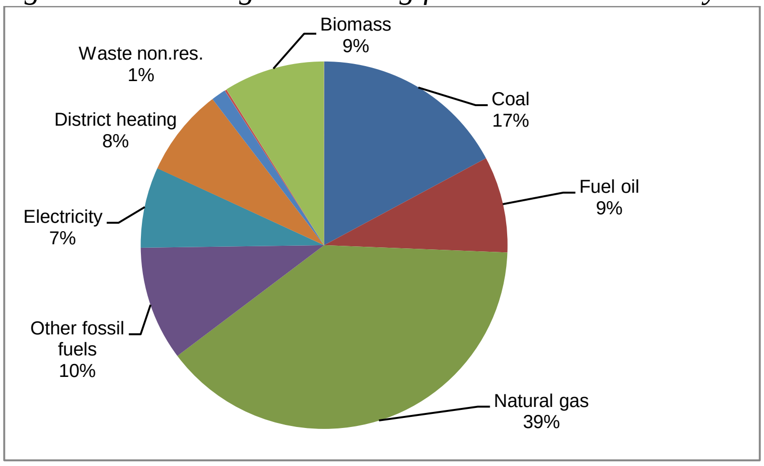
[42] Renewable energy in Europe – approximated recent growth and knock-on effects, EEA 2015.
[43] European Energy Security Strategy, COM (2014) 330.
[44] Distance to 100% in the total is due to rounding.

quality steam at large quantities with a high degree of reliability and at commercially competitive costs.

Among renewable energies, biomass is the most used in industry. It has similar characteristics allowing it to replace fossil fuels in many applications. The role of the other renewable energies is marginal, as most renewable technologies are not yet sufficiently developed to generate high temperature heat or steam, or, at least, are not perceived sufficiently scaled, reliable or of reasonable cost. Heat pumps, solar thermal and geothermal can supply heat up to around 200°C. Pilot projects are testing solar energy and industrial heat pump technologies that can provide medium temperature heat above 200°C. There is currently no or limited technology solution to directly replace fossil fuels for very high temperature process heat, e.g. in the steel and chemical sectors or in cement production.

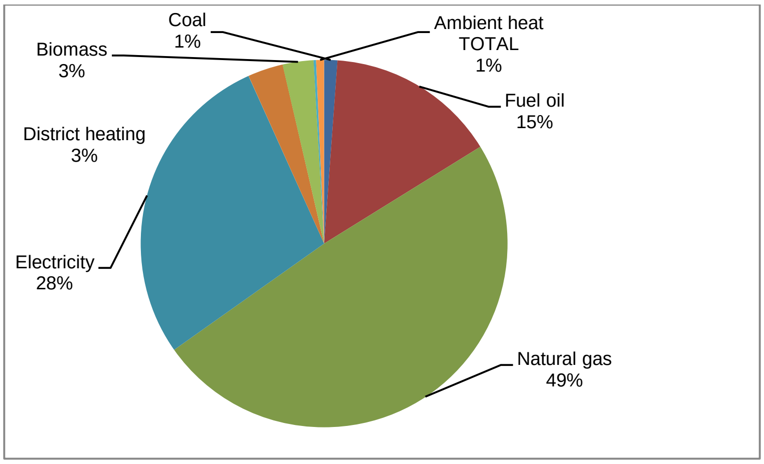
Overall, fossil fuel supplied heat in 2012 represent 75% of the final energy consumed for heating and cooling in industry, to which the share of fossils fuels in electricity and district heating should also be added. Coal with 17% still plays an important role in industrial heating. Renewables (biomass) accounts for 9% of the total supply, while the other renewable sources are negligible (below 1%).

Figure 3-7: Heating and cooling fuel mix in the industry sector (2012)



In the tertiary sector, it can be noted that overall-across-sectors renewable energy is still low. The dominant sources is by far natural gas with a share of 49%, with electricity in the second place (28%) and fuel oil (15%) in the third place. The share of renewables is 3%, and is almost entirely provided by biomass.

Figure 3-8: EU28 heating and cooling fuel mix in the service sector (2012)


Coal
1%
Ambient heat
TOTAL
1%
Biomass
3%
Fuel oil
15%
District heating
3%
Electricity
28%
Natural gas
49%

4. OVERVIEW OF HEATING AND COOLING TECHNOLOGIES

4.1. Technologies supplying heating and cooling in buildings

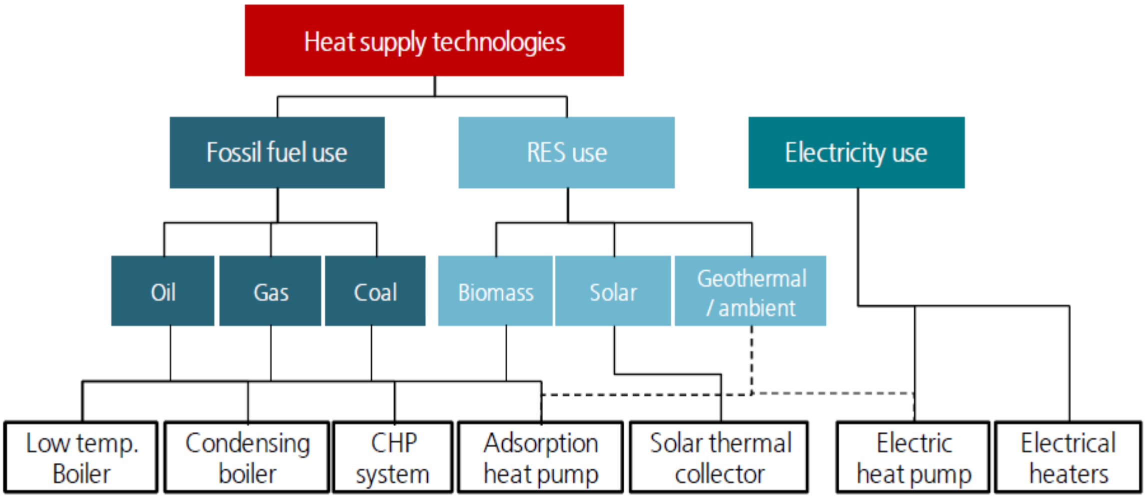
A wide range of technologies can be used to supply heat and cooling for buildings. Boilers are the most commonly used technology. They can be operated on natural gas, oil, coal and bioenergy. Boilers can be of different efficiencies. The currently most widely used standard boilers have an efficiency of 40-80%, while modern condensing boilers can reach efficiencies above 100% and are typically more than 90% efficient. Individual stoves fueled by gas, oil, coal and biomass and furnaces using coal, biomass and waste are also an important technology. Direct electric heating is also widely used in some Member States. Cogeneration technologies constitute an important family of heating technologies, which include combined cycle and steam turbines and engines operated on gas, coal or biomass, internal combustion engines using gas, and emerging technologies, such as fuel cells, Stirling engines and Organic Rankine Cycle. While cogeneration is usually applied in large capacities up to 150 MW and above, micro-CHP is emerging in the residential sector supplying individual buildings and even apartments. Out of the renewable technologies, not based on biomass or biofuels, heat pumps are the next big family of heating and cooling technologies. They can be of many types, such as air source heat pumps operating on electricity or gas, ground source and water source heat pumps using again either electricity or gas. Solar thermal heating and cooling technologies have been increasingly gaining ground. They can be either with flat plate or vacuum tube collectors. Geothermal energy technologies also provide heat and cool, but they can be applied only if there is a piping system to convey the thermal energy from the depth of around 200 meter or more to consumers and are usually applied in larger district heating systems.

Most of the heating technologies, such as cogeneration, heat pumps, solar thermal and boilers can be applied in larger capacities in district heating system supplying groups of buildings in districts or cities.

To assess the best heating and cooling technology for a particular application, different criteria have to be considered. The most relevant ones are the annual thermal load profile for water and/or space heating, the annual cooling profile, the relative timing of thermal and electric loads, space constraints, emission regulations, fuel availability and of course the cost of the technology itself and that of the utility prices for electricity and other fuel prices. Costs and performance vary widely among heating and cooling technologies and also for each individual technology because of differences in equipment prices, installation and running costs, different end-use applications, climate, technology specification, user requirements and building occupation profiles.

Various classifications of individual heating supply technologies employed in the residential sectors exist. The figure below (Fraunhofer 2015) includes the most common categories, which can be distinguished not only for the technology employed, but also for the energy carriers used, being fossil fuels and renewable energies, or secondary energy carriers, such as electricity and district heating. The various individual heating solutions compete with each other.

Figure 4-1: Categories of heating supply technologies



Source: Fraunhofer et al.; 2015

A number of new technologies, e.g. fuel cells, are emerging to complete the existing established heat technology families, while alternative fuels, such as biogases, synthetic gases and hydrogen or recovered waste heat, widen the range of available energy carriers and sources for heating.

Modern heating systems include other technologies, which complement boilers and are often used to provide more comfort to the users, depending on specific needs: heat storage and domestic hot water; intelligent thermal control and communication instruments; radiators and heat exchangers; surface (floor) heating and cooling; passive heating and cooling elements, smart metering and smart homes integrating heating (and cooling) with the wider technical systems of buildings.

European Heating Industry (EHI) statistics provide an overview of the stock and the annual sales for the different heating categories. According to these statistics, in 2010 89% of the installed stock of central space heaters was composed of inefficient low temperature gas and oil boilers (in future to be labelled in the appliance market with C and D energy labels). The more efficient condensing boilers represented only 10% of the stock, while the residual 1% consisted of heat pumps and mini-micro-combined heat and power (CHP) devices (less than 0.1%). EHI also calculated that in EU25 in 2012, 64% of the installed space heating systems were non-condensing boilers, while condensing boilers represented 26%. The residual shares were represented by biomass boilers (6%), heat pumps, and other technologies (e.g. micro-CHP).

Most of the existing heating equipment stock is old, installed before 1992, and it is thus at the end of their lifetime. Almost one quarter (22%) of individual gas boilers, a third of direct electric heaters (34%), almost half (47%) of oil boilers and more than half (58%) of coal boilers are older than their technical lifetime (Fraunhofer 2015). These data show that the level of efficiency of the installed stock is low, around 60%, below the nominal efficiencies of these appliances of between 78% and 85%, as operational performance deteriorate over time, and even more so, if regular maintenance is not followed up. The modernisation of heating and cooling systems even only to condensing boiler levels could bring significant energy efficiency gains. The gas industry estimated that replacing of the current non-condensing gas boilers with the available condensing types would increase efficiency of gas heating by around 20% in the currently non-condensing gas appliance stock, which constituted 88% of the gas appliances in 2014[45]. These savings would be further increased by around 10% if programmable radiator thermostats are also installed.

Significant differences exist across countries. In the UK, for example, the share of condensing boilers is much higher than the average, thanks to regulatory pull and incentives towards condensing boilers. In Sweden, heat pumps are the most diffused technology and reach 46% of the installed capacity.

Table 4-1: Space heaters in EU25, 2012

	EU25 (Thousands)	Italy	UK	Germany	France[46]	Sweden
Non-condensing boilers	(75.784) 64%	87%	44%	71%	80%	12%
Condensing boilers	(31.092) 26%	12%	56%	22%	12%	1%
Biomass boilers	(7.030) 6%	1%	<1%	4%	3%	18%
Heat pumps	(2.712) 2%	<1%	<1%	3%	5%	46%
Other	(1.083) 2%	<1%	<1%	1%	1%	22%

Source: EHI

The cooling sector is heterogeneous regarding its technologies and actors. Cooling shows a strong interlinkage with the electricity sector because, on the one hand, electricity is used as secondary energy in order to produce cooling (e.g. compression methods) or to satisfy the heat demand (e.g. heat pumps). On the other hand, there is an interaction of cooling with heating. One example of this is when heat is used to drive heat driven chillers for the generation of cooling e.g. tri-generation applications, or when cooling is produced from the waste heat generated in electricity production or industrial processes. Moreover, it is also possible to recover the heat rejected in compression chillers for instance for the pre-heating of hot water.

Cooling is mostly supplied from electric devices removing heat / moisture from air, using individual ventilation and air conditioning units (*i.e.* room air-conditioners and central air-conditioning units (chiller evaporators). The European market is therefore dominated by electric cooling machines. Thermal cooling machines operated with district heating and cooling or waste heat are also present to a limited extent in the high performance, large-scale classes.

Conventional cooling technologies include electrical air conditioners and chillers based on a vapour compression refrigeration cycle. High-efficiency absorption chillers, which use mixtures of water and ammonia (or lithium bromide) with natural gas or cogenerated heat sources, could replace traditional electric chillers in buildings with a high demand for cooling and/or heating and air conditioning.

[45] Eurogas and GasNaturally combined response to the Heating and Cooling Consultation Forum, Supporting Evidence, 8 September 2015.
[46] This figure for France does not reflect the particularity of France, where there is a high deployment of electric heaters which are not collected in EHI statistics. Around 6,5 million electric appliances for space heating and warm water production are sold annually in France

District cooling allows using locally available sources. Often district cooling use the direct thermal energy converting heat into cool using waste heat from industry and waste incineration (often via tri-generation) to produce cooling with heat driven sorption chillers and heat pumps. Electric compression chillers are also large portion of many of the existing systems. A new emerging application is the so-called free cooling, whereby cold from rivers, lakes and seas is transported directly or enhanced with heat pumps through pipes to the end-users, mainly service sector and public buildings. Free cooling is best established in Finland, France, Sweden and Spain.

District cooling is still a small portion with a total installed capacity of only 2.4 GW, which is less than 1% of the installed district heating capacity of 301.5 GW in EU28 (Fraunhofer, 2015). The largest district cooling capacities are in France (669 MW), Sweden (650 MW), Spain (317 MW), Finland (247 MW), Italy (172 MW) and Germany (168 MW). Austria (55 MW), Poland (35 MW), Denmark (34 MW) and Hungary (7 MW) also have district cooling systems. According to RESCUE[47], in 2011 two thirds of the cooling delivered by these systems took place in France and Sweden. In the case of Sweden, the district cooling market developed from 71 GWh in 1996 up to 888 GWh in 2011. Utility companies distribute cooling in 32 cities in Sweden. This significant development has been largely due to the phasing out of refrigerants chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFC) in 1996 and 2002.

Specific needs and requirements of the cooling process (temperature, cooling power, available energy carriers, and local requirements) determine the choice of cooling machine. Within the cooling segment, retail and supermarket cooling sorption cooling technologies are expected to diffuse more strongly in the cooling market as a promising efficient technology taking advantage of waste heat for cooling purposes.

Packaged air conditioners are standardised products, with a packaged central unit containing the heat exchanger and compressor – and sometimes the evaporator and condenser as well – all in one cabinet, usually placed on a roof. Chillers, either water- or air-cooled, produce chilled water to cool the air in buildings. Thermally driven "adsorption or absorption" chillers (using fossil fuels, solar thermal, waste energy, biomass, etc.) are a mature technology and use a similar cycle to that of conventional air conditioners. Their efficiencies are lower than electrically driven heat pumps (with coefficients of performance typically in the range 0.7-1.2). Desiccant de-humidificators use materials, or other solutions, that attract and hold moisture (desiccants) in an air conditioning system to dry air before it enters a conditioned space. They remove moisture (latent heat) from outdoor air, allowing conventional air conditioning systems to deal primarily with "dry" temperature control. Other innovative technologies include the use of 'phase change materials' to remove or absorb latent heat. In commercial buildings, the situation tends to be more complicated with integrated heating, ventilation and air conditioning (HVAC) systems often being the norm, but frequently oversized and of suboptimal operation. Better optimisation and control systems for small HVAC systems are gaining ground, often integrated with solar systems. The use of cogeneration (tri-generation), district cooling and seasonal storage is emerging, but their integration into buildings' and industries' cooling systems represents significant technological challenge. More details on cooling appliances are provided in Chapter 6.

[47] EU district cooling market and trends, 2014. Report prepared by Capital Cooling under the framework of the RESCUE project co-funded by the IEE programme of the EU.

4.1.1. Affordability of heating and cooling

The affordability of heating and cooling refers to the capacity of households to cover the energy cost necessary to adequately heat and cool their homes. On average, the cost of heating i.e. space and water heating, represents 6.4% of European household's total consumption expenditures, ranging from 3% in Malta to 16% in Slovakia[48].

The cost of heating varies widely across households as it depends on individual factors such as the energy efficiency of the dwelling, fuel type, technology used to heat and cool, price of energy, and needs and behaviours of the occupants. All these factors affect households' ability to turn income into heating or cooling.

A big proportion of the energy bill is dedicated to space heating. Maintaining an adequate level of indoor temperature improves European citizens' wellbeing. Evidence suggests that households in energy poverty are more likely to suffer from a higher rate of excess winter deaths, morbidity issues, mental health problems and social isolation[49]. Negative impacts on health are also apparent as a result of excess heat during summer time. Affordable heat and cool is even more important for those who spend more time in their houses for reasons of bad health, disability, age or lack of employment.

In recent years, increases in energy prices have outstripped household income constraining households' budgets. In these circumstances, those households with the lowest income have been forced to under-heat their houses or reduce expenditures on other purposes.

The affordability of heating and cooling should therefore be considered in the wider context of both targeted measures in favour of vulnerable customers, in line with existing EU legislation[50], and energy poverty in general. Some Member States have put forward national definitions and metrics to measure and monitor energy poverty. Energy poverty is usually defined as: (i) a situation where a household spends more than a certain amount of its income on energy services; or (ii) when a household's income is below a poverty threshold and they simultaneously have to spend an above average percentage of their household income on energy[51].

EU legislation assigns the responsibility to protect vulnerable consumers and to address energy poverty to Member States. To assist Member States, the Commission has been taking actions by identifying best practices and supporting exchange of information on how to alleviate energy poverty. The Commission services are working with the Vulnerable Consumers Working Group, an expert group established through the Citizens' Energy (London) Forum with a mandate to develop solutions for sharing best practices on protecting

---

[48] Energy prices and costs in Europe, COM(2014) 21 /2, 29.1.2014. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/20140122_communication_energy_prices.pdf

[49] The Marmot Review of the health impacts of living in cold homes provides a comprehensive overview of the evidence linking energy poverty related factors to poor physical and mental health. The document is available at: http://www.instituteofhealthequity.org/projects/fair-society-healthy-lives-the-marmot-review

[50] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity. Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas.

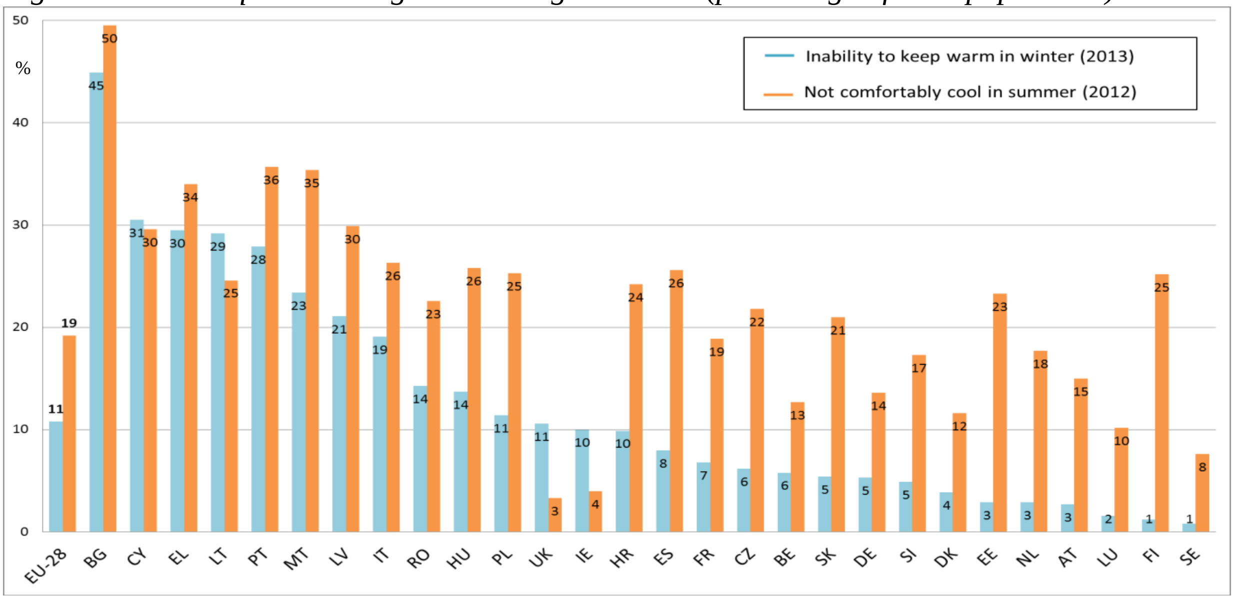
[51] Insight_E (2015) 'Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures'. Available at: http://ec.europa.eu/energy/en/news/energy-poverty-may-affect-nearly-11-eu-population

vulnerable consumers[52]. In addition, the Commission finances projects to tackle energy poverty through energy efficiency improvements and consumer empowerment[53].

The Eurostat EU Survey on Income and Living Conditions (EU-SILC) collects information on household's perception of comfort in their houses. In the survey, respondents were asked whether their homes were kept adequately warm in winter and comfortably cool during the summer.

EU-SILC estimates that in 2013, 11%[54] of the EU population was unable to keep their homes adequately warm during winter, with similar numbers being reported with regard to the late payment of utility bills (10 %)[55] or presence of poor housing conditions (16 %)[56]. In 2012, the survey included a question about level of comfort during summer. In that year, 19 %[57] of the EU population lived in a home that was not comfortably cool in summer time. The figure below shows the percentage of the EU population perceiving to have inadequate heating and cooling.

Figure 4-2: Inadequate heating and cooling in the EU (percentage of total population)



Source: Eurostat

---

[52] The Vulnerable Consumers Working Group published guidelines to help Member States define the concept of vulnerable consumers. Available at:
http://ec.europa.eu/energy/sites/ener/files/documents/20140106_vulnerable_consumer_report.pdf

[53] EASME runs specific programmes focussed on reducing energy poverty such as SMART-UP and REACH. A list of previous relevant projects is available at:
https://ec.europa.eu/easme/sites/easme-site/files/People%20have%20the%20Power%20IEE%20report_0.pdf

[54] Eurostat - Share of population living in a dwelling not comfortably warm during winter time. Available at:
http://ec.europa.eu/eurostat/data/database?node_code=ilc_mdes01
Eurostat - Share of population living in a dwelling not comfortably cool during summer time. Available at:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_hcmp03&lang=en

[55] Eurostat – Arrears on Utility bills. Available at:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_mdes07&lang=en

[56] Eurostat - Share of total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames of floor. Available at:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_mdho01&lang=en

[57] Eurostat - Share of population living in a dwelling not comfortably cool during summer time. Available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_hcmp03&lang=en

The highest reporting of people unable to keep their homes warm during winter is from Bulgaria, followed by Cyprus, Greece, Lithuania, Portugal and Malta. The figure shows that the climate characteristics are not the only factors that determine the share of households unable to keep their homes warm during winter. A number of Member States with milder climates are situated above the EU average of inadequately heated homes. In addition to low energy efficiency of the housing stock and insufficient heating, many of these countries have experienced strong economic downturns and spending on heating is likely to have been more restricted.

Energy poverty is also an obstacle to cooling. Europe, especially the Southern European countries have been experiencing heat wave events in summer during the last decade which seem to be responsible for a higher mortality rate, especially among vulnerable households. Bulgaria, Portugal, Malta, Greece, Latvia, and Cyprus were between those Member States with the highest share of respondents who were not comfortably cool during summer.

Member States have put in place a number of measures to protect vulnerable consumers and address energy poverty. An extensive review of these measures[58] shows that financial interventions are crucial for addressing affordability in the short term and can be used to complement longer term measures that address the underlying structural issues of energy poverty. The review also found that Member States with a more vibrant retail energy market tend to have more measures relating to price comparison and transparent billing. In those Member States with a specific commitment to eradicate energy poverty, energy efficiency measures, particularly those focusing on building retrofit, are a key part of the overall strategy[59]. The majority of the Member States have set up measures to protect vulnerable consumers from disconnection, particularly in winter.

Affordable heating and cooling is crucial to maintain a good quality of life for European communities while preventing them from falling into poverty and suffering from the negative health impacts of inadequate heating and cooling. Thus, it is important to understand how policy changes which have an effect on the heating and cooling sector impact households' disposable income and their ability to keep their homes comfortably warm and cool, particularly for vulnerable consumers.

4.2. Heating and cooling technologies in industry

Heating and cooling technologies in industry are either cross cutting, used across many different sectors or sector specific, adapted to the needs of a specific production process and supplying heat in defined qualities and state, usually in the form of high or medium temperature, high pressure steam. Equipment for both cross cutting and sector specific technologies are usually tailor made to fit the parameters of an individual plant. Generic technologies include steam and process heating systems such as large boilers fuelled by gas, oil, coal or biomass. Large CHP is widely used in those sectors that use low and medium temperature heat, such as refineries and chemicals, pulp and paper, food and beverage. Industry uses more and more large heat pumps for low and medium temperature heat supply. Solar thermal is gaining ground. Furnaces and ovens are technologies widely used to generate high temperature heat, but they are of specific making depending on the sector. Industry is

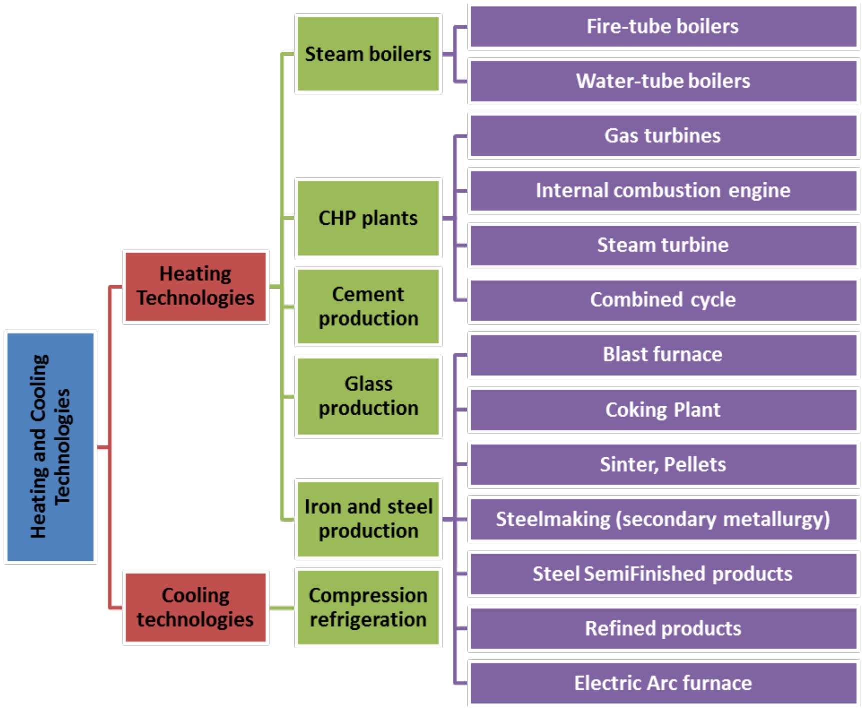
[58] Insight_E (2015) 'Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures'.

[59] Examples of these measures were grants, loans and other tax incentives for retrofitting buildings and other energy efficiency improvements in dwellings, grants to buy more energy efficient appliances and energy efficiency advice.

also supplied by district heating providing medium and low temperature process heat or space heating.

Despite the relevance of heating and cooling consumption in industry, little specific information is currently available on the technological structure of those end uses and on the energy demand for both industrial steam boilers and industrial furnaces in Europe. A set of data has been made available in the context of the corresponding Ecodesign preparatory studies on furnaces and steam boilers (DG ENTR Lots 4 & 7)[60]. Figure 4-3 includes the categorisation of the technology stock across industrial sectors, which was investigated by (Fraunhofer 2015). It includes both sector specific technologies (e.g. steelmaking) and those that can be employed across different sectors (steam boilers, CHP plants, etc.).

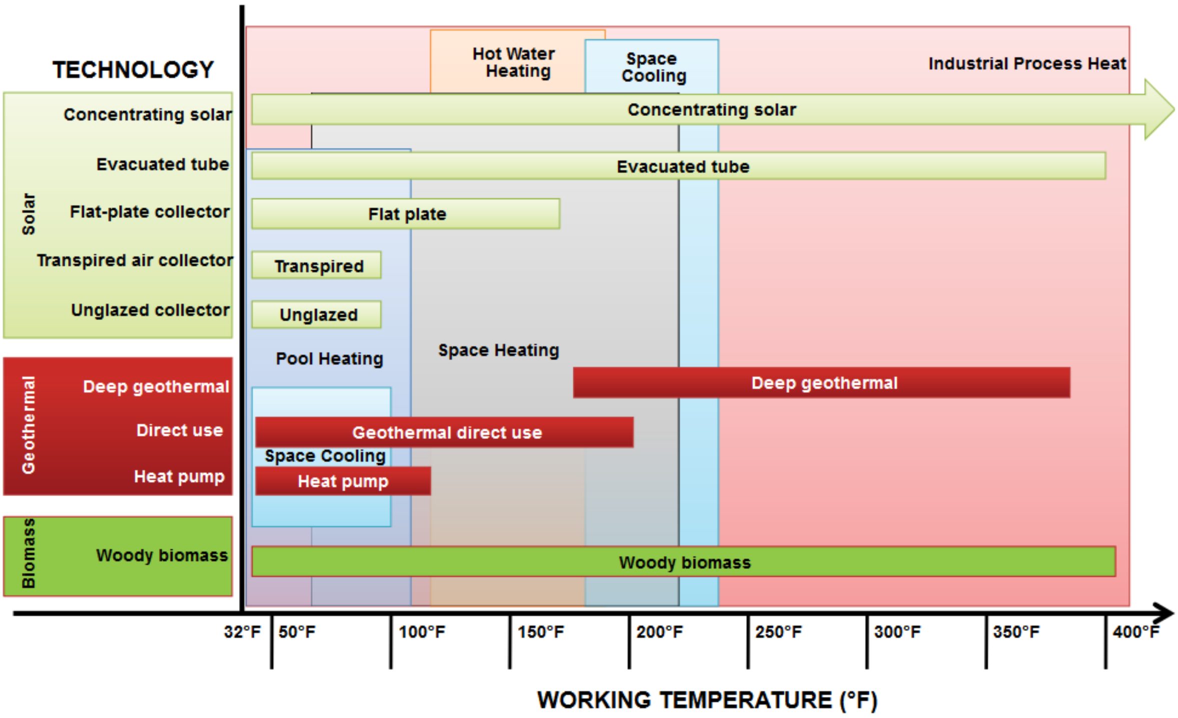
Figure 4-3: Industry technologies of the survey for heating and cooling application



The analysis of the process heating technologies is also important to understand the technical potential for a shift to renewable sources. To this end, the following figure provides an overview of the range of technologies based on renewable sources that can be employed in industrial processes, according to the process temperature output needed.

[60] See Ecodesign preparatory studies at: http://www.eup-network.de/product-groups/overview-ecodesign

Figure 4-4: Heating and cooling technologies used in industrial processes



Source: US EPA

The quality and range of data available for these technologies differ widely. As for the other technologies, there is a lack of data and there is currently no EU-wide source available that provides a detailed picture on the stock of CHP technologies used to provide heat in industrial processes.

In the following chapter, a short overview of the above-mentioned heating technologies is described based on the available data regarding cross-cutting technologies and those used in the cement, glass and steel industry. For other important industry sectors like chemical and petrochemical, paper, pulp and print the information available remains even more limited.

4.2.1 Heating technologies

Steam, which is generated by heating water beyond its boiling point, is one of the most important energy carriers in industry alongside electricity, gas and compressed air. Steam is broadly used in industry as a source of thermal energy, e.g. as an input for production processes in sectors, such as petroleum refining, chemical, iron and steel , pulp and paper, food and beverage, wood and wood products and textile.

Steam boilers

The steam boiler is a central part of a steam system. This term is used for a closed vessel in which water or other fluid is heated to generate steam. There are various types of steam boilers used in industry. Boilers based on water for steam generation are the most commonly used boilers. Steam boilers can be categorised in several ways. A typically used technical classification of these boilers is based on the way the water-steam medium is flowing through the boiler. Based on these distinctions, the two main types of boilers are fire-tube and water-tube boilers. In fire-tube boilers (or shell boilers) hot gases pass through the tubes. The boiler feeds water in the shell side which is converted into steam. Fire tube boilers are generally used for relatively small steam capacities and low to medium steam pressures. In water tube boilers, the boiler feed the water flows through the tubes and enters the boiler drum. The circulated water is mainly heated by the combustion gases and then converted into steam. These boilers are selected when the steam demand and the steam pressure requirements are high. A third, distinct category of boilers are superheated steam boilers which are used to produce steam above saturation temperature (often called superheaters). They produce steam of much higher temperature, leading to an increased overall efficiency of both steam generation and its utilisation, but require special care to ensure that no system component of the superheater fails, due to the risks associated to the losses of the superheated steam. Depending on the dominant heat transfer mechanism, superheaters can be of the radiant or convection type, or a combination of the two.

Several more specific technical classifications are also possible, but for the purpose of this analysis it is important to make a distinction based on the energy carrier used. Boilers can be operated on gas, coal, oil, electricity, biomass, solar thermal and from heat rejected from other processes such as gas turbines (heat recovery steam generators).

It should be noted that there are hardly any reliable and detailed data on the technological stock, energy demand, energy efficiency measures and fuel switch options for steam systems. The figures given below can only provide some indications of the current status of steam boilers/steam systems. Improving the availability of primary data on steam systems and collecting relevant data would be hugely beneficial to be able to conduct more reliable analyses and projections with regard to the type and amount of energy consumed by steam systems.

Figure 4-5 illustrates the stock of steam boilers in the EU-28[SIN]. It shows that steam boilers fired with natural gas are the most common ones, representing 70 % of the stock. In Sweden, biomass fired steam boilers are the most diffused (up to 50 %). Germany, Italy, UK and France are the countries with the highest number of steam boilers units installed.

Figure 4-5: Seam boiler units in the EU-28[SIN] in 2012

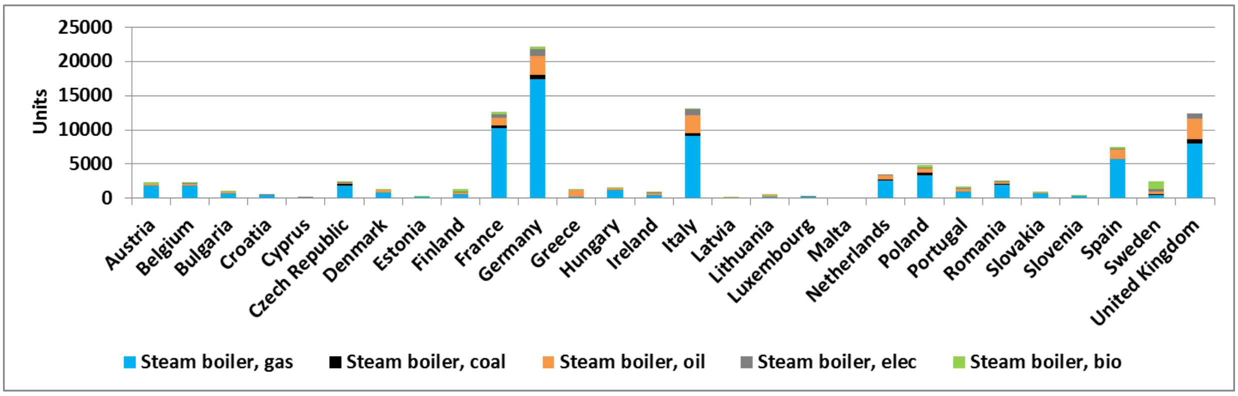


Figure 4-6: Steam boilers, number of units and installed capacity in EU-28 in 2012

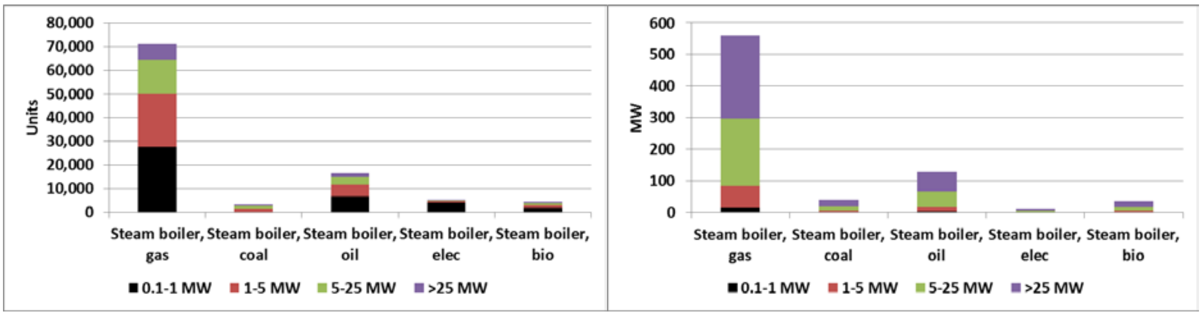


Figure 4-6 shows the number and total installed capacity of steam boilers categorised according to the fuel used and the capacity range of the unit, which could vary from 0,1 MW up to more than 25 MW. Most of the units are boilers with a capacity from 0.1 to 1 MW_{th} but their total installed capacity is negligible. This means that the number of units in the higher capacity range is smaller compared to the lower capacity range, but their total installed capacity is much higher.

The generation of steam (100-500°C) consumed about 720 TWh in 2012 in the EU-28 (22 % of the total final energy (TFE) demand in industry). Given the high share this represent on final energy consumption in industry for heating, steam boilers offer a significant opportunity to improve the deployment of renewable energies as well as the energy efficiency of steam systems.

The above figures show that there is a small number of steam boilers with a high capacity (>25MW), which indicates that these systems were developed for specific companies (custom manufacturing), therefore, a generalisation might be difficult. However, this small number of units still represents a significant installed capacity, for which efficiency improvements might results in considerable savings, while the shift to renewable energy might be more relevant for lower capacities, depending on the level of market maturity of renewable technologies.

The thermal efficiency of the steam boilers is used to describe the efficiency of the generation system, *i.e.* the thermal output of the steam boiler divided by the energy input required for its operation. The thermal efficiencies of steam boilers generally depend on factors such as the type, size, age and primary function of the boiler, the supplied steam pressure level, and the supplied fuel, etc. Efficiency data are limited, and the main source for them is the Ecodesign preparatory study for steam boilers[61]. Apart from the boilers, the efficiency of the system also depends on steam distribution. Steam distribution systems are very heterogeneous and their efficiency is influenced by many factors such as the size of the system, its layout, the connected end-uses, pressure and temperature levels or the piping material, its length, diameter and insulation. Representative information for these parameters and their actual impacts on a distribution system's efficiency is generally not available and also very difficult to generate due to technological heterogeneity. In general, several energy efficiency improvements are possible both in the generation and distribution systems. The table below summarises them based on a classification used in the US Industrial Assessment Centres' (IACs) database[62].

[61] Ecodesign preparatory study on steam boilers (ENTR Lot 7) available at http://www.eco-steamboilers.eu/eco-steamboilers-wAssets/docs/20141217-Steam-Boilers-Ecodesign-Final-Report.pdf.
[62] The IAC energy efficiency recommendations are available at: https://iac.university/searchRecommendations.

Table 4-2: Examples of energy-efficiency measures for steam systems (excluding end-uses)

	Organisational measure (incl. maintenance)	Technological add-on	Technological replacement
Generation	Keep boiler tubes clean Move boiler to more efficient location Operate boilers on high fire setting Reduce excessive boiler blowdown Use minimum steam operating pressure Analyze flue gas for proper air/fuel ratio Establish burner maintenance schedule for boilers Repair faulty insulation in furnaces, boilers etc.	Install turbulator Direct warmest air to combustion intake Minimise boiler blowdown with better feedwater treatment Use heat from boiler blowdown to preheat boiler feedwater Flue gas to preheat feedwater Preheat combustion air with waste heat Waste heat from hot flue gases to preheat combustion air Install waste heat boiler to produce steam Use waste heat from hot flue gases to generate steam Substitute air for steam to atomise oil	Replace obsolete burners with more efficient ones Replace boiler Install smaller boiler
Distribution/ recovery	Repair/replace steam trap Turn off steam tracing during mild weather Close off unneeded steam lines Use correct size steam traps Shut off steam traps on superheated steam lines not in use Increase amount of condensate returned Lower operating pressure of condenser (steam) Eliminate leaks in high pressure reduction stations	Install steam traps Install/repair insulation on condensate lines Insulate feedwater tank Install deaerator in place of condensate tank Flash condensate to produce lower pressure steam Waste process heat to preheat makeup water Use steam condensate for hot water supply (non-potable)	-
Overall system	Repair faulty insulation Repair leaks in lines and valves Repair and eliminate steam leaks Reduce excess steam bleeding	Insulate steam/hot water lines Substitute hot process fluids for steam Use heat exchange fluids instead of steam in pipeline tracing systems	-

Source: Rohde et al. 2014

CHP plants

Combined heat and power (CHP) describes technologies used to generate electricity and useful heat in a single process based on primary energy inputs. It is also known as cogeneration. The use of waste heat from electricity generation substantially increases the overall efficiency of the process compared to that of electricity-only generation, although depending on the amount of the extracted useful heat, electrical efficiencies may be reduced. CHP plants generally convert 75 – 80% of the primary energy into useful energy, while the most modern CHP plants reach efficiencies of 90% or more (IPCC 2007). In terms of primary energy and CO_2 emissions, the combined process is more efficient than individual heat and electricity generation and savings of around 20% can typically be achieved – depending on the individual plants and the reference case.

Cogeneration technology is used for various types of applications, in all sectors, in small and large capacities as well as with different fuel types. Currently, natural gas is the predominant fuel used, with a share of 47%, while the share of other fossil fuels, such as oil and coal have been decreasing over the last decade by 60% and 14%, respectively bringing down coal to 20% and oil to 5% 2012[63].

Renewable CHP is the most dynamically growing CHP sector, currently standing at 16% mainly based on biomass. Since 2005, the year after the entry into force of the first EU legislation on the promotion of cogeneration[64], the use of biomass in CHP has grown by 81%; while the use of biogas and liquid biofuels increased sevenfold, by 609% and 583%, respectively, although from a small base. New emerging technologies provide a good opportunity to introduce other renewable energy sources, such as biogas and biofuels, solar and geothermal CHP and anaerobic digestion CHP. In addition, CHP can be used to recover the useful heat content of nuclear power generation and waste incineration, including municipal and industrial waste (both renewable and non-renewable). These latter categories have also been growing in the last ten years. The incineration of renewable municipal waste through cogeneration increased by 96% and the non-renewable municipal waste's use as fuel increased by 62% since 2005. Industrial waste based CHP has also grown by 4%. The major share of cogeneration plants are found in industry, district heating and in small commercial or residential applications (Ricardo-AEA 2015).

CHP can apply a very wide set of fuels and supply options. The main ones are described below.

Biomass CHP
Biomass-fired CHP plants have capacities ranging from a few MWe up to 350MWe. Small and medium-size CHP plants are usually sourced with locally available biomass. State-of-the-art biomass plants can achieve high-performance steam parameters and electrical efficiencies above 37% (net output). Biomass-fired CHP plants are based on mature technologies with increasing generation efficiencies, while other technologies such as biomass integrated gasification combined cycles (BIGCC), which offer high technical and economic performance, are currently in the process of entering the market, following the industrial demonstration phase.

Bioliquid CHP
Conventional biofuels (commonly referred to as first generation biofuels) include sugar- and starch-based ethanol, oil crop-based biodiesel, and straight vegetable oil, as well as biogas derived through anaerobic digestion. Advanced biofuels are conversion technologies that are still in the R&D, pilot or demonstration phase. This category includes hydro-treated vegetable oil, which is based on animal fat and plant oil, as well as biofuels based on lignocellulose biomass, such as cellulosic-ethanol, biomass-to-liquids-diesel and bio-synthetic gas. Furthermore, novel technologies such as algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts are included. Advanced

[63] Background report to the review of the CHP reference values, Ricardo-AEA, 2015, ENER/C3/2013-424/SI2.682977.
[64] Directive 2004/8/EC on the promotion of cogeneration in the EU internal energy market; repealed by the Energy Efficiency Directive (2010/27/EU) as of 5 June 2014.

biofuels, produced from lignocellulose biomass, algae and other innovative feed stocks, have progressed more slowly than expected in recent years.

Anaerobic digestion CHP

Anaerobic Digestion (AD) in combination with a CHP plant is being increasingly applied throughout Europe. The digesters in AD plants and the pasteurisation tanks require maintaining at elevated temperatures. This heat demand can be satisfied by CHP plants (internal combustion engines) operating on biogas from the AD plant. Thermal efficiencies of AD CHP plants can be around 55% with overall efficiency of more than 85%, when all the heat produced can be effectively utilized.

Nuclear CHP

District heating from nuclear power plants is common in some Eastern European countries including Hungary, Slovakia and Bulgaria. Nuclear power plants have the potential to also deliver industrial process heat as in Switzerland[65].

Solar thermal CHP

Concentrating solar CHP systems concentrate the solar radiation to generate steam which is used to generate power and heat. The solar energy falling on the concentrator dish is focused on the hot end of a Stirling generator (if present) and is converted, through the Stirling energy cycle, into electricity. The excess heat from the Stirling cycle - rather than being rejected to the air through a closed loop cooling system – can be captured for water and air heating. It is expected that solar CHP will increase in the coming years.

Geothermal CHP

Geothermal resources (which mainly constitute low-grade heat) have long been used for direct heating applications (e.g. district heating, industrial processing, domestic hot water, space heating, etc.). However, some high-grade heat (e.g. high-temperature natural steam at less than 2-km depth, mainly available in areas with volcanic activity), has also been used for power generation.

In 2008, with a global capacity in operation of approximately 9 GWe (out of a total installed capacity of about 10 GWe), geothermal power plants generated approximately 60 TWh, which represents around 0.25% of the global electricity generation. Geothermal heating plants produced around 63 TWh of heat, with an installed capacity of approximately 18 GWth.

In geothermal CHP, heat passes through a turbine (e.g. Organic Rankine Cycle, ORC) generating power and heat. Geothermal CHP using ORC technology and a low-temperature boiling process fluid is cost effective if the demand for heat is sufficiently high (e.g. in district heating). In general, CHP plants are economically viable and largely used in (Northern) Europe where heating demand is significant and constant over the year.

CHP technologies in industrial sectors provide heat and steam below 500°C. These plants are often large systems (several MW_{th}) typically using gas and steam turbines. The main sectors where CHP is installed are refineries, chemical, pulp and paper, food and beverage industries.

[65] http://setis.ec.europa.eu/system/files/4.Efficiencyofheatandelectricityproductiontechnologies.pdf

The ratio of electricity to heat produced varies *inter alia* by type of technology. Typical power to heat ratios range from 0.45 (Steam turbines), 0.55 (gas turbines) to 0.95 (Combined cycle gas turbines) or even above 1.00 (European Commission 2009). They can, however, vary substantially depending on the operation mode. Observed real-life power-to-heat ratios can be different. For the UK, very comprehensive data is available on the overall stock of CHP installations from the Department of Energy and Climate Change (2015). Accordingly, power-to-heat ratios range from 0.2 for steam backpressure turbines to 0.45 for gas turbines, 0.51 for combined cycle technology and 0.68 for internal combustion engines. In the UK, the average power to heat ratio was 0.48 across all technologies in 2012.

CHP plants can be constructed to use more than one fuel in order to allow flexible reactions to changing fuel prices. Gas turbines require a gaseous fuel, typically natural gas, whereas steam turbines can also operate on coal, oil or waste materials, which are typically cheaper than natural gas. In terms of renewable energy sources (RES) for CHP fuelling, biogas or solid biomass are the most common choices. Biogas-fired CHP plants typically have smaller capacities, of between 50 kW and a few MW. In smaller units, internal combustion engines are the dominant technology, while for larger units gas turbines are used. CHP plants fired with solid biomass are larger, with capacities ranging from a few MW to several hundreds of MW. Biomass CHP plants based on steam turbines can be considered a mature technology, while combined cycle CHP plants with integrated gasification of biomass are only just entering the market (IEA ETSAP Biomass 2010).

Co-firing of biomass in fossil fuel fired CHP plants can be a cheap option in the short term to increase the use of RES without large investments (IEA-ETSAP, IRENA 2013). In this case, biomass is fed, together with coal, into the boiler of a steam turbine. The IEA estimates that this costs several hundred Euros per kW of installed electrical capacity, which is low compared to investments in new biomass-fired CHP plants (IEA-ETSAP, IRENA 2013). However, co-firing rates are often below 5%, although they can technically reach 20% or more.

CHP plants can be distinguished between those using gas turbines, steam turbines, combined cycles (gas and steam turbines) and reciprocating engines. Gas turbines require a gaseous fuel whereas steam turbines can also operate on coal, oil or waste materials.

Figure 4-7 shows the number of installed CHP units employed in industry in EU-28[SIN]. Spain stands out as the country with the highest number of units, followed by United Kingdom and Portugal, where most of the installed CHPs are reciprocating engines, whereas in Germany, France, Poland and other countries steam turbines are more diffused.

Figure 1-7: Numbers of installed CHP in EU-28^SIN in 2012

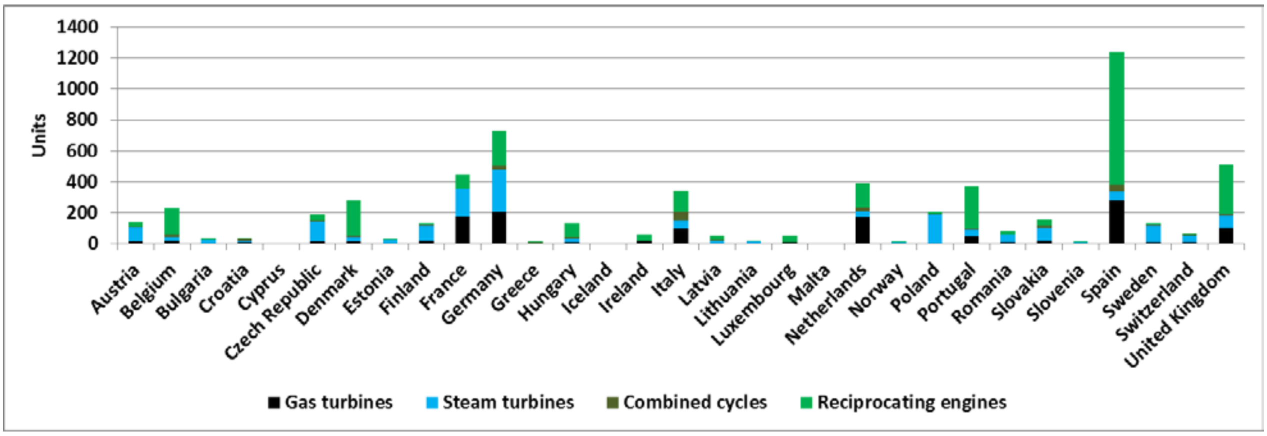


Figure 4-8: Installed CHP units according their capacity and age in EU-28^SIN in 2012

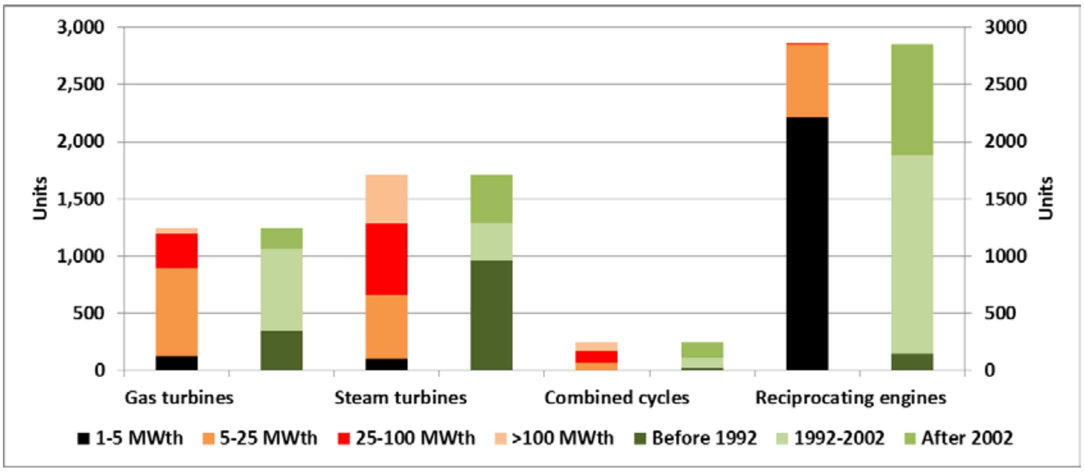
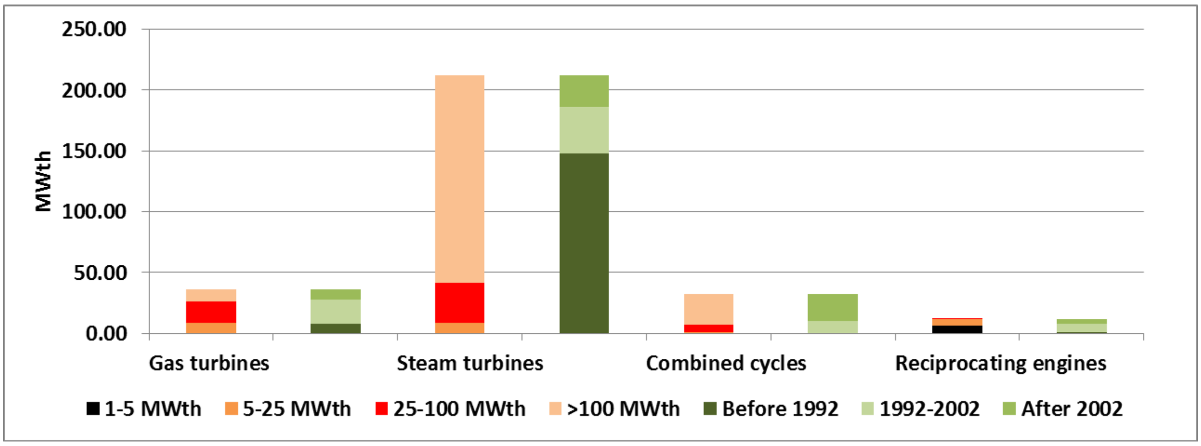


Figure 4-8 shows that reciprocating engines (CHP_{RE}) are mostly used for the lower capacity range. The large majority of the CHP_{RE} were small units constructed after 1992 . In contrast to these numbers, the installed CHP steam turbines (CHP_{ST}) have mainly been constructed before 1992 and are used for a higher capacity range. Most of the CHP gas turbines (CHP_{GT}) were constructed after 1992 and like CHP_{ST} the units were used mostly for capacity ranges over 5 MW_{th}. CHP combined cycles (CHP_{CC}) are not so common than the other CHP kinds. Similar to CHP_{RE} and CHP_{GT}, these units have mostly been installed after 1992.

Depending on the lifetime of such applications, CHP_{ST} and CHP_{GT} could be of interest in relation to increasing energy efficiency because nearly 50 % of these units were constructed before 1992 and might need to be replaced in the next 10 years, since their operation lifetime has already exceeded 20 years. However, accurate values about the average lifetime of such applications are not available.

Figure 4-9: Installed capacity of CHP units in EU-28^{SIN} in 2012



Figure

Figure 4-9 shows the installed capacity of CHP units. The highest total installed capacity belongs to CHP_{ST} with a capacity per unit of above 100 MW_{th}. Similar to steam boilers, the smallest number of CHP, which includes the units with highest capacity can contribute mostly to the energy demand depending on their operation time per year. Furthermore, the units with the highest total installed capacity were mainly constructed before 1992.

The number of other (new) CHP technologies like Stirling engines, fuel cells, ORC is small (around 100 units) and their capacity range is below 25 MW_{th}. Most of the units were installed after 2002 and are located in Germany, Austria and Italy.

Industrial furnaces in cement production

Cement is produced following different steps and starting from different feedstock of limestone, clay and sand, which provide the four key necessary ingredients: lime, silica, alumina and iron. The material is crushed, homogenised, preheated, precalcined and then the clinkers are produced using temperatures of up to 1,450°C. After cooling, the clinker is blended with other mineral components and grinded.

Cement manufacturing requires both thermal energy and electrical energy, which represents around 10% of the total energy needed. Most of the energy is consumed in the production of clinker from limestone and chalk. The most important factors determining the thermal energy demand are the chemical and mineralogical characteristics of the raw materials (e.g. moisture content, chemical composition, raw material types, burnability), the production capacity of the plant, the technical status of the plant, the used fuel and the type of kiln operation.

There are two basic types of cement production processes, which depend on the water content of the raw material feedstock. The ‘wet’ process allows easier control of the chemistry and is better when moist raw feedstock are available, but it consumes more energy to evaporate the 30 % plus slurry water before heating the raw materials to the necessary temperature for calcination. In contrast, the ‘dry’ process is more efficient.[66]

Most of the facilities use the dry production process (Figure 4-10). The highest number of installation exists in Italy, followed by Spain, Germany and France. Spain is the country with the highest installed production capacity, which reaches nearly 45 Mt/a (*Figure*).

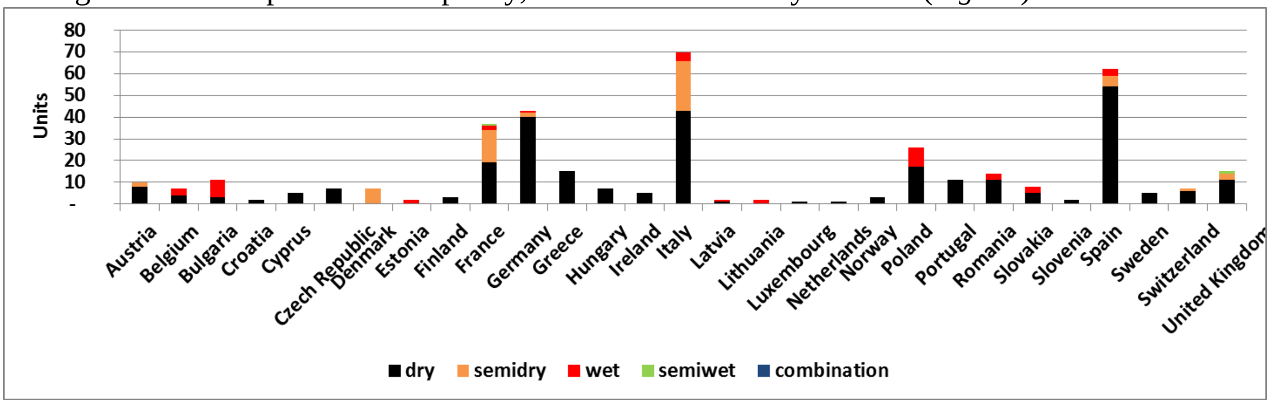


Figure 4-10: Cement production units in the EU-28[SIN] in 2012

[66] Fraunhofer 2015

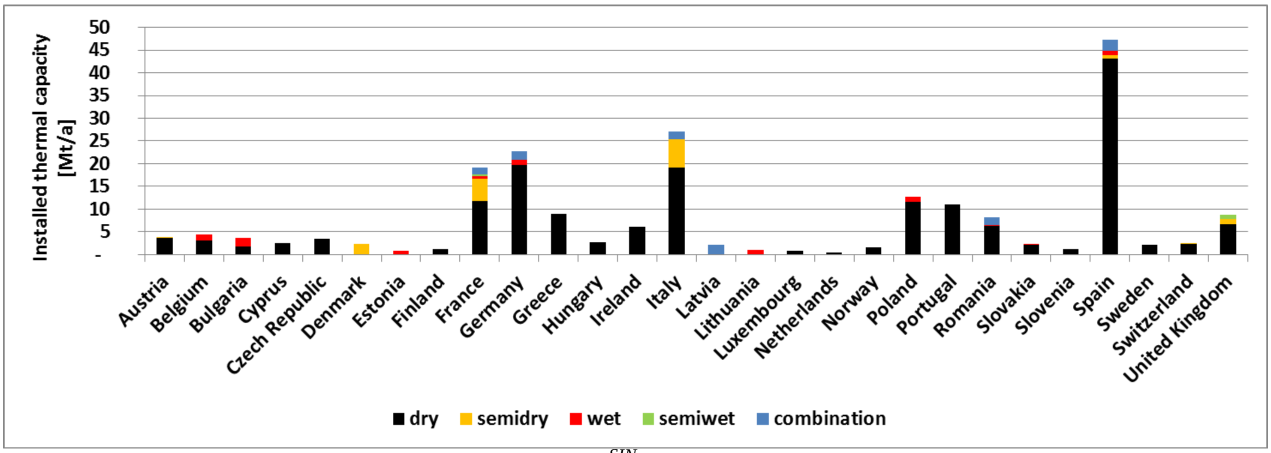


Figure 4-11: Cement production capacity in EU-28[SIN] in 2012

Since 1990, cement companies started to increase the share of alternative fuels in power and heat generation like biomass or waste products (tyres, wood, plastics, chemicals, treated municipal solid waste). For example, Germany and Austria increased the share of waste and biomass from around 10% in 1990 to 50% in 2006. Some individual plants have achieved nearly 100 % substitution using alternative fuels.

The lifetime of cement kilns is usually 30 to 50 years, but the original equipment is replaced after 20 to 30 years and is always adapted to modern technologies. Huge retrofits, like changing from wet to dry processes, can result in a substantial increase in energy efficiency. At the same time, smaller but still significant improvements are possible by using the best available technology, or by improvements in raw mix burnability, waste heat recovery, oxygen enrichment technologies, increasing the cyclone stages etc.

The use of alternative fuels in the cement industry is a long-established practice in many countries. It offers the opportunity to reduce production costs and fossil fuel use, to dispose of waste and increase the use of renewable sources. Where fossil fuels are replaced with alternative fuels such as waste products that would otherwise have been incinerated or land filled, CO_2 emissions can be reduced. Cement kilns are well suited for waste combustion because of their high process temperature and because the clinker product and limestone feedstock act as gas cleaning agents. Used tyres, wood, plastics, chemicals, treated municipal solid waste and other types of waste are co-combusted in cement kilns in large quantities (IEA, 2009).

European cement manufacturers derived 3% of their energy needs from waste fuels in 1990 and 15% in 2005. Cement producers in Austria, Belgium the Czech Republic, France, Germany, and the Netherlands have reached substitution rates of between, 7% and more than 43% of the total energy used in this time horizon. Some individual plants have achieved nearly 100% substitution using alternative fuels. Where alternative fuels are used at high substitution rates, tailored pre-treatment and surveillance systems are needed. In Europe, the burning of alternative fuels in cement kilns is covered by Directive 2000/76/EC of the European Parliament and Council (IEA 2009).

Glass production

Due to the high temperature needed in the melting process, glass production is energy intense. Natural gas and fuel oil are primarily used to provide sufficient heat for the process. Due to the decomposition of some of the ingredients the process of glass production emits CO_2 in addition to that caused by the burning of the fuels.

Glass and glass products are used in various forms and applications and are produced by melting raw materials (mostly silicon oxide) and casting it into the desired form. The products of the glass sector can be divided into: container glass for beverages and other liquids, flat glass for windows or windscreens, glass fibre (e.g. reinforcement of plastics) and glass used in other forms.

Pure quartz-sand requires temperatures above 2,000°C to be processed into glass. Therefore, the furnace is the main consumer of heat in the glass production process. After melting the raw material, fining and conditioning is necessary to get a homogenous mass and to ensure that the trapped gas is eliminated. After cooling and conditioning, the molten glass is processed into the desired product. An important step is the controlled cooling of the products, since uncontrolled (fast) cooling leads to tensions within the product, making it vulnerable to external force.

Figure 4-12: Glass melting units in EU-28^{SIN} in 2014

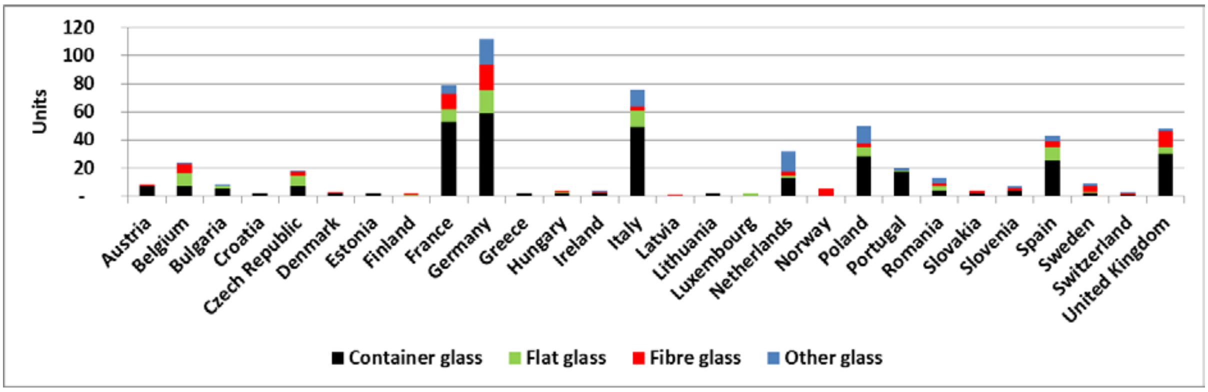
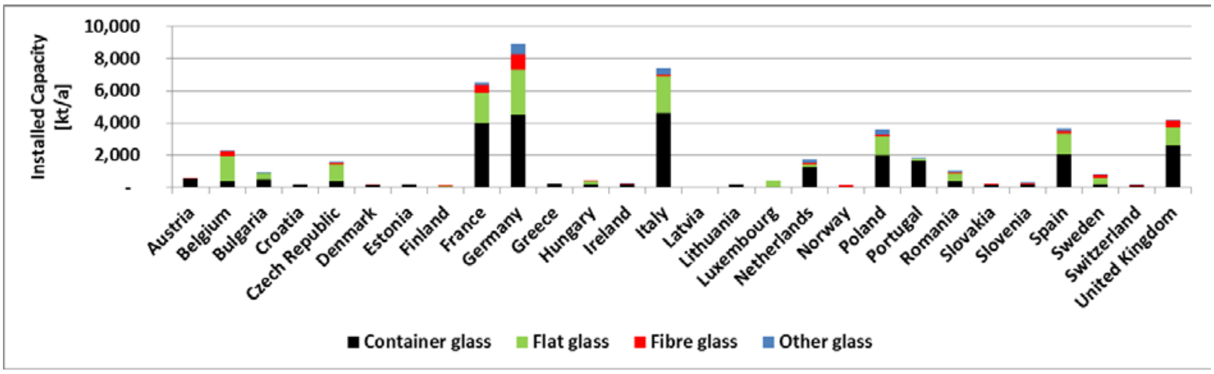


Figure 4-13: Installed capacity of glass production units in EU-28[SIN] in 2014



Nearly every European country has some glass furnace plants, but the majority of the installed capacity is in Germany, France, Italy, UK, Poland and Spain (Figure 4-12, Figure 4-13).

The aging of the furnace also contributes to higher energy demand. It is stated that the energy demand per tonne of melted glass increases by about 1.5% to 3% (IPPC 2010; p. 114) with every year. This leads up to 20% higher energy demand per tonne of melted glass by the end of the furnace campaign (IPPC 2010; p.93).

There are four main types of furnaces: regenerative, recuperative, oxy-fuel and electric melting furnaces. Regenerative furnaces are the most common furnaces and there are two main configurations: cross-fired (side-port) or end-fired (end-port). End-fired regenerative furnaces have a 10 % higher efficiency but they are adapted only to medium to small sized capacities. The difference between these two types is the configuration of the burners and ports which heat the material.[67] Recuperative furnaces use a continuously working heat exchanger to transfer the heat from the exhaust gases to the incoming air. Due to the material of the heat exchanger, the pre-heated air is limited to approximately 800°C. Recuperative furnaces are less energy efficient than regenerative furnaces, have less capacity and therefore, they are not very common.[68]

The theoretical minimum energy efficiency demand for melted glass is assumed to be between 2.1 and 3.24 GJ/t_{glass}. This value is depending on different variables (e.g. the type of furnace installed), which defines the energy efficiency of the process. The quality of the product has also an impact on the energy consumption as well as the age of the furnace, the mixture of raw material with cullet, the recovered heat and the insulation of the furnace. Modern regenerative furnaces have an overall thermal efficiency of about 50%, with waste gas heat losses in the range of 25% to 35%. These gas losses can be reduced to 14% to 20%

[67] Regenerative furnaces can reach a thermal energy efficiency of up to 65%. Energy savings are correlated with the preheated combustion gas temperature. For example, with a combustion air temperature of 800ºC, energy saving of 35% can be achieved. Institute for Industrial Productivity, Industry Efficiency Technology Database, Washington U.S.A.: http://ietd.iipnetwork.org/content/regenerative-furnaces.

[68] The burner of oxy-fuel furnaces uses gas with 90% oxygen. This leads to a higher efficiency because the atmospheric nitrogen is not carried through the process and is not heated. The disadvantage is the needed energy to produce the oxygen gas. A container glass manufacturer in Germany was able to reduce energy consumption from 5.02 GJ/t_{glass} to 3.02 GJ/t_{glass} (including energy consumption for oxygen generation) and to realise energy savings of 35 % by installing an oxy-fuel furnace with preheater. For electric melting the raw material must be heated, mainly by fossil fuels, until the glass comes molten and the conductivity increases that allows resistant heating. Thermal efficiency of electric furnaces are 2 to 4 times better than air-fuel-fired furnaces. Institute for Industrial Productivity, Industry Efficiency Technology Database, Washington U.S.A.: http://ietd.iipnetwork.org/content/electric-melting.

when using cullet and raw-material pre-heating. In comparison, recuperative furnaces only reach a thermal efficiency of 20% to 30% without further heat recovery.[69]

Figure 4-14: Share of capacity of the respective technologies in EU-28[SIN]

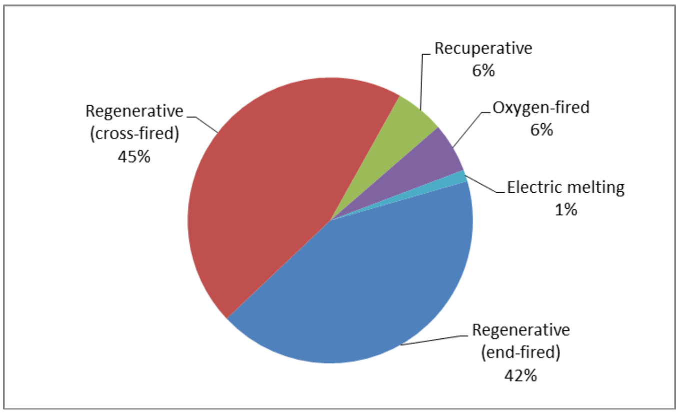


Figure 4-14 illustrates the share of regenerative furnaces for the two main glass manufacturing sectors (container glass and flat glass). Glass fibre production and other glasses types rely on more diverse technologies.

Conventional furnaces rely on mineral oil or natural gas as their primary heat source. An exception can be made for the electric melting furnaces. Natural gas use is increasing because of its ease of control, high purity, economy, lower storage requirements and lower sulphur dioxide emissions. The main advantage associated with mineral oil is a better heat transfer for the melting process due to more radiant flames (IPPC 2010; p. 46). The use of biogas is still limited and subject to research and demonstration.

As for the use of waste heat, the amount of heat leaving the furnace with the flue gas depends on the installed air pre-heating system. The waste gas has temperatures between 300° C and 600° C on leaving the pre-heater. The heat in the waste gas can then either be utilised to produce steam or to pre-heat the raw materials. The BREF on glass states that the first option is no longer economically feasible, since the air pre-heating systems generate too little heat for economical operation of the boilers (IPPC 2010; p. 316).

Iron and steel production

The European iron and steel market can be divided into primary production based on iron ore (accounts for ca. 60%) and secondary production based on scrap (accounts for ca. 40%). The primary steel production can be described in six steps: coke production, sinter production, iron production (blast furnace), steel production (basic oxygen furnace), semi-finished product preparation and finished product preparation.

A necessary product for iron production is coke which is produced out of high-grade hard coal by pyrolysis. The energy demand is estimated to be between 2.5 GJ/t_{coke} to 3.2 GJ/t_{coke}. Another material is an agglomerated product which needs a sinter process that converts raw materials (e.g. iron ore, coke, limestone, etc.) into a suitable size for further processing. The specific energy consumption is estimated to reach on average 1.8 GJ/t_{sinter}. For the next step of iron production, the sinter product is melted in blast furnaces by using coke or coal as reducing agents and hot air. Iron oxides, coke and fluxes react with the blast air to form

[69] Fraunhofer (2015).

molten reduced iron, carbon monoxide (CO), and slag. The net energy consumption in blast furnaces was estimated to reach 12.2 GJ/$t_{hot\ metal}$ in 2010 in Germany, making the blast furnace
the most energy intensive process within the iron and steel sector. A by-product of the blast furnace is blast furnace gas (top gas) that is used within the steel sector for the heating of hot stoves, in reheating furnaces in the process of rolling or to be fed to onsite power plants for the production of electricity. The net energy consumption could be reduced to 11.6 GJ/$t_{hot\ metal}$ to 12.3 GJ/$t_{hot\ metal}$, by using the best available technologies but further energy reduction potential is limited.[70]

Another possibility for iron production is electric arc melting using recycled iron and steel scrap. The final energy consumption of electric arc furnaces could reach only about 30% of that of primary steelmaking and depends on the input material and the technology used. After the melting process, sulphur in the molten metal is eventually reduced before charging into the steelmaking furnace by adding reagents. The secondary metallurgy process uses a basic oxygen furnace for further treatment of the molten metal (e.g. alloying, remelting, degassing) to achieve homogenous chemical composition and special properties. Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities. Most furnaces are equipped with oxygen lances to speed up melting and refining. The energy consumption for heating processes depends on the reheating of the metal and production of oxygen. The last step is the production of semi-finished of finished products; this includes wires, bars, plates or structural shapes (e.g. rails, tubes, etc.) which can be coated, annealed or pickled.

Most of the countries in EU-28^{SIN} have one or more units in the iron and steel sector with an installed capacity of more than 1,000 kt (

[70] Fraunhofer (2015).

Figure , *Figure*). Figure 4-17 shows the installed capacity on EU-28^{SIN} level[71]. Depending on the country, some sub-sectors are more important than others. For example, Poland has the highest installed capacity of coking plants and Italy of electric arc furnaces in the EU-28^{SIN}. Big producers with a high installed capacity for semi-/finished steel products are Germany, followed by Italy, France and Spain. Bulgaria, Croatia, Greece, Luxembourg and Slovenia have only electric arc furnaces and some post processing plants. Denmark and Latvia have only some post processing plants without iron and steel production furnaces. As for blast furnaces, operations exist in about half of the EU28 countries. Germany, France, the United Kingdom and the Netherlands account for 60% of the installed nominal capacity of 106 Mthm/a in 63 plants. Overall capacity utilisation is about 88% (Worldsteel Association 2013). 70% of the total operating blast furnace capacity is older than 35 years. Assuming a normal technical lifetime of about 45 to 50 years, this part of the installed capacity would be at the end of its life cycle in 2025.

[71] The installed capacity reflects the ratio for 1 tonne of iron production (blast furnaces) for which 1.4 tonne of sinter products (sinter and pellet plants) and 0.5 tonnes of coke (coking plants) are necessary. In 2014 in the EU-28, 91.3m tonnes of steel scrap were used for steelmaking and 169.3m tonnes of crude steel were produced. Furthermore, EU-28 imports 3.1m tonnes of steel scrap but also exports 16.9m tonnes (including around 0.4m tonnes to Switzerland). Bureau of International Recycling, Ferrous Division (2015): "WORLD STEEL RECYCLING IN FIGURES 2010 – 2014; Steel Scrap – a Raw Material for Steelmaking: http://bdsv.org/downloads/weltstatistik_2010_2014.pdf

Figure 4-15: Iron and steel producing units in the EU-28^{SIN} in 2014

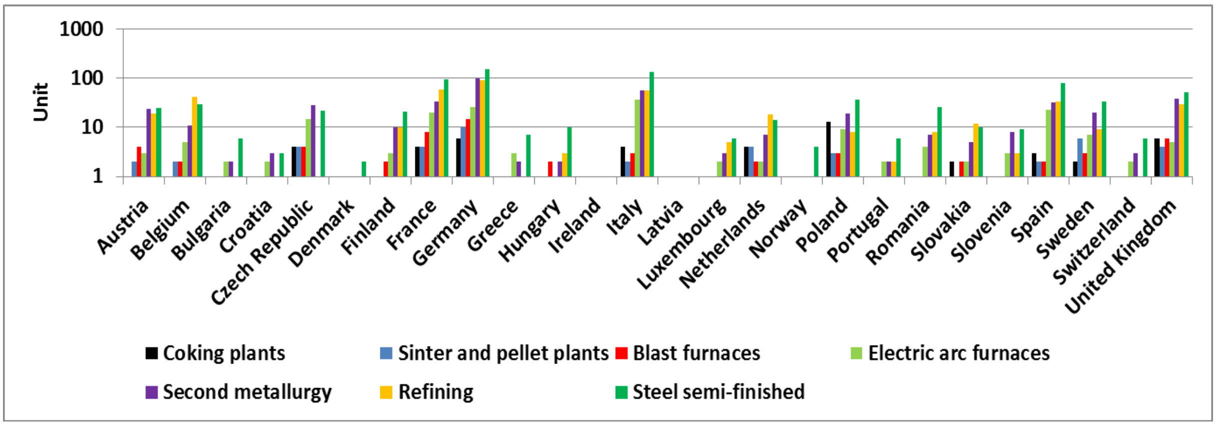


Figure 4-16: Installed capacity of iron and steel producing units in EU-28^{SIN} in 2014

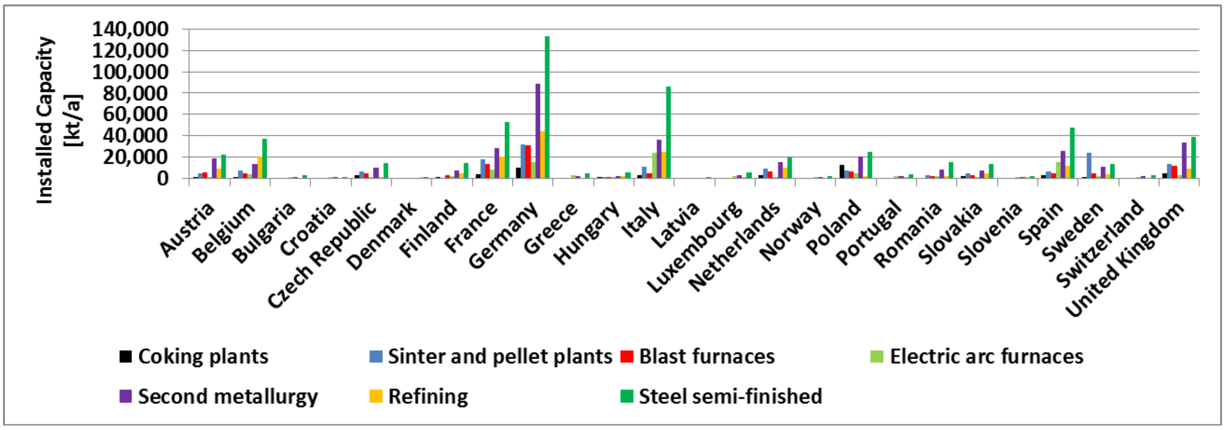
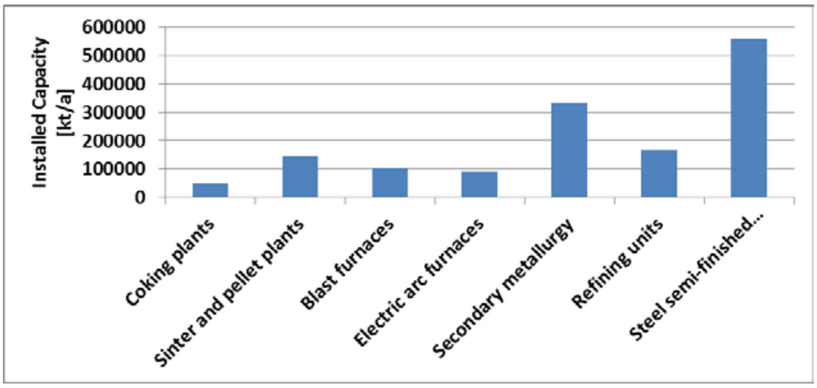


Figure 4-17: Installed capacity in EU-28^{SIN} of the different iron and steel processing units in 2014



4.2.2. Energy efficiency opportunities in industry and services

Various studies have looked at the technical potential for improvement of energy consumption in industry. JRC (2012) reports that, as for the chemical and petrochemical industry, at global level, the improvement margin of energy consumption is of 30 %. This improvement is split in a 15 % which comes from the full implementation of best practice technologies and the additional 15 % could be achieved with measures such as process intensification, process integration, greater use of combined heat and power (CHP) and life time optimisation by recycling and energy recovery from post-consumer plastic waste.

For Pulp and Paper, the expected improvement in energy consumption and emissions is roughly estimated at about 25 % by 2050, achievable through the deployment of best available technologies from now to 2050 (JRC-IE 2010).

Another significant driver is the diffusion of best available technologies. The full alignment of all plants to the best performers could result in an increase of about 10 % to 15 % of the global efficiency (in next 15 years) (JRC-IE 2010). Additional incremental improvements are also expected due to learning effects and R&D that can result in a 2 % to 5 % efficiency gains with respect to the current best available plant. All these progresses will be driven by energy integration and optimisation, and by the recovery of waste heat, including low temperature heat.

Regarding the ceramics materials, the alignment of the kilns with best practices could decrease the energy consumption in bricks and roof titles from 2.3 GJ/t to 1.7 GJ/t (Ecofys and JRC-IPTS, 2009). The specific energy consumption within reach using latest kilns in the wall and floor tiles and in refractory products are 4 GJ/t and 4.7 GJ/t (Ecofys and JRC-IPTS, 2009). The main driver for the decrease of the energy consumption of the non-ferrous metal industry is the increased use of the recycling route. It can be expected that by 2030, the overall production from the recycling route will be around 60 %, up from 40 % in 2000 (European Commission 2007).

Based on a bottom-up modelling approach ICF has evaluated the savings potentials in 8 energy intensive sectors. The modelling included more than 230 energy saving measures, of which some 100 related to heat. Around half of these measures are horizontal, i.e. can be used in the 8 sectors, and half are related to processes that are specific to a sector. Measures include integrated control systems, exhaust gas and low temperature heat recovery, sub-metering and interval metering, high-efficiency burners, flue gas monitoring, optimisation of kiln efficiency and combustion, materials substitution[72]. ICF identified three types of potentials – “technical” (the amount of savings that can be achieved if the energy efficiency measures are implemented by companies regardless of whether they are economic); “economic 1”; and “economic 2”, taking into account only those measures that have a pay-back time of less than 2 years and less than 5 years, respectively. The study found that realising the maximum technical potential in the 8 energy intensive sectors would lead to around 20% of demand reduction compared to a Business-as-Usual scenario, while the economic 1 and 2 scenarios would result in 4-5% energy savings by 2030 and 8-10% by 2050.

The biggest energy efficiency improvement areas in most industries, including SMEs, consist of innovative and efficient technologies, process intensification, and the integration of renewables.

Energy efficiency improvements for heating and cooling in energy-intensive industries can be achieved in three main ways: (1) in-process improvements, (2) inter-plant heat integration (and other energy and resource integration) between processes on-site, often through industrial symbiosis in industrial parks, and (3) cascading low temperature heat outside of the industrial site to nearby heat consumers, such as municipalities, through heat networks.

[72] A full list of measures is provided in Annex II.

In-process improvement (1) can be achieved through efficient equipment, better plant and process organisation and optimisation of operations, including behaviour changes. The most common energy efficiency measures are the installation of efficient boilers and steam systems, the use of state-of the art kilns, furnaces, ovens and dryers (e.g. with efficient burners), industrial cogeneration, pre-treatment and pre-heating (e.g. materials, air), integrated and advanced control systems, sub-metering and interval metering, flue gas monitoring (e.g. for boilers and dryers), industrial insulation, optimisation of the functioning of equipment (e.g. combustion), heat and flue gas recovery (for power generation), optimised process re-design, preventive maintenance, and organisational measures such as energy management systems.

Further energy efficiency can be achieved by (2) inter-plant process integration, whereby several plants and networks are integrated to share energy utilities. The prerequisite of inter-plant integration is the clustering of industries, to allow adjacent or nearby facilities that have synergies to share waste heat, other waste streams and energy utilities.

Reusing waste heat is a known and emerging energy efficiency measure to increase the overall efficiency of a heat system inside an industrial plant or within a site helping internal process improvement. In addition, it can be part of (3) heat integration and energy cascading, when waste heat is recovered and exported outside the plant or site to nearby heat users, such as by providing space heating or space cooling to residential consumers through district heating and district cooling networks.

Several other studies have estimated the energy savings potentials in industry. These highlighted industrial heating and cooling as the largest source for energy efficiency improvement as compared to other energy uses. An earlier study[73], calculated that industry[74] overall could reduce final energy consumption by 26% by 2030 and by 52% by 2050 compared to the PRIMES 2009 baseline scenario[75]. The bulk of these savings was identified in steam systems and hot water generation with a possible 13% final energy saving in industrial heat production by 2030 and 26% by 2050. These savings were calculated to correspond to a 17% primary energy use reduction by 2050, with a possibility to reach up to 46% savings, when conversion efficiencies, including from the switch to renewables, were taken into account[76]. The measures included in the calculation covered various established and new CHP technologies, the efficiency improvements of separate heat and electricity production and of industrial space heating.

Significant efficiency opportunities exist also in the service sector. For the wholesale and retail sector the options go from the cheaper solutions related to temperature setback scheduling on building automation, to the more expensive ones like the use of efficient compressors to reduce cooling demand. In the accommodation sector, higher efficiency can be reached following the same patterns required for buildings in the residential sector, although more specific solutions would be required to reduce the demand for cooling. In the

[73] Fraunhofer ISI (2012), Concrete Paths of the European Union to the 2°C Scenario: Achieving the Climate Protection Targets of the EU by 2050 through Structural Change, Energy Savings and Energy Efficiency Technologies.

[74] The savings relate to the energy-intensive sectors of iron and steel, refineries, non-ferrous metal industry, cement, chemicals and glass industry and other minor energy intensive branches.

[75] The PRIMES 2009 baseline scenario has been also used to establish the EU 2020 and 2030 energy efficiency targets.

[76] These savings represent technical potentials.

insurance sector, the potential and opportunities to reduce space heating and cooling are linked to the energy performance levels of the buildings occupied. Also for this sector, building automation is one of the options with the shortest payback time.

In data centres, which represent most of the energy consumed in the ICT sector, various options are available to reduce the demand for cooling. The most holistic ones refer to the data centre's design itself and are followed in the current trend towards the design of new “green data centres”, which starts from the choice of a favourable site location with low ambient temperatures and low humidity climates and pay attention to the building design itself. It has been estimated that, in existing data centres, by replacing existing cooling equipment with high efficiency chillers and cooling towers and intelligent controls system, from 10% up to 30% of legacy consumption can be reduced depending on the existing equipment (ICF; 2015).

Energy intensive and non-energy intensive industries have different approaches and prioritise differently energy efficiency and renewable energy. A marked difference also exists between large companies and SMEs.

The most energy intensive industries (refineries, iron and steel, non-ferrous metals, not metallic minerals, chemicals and pulp and paper) are in general already implementing energy efficiency and renewable solutions to the extent that those are compatible with their need to have a reliable, stable, low risk/risk free and competitive energy supply to sustain their core processes. The most adopted solutions are high-efficiency cogeneration, waste heat recovery, renewable energy based on biomass and energy management systems. Such well-established energy efficiency and renewable energy solutions allow to reduce production costs, increase competitiveness, diversify energy supply to reduce risks, especially the one of supply disruption, e.g. by using decentralised CHP and biomass.

However, less energy intensive and non-energy intensive industrial enterprises are more reluctant to adopt industry wide practices for energy efficiency and renewable solutions, because they consider those as risk to the core business. Industrial companies, especially and SMEs, therefore, tend to use mainstream and often old energy supply and distribution systems and technologies, characterised by low energy efficiency, overcapacity, high energy costs and large dependency on fossil fuels, driven by conservative business models favouring risk aversion in decision-making and the use of solutions that are well-established in sector practices.

The barriers to energy efficiency can be specific to each energy sector or sub-sector; however, there are common barriers generally hindering the implementation of energy efficiency and renewable energy. The general barriers include low awareness, lack of knowledge, expertise and resources, perceived risks and lack of access to capital. A grouping of barriers can be found in the table below.

Table 4-3: A taxonomy of barriers

Origin	Area	Barriers
External	Market	Energy price distortion
		Low diffusion of technologies
		Low diffusion of information
		Market risks
		Difficulty in gathering external skills
	Government / Politics	Lack of proper regulation
		Distortion in fiscal policies
	Technology / Services suppliers	Lack of interest in energy efficiency
		Technology suppliers not updated
		Scarce communication skills
	Designers and manufacturers	Technical characteristics not adequate
		High initial costs
	Energy suppliers	Scarce communication skills
		Distortion in energy policies
		Lack of interest in energy efficiency
	Capital suppliers	Cost for investing capital availability
		Difficulty in identifying the quality of the investments
Internal	Economic	Low capital availability
		Hidden costs
		Intervention related risks
	Organisational behaviour	Lack of interest in energy efficiency
		Other priorities
		Inertia
		Imperfect evaluation criteria
		Lack of sharing the objectives
		Low status of energy efficiency
		Divergent interests
		Complex decision chain

		Lack of time
		Lack of internal control
	Barriers relating to competences	Identifying the inefficiencies
		Implementing the interventions
	Awareness	Lack of awareness or ignorance

Source: Cagno et al, 2012

One of the main barriers is the low prioritisation of energy efficiency (ICF, 2015). Even energy intensive industries do not consider energy efficiency as their core business, despite the fact that energy constitutes an important share of their costs. Most industrial companies, especially SMEs, lack awareness and knowledge of energy efficiency and renewable energy. They would benefit from sector and sub-sector specific know-how-transfer of solutions, easy-to-use-tools to identify and evaluate optimisation potentials, sector specific concepts and standards for audits, tailor-made funding and financing instruments, R&D support, best practice examples addressing the different sectors and sub-sectors, as well as contact and information points.

Specialised energy utilities providing professional energy supply and management services, based on energy efficiency combined with renewable energy and other sustainability and circular economy solutions proved a valuable instrument in many industrial clusters, and could be important instruments to enable the process of developing the existing energy efficiency potential, especially if combined with the strengthening of industrial clusters[77].

Waste heat recovery often faces further obstacles beyond those internal to enterprises, because heat integration between sites and energy cascading to supply off-site consumers requires partnerships within companies located on the same industrial site and between these companies and the local authorities/municipalities. Developing these various partnerships is a long and complex process, which necessitates a stable framework and a long-term perspective from both companies and local authorities. Such a framework must secure aligned incentives, shared risks and benefits, and governmental support throughout the process of development of the clusters and its common infrastructures.

Furthermore, supplying waste heat from industries to off-site consumers, typically nearby cities, requires the connection with and the construction of district heating and district cooling infrastructures. Industrial companies would not typically contribute to the investment in heat or cool networks that are needed for them to export their surplus heat to local communities and buildings nearby. However, they could be willing to enter into partnerships with district heating and cooling companies and local authorities and this can be facilitated by those local authorities.

Industrial clusters often foresee energy efficiency and renewable energy programmes as part of overall sustainability and circular economy objectives, and are focused on continuously improving energy efficiency and the optimisation of supply chain of all resources, such as waste, water and energy value chains. These objectives could be linked with each other to

[77] UK, Heat Strategy and related Industrial Roadmaps, https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050.

achieve even more savings. However, the creation of industrial clusters also requires coordination and participation of local, national authorities and necessitates integrating energy issues into local space planning and regulations.

As described before, recent analyses show that, of the 20% energy savings potential existing in energy-intensive industrial sectors, only 4-8% is economic if we consider a 2-year pay-back time and 4-10% is economic with a pay-back time of 5 years. However, such economic potential, and even the measures with a very short pay-back time and which will reduce in the short term the energy bill, are not realised due to various barriers. Best practice examples show that an enabling regulatory framework supporting companies to raise the importance of energy efficiency and renewable energy could facilitate access to expertise and financing and therefore overcome such barriers.

Companies in the service sector share lots of the cross-cutting barriers identified for industry, notable the low-priority attributed to energy efficiency issues and the scares knowledge and information about the available opportunities to reduce the energy bill. For instance, hotels are mostly family enterprises that have limited awareness on energy issues. Furthermore, even within large organisations, budgets (profit and loss) and operations are localized to specific retail units, restaurants, warehouses, etc. Consequently, awareness is impacted by the limited availability of human and capital resources required to investigate and implement energy efficiency opportunities.

Large, expensive equipment (e.g., food service, data centres) is typically replaced when existing equipment fails or maintenance costs become prohibitive. A further barrier can be seen in standard procurement practices which usually entail obtaining bids and then selecting the one with lowest purchase price. In the case of energy-using equipment this usually means not only low first-costs but also lower efficiency, making the equipment more expensive to own and operate over the life of the product.

4.3. Overview of technologies based on renewable energy sources

4.3.1 The use of renewable energy sources in the building sector

The most common technologies using renewable sources to deliver heating and cooling services in the residential sector are solar thermal, biomass boilers, and high Coefficient of Performance heat pumps. These technologies can be used in individual units of small capacity or in district heating and cooling in larger capacities[78].

Solar thermal technologies for heating and cooling

Solar thermal technologies provide heat that can be used for any low-temperature heat application in buildings, including space and water heating, and cooling with thermally driven chillers. They include a range of commercial technologies and systems that are competitive for water heating in markets where low-cost systems are available, energy prices are not low and solar radiation is good throughout the year. Solar domestic water heating technology has become a common application in many countries and is widely used for domestic hot water preparation in single or small multi-family homes. The technology is mature and has been commercially available in many countries for over 30 years, but on a

[78] Small individual units are typically between 1-400 kW and below 1 MW, while large capacities used in district heating and cooling range typically from 1 MW to more than 100 MW units. The basic technology principles are the same, but the design and technical specification, including the quality of the fuel needed, may differ depending on the size.

global level contributes to 0.4% only of energy demand for domestic hot water. In recent years, systems that combine water and space heating – called Solar Combi-Systems (solar CS) – have been developed. Solar CSs are used to provide space heating as well as hot water and consequently require significantly larger solar collector areas. Countries with the highest market shares for solar CS are Sweden, Norway, the Czech Republic, Germany and Austria (IEA-SHC 2014).

The cost competitiveness of solar thermal heating and cooling technology is defined by three main factors: the initial cost of the solar thermal system (which includes the integration and/or installation costs), proper maintenance and the price of alternatives. The cost of solar thermal systems differs by a factor of three to ten depending on the country and strongly depends on the quality of the solar collector, labour costs and local ambient climate conditions. In Europe, the cost per kWh of solar thermal systems is already cheaper than natural gas and electricity heating and cooling in Central and Southern Europe. Similarly, in Denmark, solar thermal systems (STS) for district heating are competitive with gas-supported district heating systems. The adoption of a life cycle cost analysis perspective, when choosing and investing in new heating and cooling systems would further strengthen the cost-competitiveness of solar thermal (but also of many other renewable and energy efficient) heating and cooling technologies.

Cost reductions and improved performance are likely as there is substantial room for innovation and for improving existing technologies and applications. Several solar heating technologies are already relatively mature and can be competitive in certain areas in applications such as domestic hot water heating and swimming pool heating. Solar assisted district heating and low-temperature industrial applications are in the advanced demonstration stage and commercially available in some European countries[79]. Other applications, such as solar space cooling and solar space heating at medium and high temperatures (>100°C), although cost competitive under certain conditions, require further development to achieve cost effectiveness, market entry and widespread uptake.

Improved solar cooling systems offer the potential to address the expected rise in cooling demand in a number of regions with good solar resources. Large-scale solar district systems are connected to cooling networks in Europe (IEA-SHC 2014). However, compared to the potential for using solar energy to generate cooling, deployment levels are very low. Solar thermally driven cooling is still in an early phase of development and a number of R&D challenges need to be addressed to enable increased deployment. To fulfil their potential, solar cooling systems will need optimised thermally driven cooling cycles (sorption chillers and desiccant systems), with higher coefficients of performance, lower cost and easier hybridisation with other waste heat, backup heating and backup cooling technologies. On the component level, this will require R&D into new sorption materials, new sorption material coatings for heat exchange surfaces and new heat and mass transfer systems. It will also require the design of new thermodynamic cycle systems. These technological developments will need to be complemented by design guidelines, system certification, labelling and tools specifically developed for solar cooling systems and applications.

There is a general lack of public awareness and knowledge about many solar thermal technologies and the broad spectrum of the possible applications, which ranges from a few

[79]IEE SDHPLUS Project No: IEE/13/803. www.solar-district-heating.eu/ Project co-funded by the Inteligent Energy Europe programme of the EU.

kW solar water heating systems to several MW solar district heating and industrial solar-based process heat systems. There are also other barriers to wider market take-up, in particular split-incentives between owners and tenants of buildings and unfavourable urban planning and building regulations. These barriers are generally shared with other types of renewable technologies. However in some Member States these barriers for solar thermal have been successfully overcome. Small solar heating systems are the dominant technology for hot water supply in Cyprus and Greece, while in Austria some cities and towns already rely to a large extent on solar thermal district heating. Increased public recognition and acceptance are necessary prerequisites for the diffusion of solar thermal heating and cooling in residential and public buildings, as well as in heavy industry and the service sector.

From the supply or new construction perspective, barriers to the increased uptake of solar heating and cooling systems are caused in part by the nature and complexity of the heat market.

Small-scale system design requires R&D effort in order to develop low-cost systems, integrate them with existing equipment and optimise operation in new developments. Whereas large scale thermally driven cooling is already available, and is favoured by economies of scale, small scale technology is still emerging and requires low-cost systems with minimal maintenance requirements. For larger systems (more than 50 kW cooling capacity), technical developments are required to improve efficiency and cost competitiveness. That will involve system packaging and standardisation, and innovations to simplify system operation and maintenance.

Bioenergy

Bioenergy is the most widely used renewable energy for heating today, representing some 90% of all renewable heating. Bioenergy takes many forms but can be categorised in three main types: solid, liquid and gaseous biomass.

Solid biomass is well-established and the most used in modern heating systems mainly in the form of wood pellets, wood chips or split logs. Wood pellets are small, standardised, cylindrical pieces made from untreated wood. They can be made from different feedstocks, which can have different potential sustainability impacts.. 2 kg of wood pellets correspond to the energy content of about 1 litre of heating oil. Pellets have a heating value (energy content) of approximately 5 kWh/kg. Pellets can be used in small scale residential installations for space heating and hot water. They can also be used in medium-scale installations (50 kW – 20MW), typically for the service sector while large-scale installations (above 20 MW) for power generation, industry and large district heating, typically use similar but larger industrial wooden pellets.

Split logs have been the traditional form of biomass for heating, but their relative share is slowly declining, while the shares of pellet and woodchip boilers are increasing. Wood should be as dry as possible, ideally to have a moisture content of 20% or below. To achieve this through simple air drying, wood typically needs to be stored for 2 years, and protected from rain water.. Wood with water content between 15% and 20% has an average energy value of 4 kWh/kg. Wood chips are manufactured in various ways. They can be used as fuel for boilers in sizes of 10 to 50 mm per piece (EHI 2015). However, given that chipping is most often done on fresh wood at source, the moisture content of chips is often high and air-drying “in the stack” rarely reduces the moisture content below 30 % whilst there are often risks of biological degrade and/or fire.

Liquid biofuels (e.g. bio gasoline, biodiesels and fast pyrolysis oil) and gaseous biofuels (biogas, bio-methane) can also be used for heating and are convenient substitutes of liquid and gaseous fossil fuels; but their use in heating today is marginal, although rapidly growing in small CHP applications. However, advanced biofuels still need R&D efforts to compete with fossil fuels in terms of quality, availability and costs and it is unclear whether these would find their way into the heating and cooling market or would be rather deployed in the transport sector.

Heat pumps

Heat pumps provide space heating and cooling, and hot water in buildings. They are the predominant technology used for space cooling, either in simple air conditioners, reversible air conditioners or chillers. Heat pumps are very efficient, although their overall energy efficiency depends on several factors, such as the outside temperature for air-source heat pumps, and the efficiency of electricity production if operated on electricity (or of other energy source they use). They are proven, commercially available technologies, which have been available for decades. Globally, an estimated 800 million heat pump units are installed (including room air conditioners, chillers, and heat pumps for space heating and hot water).

Heat pumps use renewable energy from their surroundings (ambient air, water or ground) and "high-grade" energy, e.g. electricity or gas, to raise the temperature for heating or to lower it for cooling. They achieve point-of-use efficiencies greater than 100%, *i.e.* they provide more useful cold or heat (in energy terms) than the electricity or gas input. The heat pump cycle can be used for space heating or cooling; reversible systems can provide cooling in reverse mode and can alternate heating and cooling, while hybrid systems (depending on the system design) can provide heating and cooling simultaneously.

Heat pumps can provide space heating and cooling as well as sanitary hot water with the possibility of providing all three services from one integrated unit. Most heat pumps use a vapour compression cycle driven by an electric motor, although other cycles exist and some heat pumps are driven directly by gas engines. The following are the most common forms of heat pumps in the residential sector: (1) Air-to-air central, split and room air conditioners are the standard technology for air conditioning (either one room, or the entire dwelling/building) in many regions. They can be reversible, allowing them to also provide heating; (2) Air-to-water heat pumps, often called air source heat pumps (ASHPs), provide sanitary hot water and space heating, while avoiding the need for expensive ground or water loops; (3) Water-to-water and water-to-air heat pumps take advantage of an available water source as the heat source or sink and are typically more efficient than ASHPs; (4) Ground-source heat pumps (GSHPs) utilise brine-to-water or brine-to-air heat pumps coupled with a heat exchanger loop buried in the ground. Direct exchange with the heat sink/source systems is also possible. They have higher efficiencies in cold weather than ASHPs.

Electric heat pumps are the most prevalently used, however gas heat pumps are also on the market and can be a straightforward option where gas grids are available, especially if the expansion of electricity grid is difficult due to environmental reasons or the use of existing gas grid offers a cheapest option. Gas heat pumps combine condensing technology with ambient energy and like electric heat pumps extract heat from low-temperature sources (air, water, ground) and upgrades it to a higher temperature releasing it when required for space and water heating. Gas heat pumps can also be operated in reverse mode for cooling.

Heat pumps have become more efficient, but room for improvement still remains. Performance improvements have been achieved through advances in individual components and better overall system integration. The incorporation of inverters in heat pumps has allowed high coefficients of performance (COPs) to be achieved when operating at part loads. The efficiency of a heat pump depends on several factors, but the most critical is the temperature lift or reduction that is being sought. The choice of refrigerant also influences the efficiency. The phase-down of fluorinated greenhouse gases introduced by the Regulation 517/2014 might trigger the higher uptake of natural refrigerants leading to higher efficiencies. Heat pumps applications that use sources other than the ambient air can offer improved seasonal coefficients of performances, because they are able to reduce the temperature difference between the heat or cold sources and the temperature required for the specific application. Ground source heat pumps[80] (utilising the temperature of the upper layer of the ground originating from solar energy) and geothermal heat pumps in general are an example of this as they take advantage of the temperature levels found in underground[81]. The use of waste heat with temperatures of e.g. 20 °C to 50 °C as the heat source of heat pumps can lead to very high coefficient of performances (COP) and therefore is promising in terms of increasing the energy and economic performance of a plant, but require further R&D.

Another development is cascade heat pumps, which use two refrigeration circuits, each with a low to moderate temperature lift. The net result is a heat pump that is able to supply space heating at 60° C with an acceptable seasonal performance factor. Such cascade heat pumps are already available on the market.

Hybrid applications

Hybrid applications combine two or more different renewable technologies or two or more renewable and fossil based technologies.

Solar heating and cooling technology is suitable for combination with other (renewable) energy technologies. Applying solar heating and cooling technology in combined or integrated solutions serves to maximise the yield and thereby economics of solar heating technology and/or to optimise the use of limited available roof surface. Examples are photovoltaic/solar thermal hybrid (PV-T) collectors and solar heating or cooling technology combined with heat pumps or with biomass boilers.

Solar assisted heat pumps can reduce the temperature lift that the heat pump will have to bridge, thus improving their performance (IRENA 2015). In the case of ground source heat pumps injecting solar heat into the ground, these can also help in balancing the underground temperature in cases where the borehole is somewhat shorter than needed or when there is more heat extraction in winter than recharge from cooling in summer. Alternatively, heat pumps can be used to boost the temperature of solar heated water to allow for direct use (IEA-SHC 2014). More than 90 solar-assisted heat pump systems have been installed in Europe, especially in Austria, Germany and Switzerland (IEA SHC 2013).

---

[80] For more information see the IEE REGEOCITIES Project No: IEE/11/041. http://regeocities.eu/ Project co-funded by the Intelligent Energy Europe programme of the EU.

[81] Although the term shallow refers normally to a depth until 400 meter, in most practical cases the depth is about 100 m or less). Technologies include open and closed loops geothermal systems heat pump (commonly referred to as ground source heat pumps) and underground thermal energy storage systems, including aquifers and boreholes.

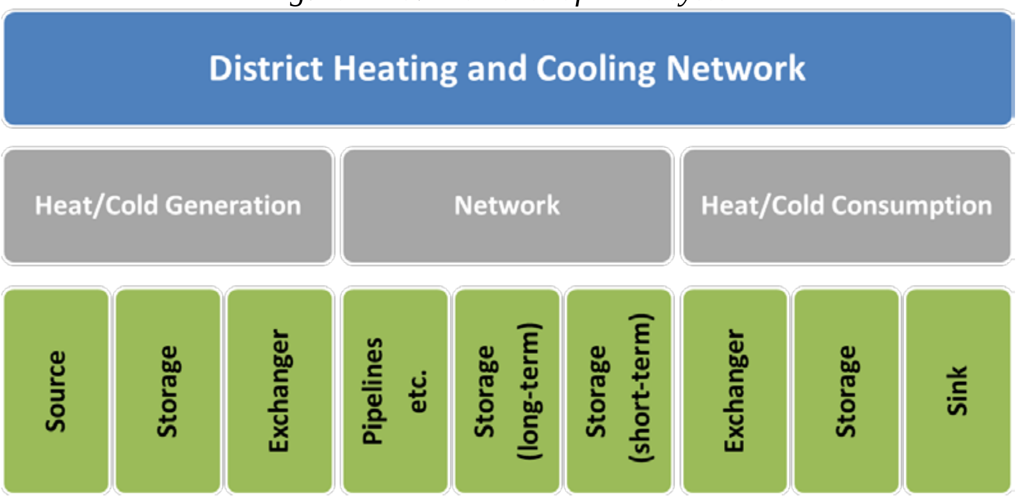
Solar heating systems combined with biomass boilers can provide 100% renewable heating systems. The combination is technically straightforward and several manufacturers already offer combined systems that are perfectly integrated and available in high performance kit systems.

Renewable heating and cooling solutions can also be integrated with high efficient gas solutions and other low-carbon efficient technologies as back-up technologies in the transition period towards full decarbonisation. A low carbon, highly efficient hybrid application is for example the combination of a gas-condensing boiler with an electric heat pump. Electric heat pumps become less efficient as the outdoor temperature drops because there is less heat available from the air, ground or ground water. During periods of lower temperatures, the gas-condensing boiler provides the heat. This results in a better overall efficiency of the system, while also reducing the load on the electrical grid in periods of very high electricity demand.

Renewable energies in district heating and cooling

Enhanced penetration of renewable energy sources can be achieved through district heating and cooling. District heating and cooling provide common solutions for groups of buildings and industrial sites. District heating and cooling are thermal energy distribution systems transporting heat or cool from thermal sources (natural sources or generation units) to direct use by consumers. Suitable demands for district heating are space heating and hot water needs of residential, commercial and public buildings and the low temperature needs of industries (space or process heating). District cooling is well adapted to supply services sector buildings with large cooling demand (offices, data centres, leisure centres, shopping malls, etc.), but also residential buildings. Depending on the system, e.g. the timely behaviour of heat/cool consumption and heat/cool production, district heating and cooling systems can include additional large thermal storage capacities. Storage capacities can be installed at supply or demand site or can be integrated in the network.

Figure 4-18: Elements of DHC system



Beside the temperature of the heat supplied, another important characteristic is the length of the network. DH systems can be differentiated on a qualitative scale as small and large DH systems, called respectively micro and macro DH networks. Micro-DH networks typically supply a small number of consumers (households in a residential area or a town) within a short pipeline of few kilometres. Micro-DH networks are common in rural areas, using biogas or woody fuel often in combination with CHP plants. Micro-DHC is often the initial stage of development for macro-DHC. Macro-DH networks instead produce heat for a large number of consumers, for instance for city districts, and the length of their pipeline can reach up to hundreds of kilometres.

From an historical perspective, district heat distribution technologies went through four development phases (generations)[82][83]:

1st: steam-based systems (> 120°-150° C)
2nd: pressurized high-temperature water systems (HTDH, T_{supply} > 100°C)
3rd: pressurized medium-temperature water systems (MTDH, T_{supply} < 100°C)
4th: low-temperature District Heating (LTDH, T_{supply} 30-70°C)

The reduction of the heat network temperature increases the efficiency of low-temperature district heating networks and reduces the heat losses. Furthermore, other materials can be used for the networks (e.g. plastic pipes instead of steel pipes) and different heat sources can be integrated in the network. Low-temperature district heating makes technically and economically available a more extensive range of energy sources that deliver heat at lower temperatures, such as waste heat and most renewable energies (e.g. a large part of the geothermal resource in Europe has temperatures between 40°C and 80°C). It also allows to achieve higher coefficient of performance in heat pumps (in combination with, for instance, heat recovery from industry or cooling processes or with sources of heat such as ground water) and in solar thermal applications. By doing this, district heating and cooling allows replacing the use of high value, high energy density fossil fuels and electricity with low value, low grade heat sources, whilst providing the same thermal comfort to buildings. These applications are especially interesting for new or refurbished buildings, which have lower heating requirements. Lower supply temperatures also reduce energy losses in the heat distribution pipes. On the other side, the reduction of heat network temperature can generate some other difficulties. The current barriers identified for LTDH are high-temperature heat demands, legionella growth at low hot-water temperatures, substation faults, and shortcut flows in distribution networks.[84]

The advantage of district heating is that the use of different heating sources and technologies is possible and used often in the same system, e.g. renewable energy sources, waste heat from industry, CHP plants or electrical heating (e.g. heat pumps), and it can provide a buffer function through the integration of large storage systems that allow using not only continuously but also discontinuously generated heat.

The disadvantage of district heating is that it requires large up-front investments in the distribution network, control equipment and pumps. The initial investment costs make district heat economically viable mostly in areas with sufficient heat demand to justify the investment. The economic viability of district heat is affected by the overall heat demand, i.e. whether the number of aggregated heat demand points and the heat requirements of these demand points can produce the critical mass required to pay-back the investment. The transition to nearly zero energy buildings in new construction and deep energy renovations in existing buildings, where energy demand is assumed to be very low, may affect the future

[82] Rosa, D. A. et al (2014): "Annex X Final report - Toward 4th Generation District Heating".
[83] Lund, H. et al (2014): "4th Generation District Heating (4GDH) - Integrating smart thermal grids into future sustainable energy systems", Energy 68 (2014) 1-11.
[84] Rosa, D. A. et al (2014): "Annex X Final report - Toward 4th Generation District Heating".

development of DH. This has to take into account also that between 5% and 20 % of the heat generated is lost during the distribution of heat to the end customers in the network.

District heating and cooling can tap a wider range of locally available renewable energy sources, e.g. solar thermal, geothermal, biomass, often in lower qualities and grades, as well as waste and waste heat sources, e.g. municipal waste, and waste heat of power plants, industrial processes and other processes (e.g. sewage water treatment). District heating can easily integrate more renewable electricity through the use of large heat pumps, electric boilers and large-scale thermal storage. Many local energy sources are often not available for or feasible to exploit with individual heat and cold supply technologies, due to technical or economic constraints. Examples are industrial waste heat, municipal and industrial waste, deep geothermal and low grade biomass.

Unlike small individual heating and cooling units, district heating and cooling generation technologies can utilise low quality fuels that are difficult, bulky, polluting or dangerous to handle in small boilers, such as most combustible renewables (e.g. wood, straw, olive residues, etc.), waste heat and various waste streams (waste incineration). Furthermore, district heating and cooling can tap on 'free' natural sources (such as direct geothermal heat or cold from lakes, rivers and seas).

In correlation with the wide range of thermal energy sources, district heating and cooling apply a large palette of technologies. These are either larger-sized variations of small individual generation units applied in the household and service sectors or '*sui generis'* technologies, such as the technologies for deep geothermal energy, waste heat and waste, and utility scale applications of conventional technologies (typically ranging from 1 MW to above 100 MW).

District heating and cooling are technically flexible due to the possible to apply multiple and many type of sources and technologies. They can deploy new, innovative low-carbon and renewable energy sources at a more rapid pace, while in parallel offering potentials to achieve primary energy savings through the increased transformation efficiencies of larger generation units and reduced air pollutions.

The most commonly used generation technologies today are CHP and heat-only boilers[85], which can handle a variety of fuels, as well as their combinations, and even those fuels that in small units present difficulties in terms of conversion efficiency, wear, fouling and compliance with environmental regulations, e.g. brown and hard coal, lignite and peat, lower quality biomass (e.g. straw, woodchip, demolition board), and municipal waste. CHP and heat-only boilers are mostly fuelled by natural gas, various coal products and biomass. Oil[86] is used marginally.

[85] Boilers and CHP units can be of many types using different technologies. Then technology is largely defined by the fuel combusted and different families of technologies were developed for solid, gaseous and liquid fuels. Units that are combusting solid fuels generally are steam tube boilers, where the heat transfer takes place from the outside of tubes to the inside containing water or steam. These can be again of many type, the oldest being grate boilers (burning coal, biomass or municipal waste), replaced later in many cases by modern technologies developed mainly to reduce emissions at the source and avoid costly clean-up systems. Newer technologies for solid fuels include various fluidised fuel design (fluidised bed boilers, bubbling fluidised bed boilers, circulating fluidised bed boilers) and pulverised fuel designs.

[86] Old district heating systems used heavy fuel oil, which by now is phased out. Currently light distillation oil is still marginally used for peak, back-up and base load purposes, mainly in heat-only boilers.

District heating and cooling can apply recycling technologies to recover waste heat from industrial and other processes or harvest thermal energy from natural sources, such as geothermal heat or cold from lakes and rivers. The technology can be relatively simple, when heat is available at temperature levels in excess of, or on par with, the operating temperatures in the networks, since the energy recovery is done by installing heat exchangers[87] without generation units being needed. If the source, *i.e.* the industrial plant, is located at some distance from the district heating system, a transmission line is needed and the network (if already exists) must be reinforced to accommodate the heat transport within the network from the connection point to the transmission line, often with a peak boiler installed at the connection point. When the heat energy available from an industrial plant is at relatively low temperature, it must be upgraded through the use of a heat pump. When the temperature step-up is small, a very high coefficient of performance can be achieved, even above a value of 8 in some cases, using vapour compression heat pumps. Heat can be recovered also from other sources, such as sewers[88], and the technology can be used to upgrade the temperature of natural water bodies, e.g. lake or sea. If the temperature is high, the types of heat pumps are the kinds used in industrial plants.

Heat pump technologies are also used in district heating (and cooling). These are most often large-scale ground source heat pumps, boosting the temperature of heat energy stored close to the surface of the earth to a level that is useful for the purposes of space heating and domestic hot water. The main types are vapour compression heat pumps and chillers. For cooling absorption heat pumps and chillers are mostly used transforming heat into cold. Cold can be extracted from ambient sources directly, which is called free cooling. Lakes, seas and rivers provide large enough source to supply district cooling and again the cold water can be directly fed into the cooling networks[89]. If the natural source is not low enough in temperature for direct use, a chiller must be interposed, which can be vapour compression chiller or an absorption chiller. Ground source heat pumps are used in 'shallow geothermal' installations, that use energy from a depth that typically ranges from zero to two hundred meters.

An important energy source for district heating might be 'deep geothermal' energy that uses heat stored in the outer shell of the earth, down to a depth of 10 kilometres. The geothermal resource is of impressive magnitude as, theoretically, it is large enough to meet the total world energy consumption at its current rate for a period of 6 million years. Only a small fraction is used today. Geothermal energy[90] is usually divided into power plant geothermal

[87] A heat exchanger is an equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment.

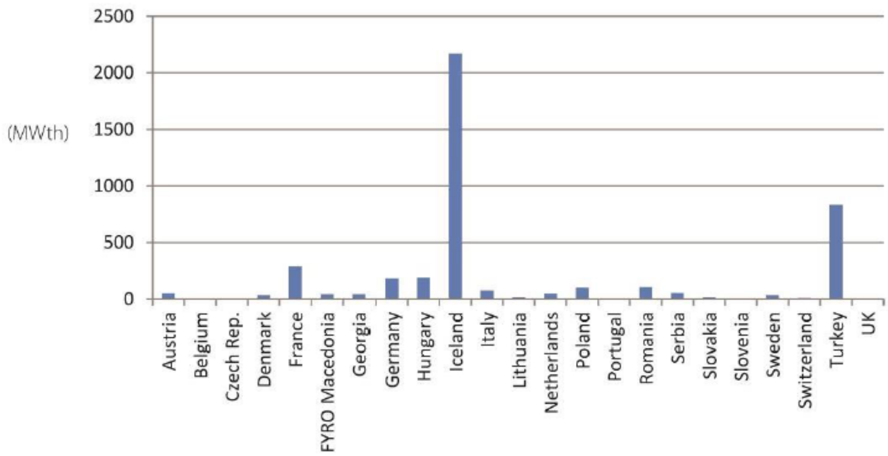
[88] An example of this is being investigated in the Smart Cities and Communities project CELSIUS. http://celsiuscity.eu/ . Project co-funded by the Framework programme 7 of the EU.

[89] Stockholm in Sweden operates a large district cooling system collecting cold at temperatures of no more than 4°C from the bottom of the city's harbour.

[90] According to GEODH (project No11/813 supported by the IEE programme of the EU http://geodh.eu/), in Europe there are around 240 geothermal district heating plants (including cogeneration systems) representing a total installed capacity of more than 4.3 GWth and a production of 4250 GWh or ca. 370 ktoe. More than 180 geothermal DH plants are located in the European Union with a total installed capacity in the EU-28 of around 1.1 GWth with several hundred additional plants being planned. Important markets for deep geothermal district heating are in France, Iceland (32), Germany (25) and Hungary (19) although significant potential exists across other European countries. The Paris and Munich basins are the two main regions today in terms of number of geothermal district heating systems in operation. The Pannonian basin is of particular interest when looking at potential development in Central and Eastern Europe countries (in Hungary a number of cities have converted

technologies and direct use geothermal energies, depending on the temperature (enthalpy) level of the source. Direct use technologies can be as simple as extracting geothermal hot water with a pump to provide hot water directly to district heat network[91] or heat via a heat exchanger. If temperature are not high enough to directly supply the heat, it can be boosted with large vapour compression heat pumps[92]. When temperature is high enough, geothermal energy can be used to also generate electricity in cogeneration[93]. Geothermal energy is available all over Europe. The most favourable conditions (highest temperature, high enthalpy, feasible depth) are in mid-western Italy and the Paris, Munich and Pannonian basins.

Figure 4-19: Geothermal DH capacity installed in Europe, per country in 2013 (MWth).



Source: EGEC Geothermal Market Report 2013/ 2014.

Another important and emerging technology is solar district heating and cooling, which uses a large array of ground-based collectors or in a decentralised manner with rooftop mounted collectors on buildings that are connected to the district heating or cooling networks. Mixed alternatives are also possible, as are combinations of solar district heating and district cooling. These systems are often complemented with large heat storage facilities, charged with solar heat during the summer and discharged in late autumn and winter. While these systems can cover a significant part of a town's heat and hot water demand at competitive

fossil fuel fired district heating schemes to geothermal energy). There are other Eastern and Central European countries, such as Poland, Slovakia, Slovenia, Czech Republic, and Romania with geothermal district heating systems installed. An overview of the deep geothermal potential of 14 MS combined with the existing heat demand is presented in a GIS map viewer where for instance temperatures distribution at 1000 and 2000m is presented , thus showing best potential areas for future geo- district heating developments.

[91] The district heating system of Reykjavik in Iceland is an example of such a simple direct use. The geothermal water is lead directly into the network; there are no heat exchangers and there are no return pipes. The network is open; that is geothermal water is fed into radiators and to hot water faucets and dumped thereafter into the drain.

[92] An example is the Swedish City of Lund, where geothermal energy is derived from an underground source at a depth of 800 m and at a temperature no more than 25°C.

[93] Most geothermal CHP power plants are based on a steam cycle or an Organic Rankine Cycle. The water is extracted mostly in liquid form, but can also be steam. Depending on the steam quality, e.g. superheated or super-critical of very high pressure, it can be fed directly to a steam turbine. Depending on whether water or steam is extracted the technology are different. Technologies include dry steam power plant, binary geothermal power plants, Organic Rankine Cycle power plants or Kalina cycle power plants. More information can be found in the GEOELEC project website http://www.geoelec.eu/ (project supported by the IEE programme of the EU).

prices, currently only one percent of the installed solar collector surface is connected to district heating systems[94], mainly in Denmark, Sweden, Austria and Germany.

Modern district heating and cooling networks are often equipped with large scale thermal storage, which allows shifting of the heating and cooling demand (end when electricity driven heating and cooling technologies are used also the electricity demand) to match the availability of variable renewable heat, cold and electricity supply[95]. Thermal storage is inter-seasonal or short-term storage. Whereas inter-seasonal thermal storage is still in the development phase, short-term storage[96] can be made with well-proven technologies. Both already have practical applications in existing systems. One purpose of short-term storage is to shift loads away from hours of peak demand to hours of lower demand, thus also entailing less need for expensive peaking capacities. Another purpose is to provide rapid heat or cold supply reserves that generating equipment is not capable of meeting or to avoid losses associated with quick starts and stops of the generating equipment[97]. Cold storage is as important for district cooling as heat storage for district heating[98]; and even more so, because cooling demand usually varies much more than heating demand during a day[99].

District cooling uses a centralised source to produce cold water which is then distributed through pipes to the end user. This approach is mostly used in urban areas[100]. District cooling

[94] By the end of 2013, 192 large-scale solar thermal systems were connected to heating networks, 40 of which were solar district heating systems with nominal thermal power >3.5 MWth. Thirty of these large-scale plants are located in Denmark. The world's largest solar district heating system is a 35 MWth plant (50 000 m2) being built in Vojens, Denmark. The largest operating solar thermal district heating plants is also in Denmark with a nominal thermal power of 26 MWth consisting of 2 982 collectors (37 573 m²) and a 61 700 m³ seasonal pit heat storage (IEA-SHC, 2014). In Denmark, costs for these plants have decreased such that they are below those for gas-fired district heating (REN21 2014). Large solar district heating systems typically have collector areas from 1 000-37 000 m2 and seasonal heat storage of 3 000 m3 to 61 000 m3. These can provide up to 50% of the heating and hot water demand of large building complexes and towns.

[95] Smart thermal networks equipped with thermal storage are able to shift loads, call-up and dispatch various generations sources and thus adapt flexibly to the variations of heat and cooling demand ensuring the cheapest source is applied. When connected to smart electric networks, smart thermal networks can participate in the balancing of the electric grids, including the integration of variable renewable electricity. They can also provide additional flexibility and control to provide more comfort to consumers. See also Issues Paper IV – Linking Heating and Cooling with Electricity for the role of storage.

[96] The most common storage technologies are pressurised storage tanks for hot water designed for the same pressure as that of the network, usually a pressure vessel of mild grade steel. The size of such tank can be up to approximately 50,000 m3. More tanks can be connected in series to accommodate large volume storage. Another technology is atmospheric pressure storage, made of steel vessel, often converted from oil tanks at low cost.

[97] An important function of short-term heat storage to maximise the efficiency of cogeneration by allowing boosted electric output when electricity is needed, e.g. due to the unavailability of wind or solar electricity, while actual heat demand is low by directing heat production to storage. See also Issues Paper IV – Linking Heating and Cooling with Electricity.

[98] Cold storage is already common in countries, where air-conditioning is widespread (e.g. US). In Europe large district heating storage facilities outnumber large cold storage, but the use of cold storage is increasing with the growing importance of district cooling.

[99] Storage technology within district cooling systems bears many similarities with those used for district heating. Steel tanks storing chilled water represent the most frequently used technology, storage in rock caverns being an alternative. Sometimes cold is stored in ice or in a brine (e.g. water-glycol brine), which requires a different technology.

[100] According to the analysis done under RESCUE (project No IEE/11/977 funded by the IEE programme of the EU www.rescue-project.eu), the share of district cooling today is still small, about 1-2% in the service sector (equivalent to around 3 TWh) and less than 1% of the total European cooling market today. In 2011 two thirds of the cooling delivered by these systems took place in France and Sweden. To a smaller extent DC is also used

often uses locally available natural sources of cold energy (natural cooling), such as air, snow or ice, river water, sea water, lake water and ground water. In many cases, sources of cold energy can be found at low enough temperatures in order to provide direct cooling, where no active cooling equipment, such as chillers, are required. In these cases, district cooling is used to pump cold water at the temperatures required to provide space cooling to end users. The Stockholm district cooling system, one of the largest in Europe with 250 MW capacity, provides cooling to the city's buildings using a combination of sea water, heat pumps, electrical chillers, cold water storages and aquifers. Waste sources of heat can also be used to generate cooling using heat driven chillers. As the efficiency of conversion of heat driven chillers is low relative to electrical chillers, the driving heat needs to have a lower price for this to be competitive. This is why heat driven chillers can be found in cities having access to waste energy, e.g. from industry. Examples of cities where absorption chillers are used in the district cooling plants are Barcelona, Gothenburg, Vienna, Halmstad and Copenhagen. In most of the cases, district cooling schemes use a combination of sources and it is this flexibility that allows the obtaining of very high efficiencies and significant primary energy savings relative to individual applications.

4.3.2 The use of renewable energy sources in industry

The use of renewable energies is much less developed in industry, as heavy industry requires steam mostly at high temperatures, and most renewable technologies are not yet sufficiently developed to generate such heat qualities - or at least, to generate it in a way that is perceived as sufficiently scaled, reliable and of reasonable cost.

While renewable technologies are already capable of supplying low and medium temperature process heat, mainly through biomass, heat pumps and solar thermal, there is currently no technology solution to directly replace fossil fuels for high temperature process heat, e.g. in steel making, some chemical processes and cement making.

In the vision described in the IEA solar thermal 2050 roadmap (IEA 2014), solar heat has a significant role to play in the industrial sector at global level. By 2050, it is estimated that solar heat in industrial applications could contribute up to 7.2 EJ per year, on the basis of an installed capacity of over 3200 GWth, in industrial low temperature applications up to 120°C.

For the industrial sector, more product development is needed in order to be able to tap into the enormous potential for solar process heat. It has been estimated that 37% of process heat demand in the European industry sectors in 2012 consists of low and medium temperature heat[101]. This opens up a considerable potential for solar heat supply by advanced flat-plate and evacuated tube collectors, which can supply temperatures up to 120°C already today. Current solar collectors covering higher temperature levels are not yet market mature. In this respect, double glazed flat-plate collectors with anti-reflection coated glazing, stationary CPC collectors and Maximum Reflector Collectors should be further developed and commercialised. Challenges consist of material resistance to high temperature levels and durability of components.

Solar Heat for Industrial Processes (SHIP) is currently at a very early stage of development. Less than 120 operating SHIP systems are reported worldwide, with a total capacity of over 40 MW th (>90,000 m²) (RHP 2015). Most of these systems are pilot plants with a relatively

---

in other countries including Finland (with a steady growing DC market), Norway, Italy, Spain, Austria and Poland.

[101] This is heat below 500°C (Fraunhofer 2015).

small size. Solar industrial process heat costs depend to a great extent on the type of application and, especially, on the temperature level needed. Up to now, several solar thermal process heat systems exist in Europe with heat costs between €38 and €120 per MWh.

Concentrating solar for heat applications

Concentrating solar heating technology development today is mainly focusing on R&D aiming at goals related to power production, e.g. realising higher temperatures. But the thermal energy produced by concentrating solar technology can also be used for heat applications, e.g. for high-temperature industrial processes in areas with good levels of direct normal irradiance (DNI), and for cooling purposes (via heat driven chillers), although these applications have thus far received far less attention. Parabolic trough collectors, parabolic dishes and linear concentrating Fresnel collectors can be adapted to serve medium-temperature process heat applications. This requires development of, for example, smaller scale concentrating solar collectors, which can be installed on rooftops of industrial production halls, and which produce the appropriate temperatures for the processes. Deployment of concentrating solar technology in industry will need adapted industrial system designs and optimisation of industrial processes to increase the potential integration of solar concentrating technology. Standardised system integration for solar heat in industrial processes is needed to encourage this use of concentrating solar technology.

Biomass

Covering almost 10% of the industrial heat demand in 2012, biomass represents the most important renewable energy source in this sector. Its main advantage lies in it being a well-established technology, capable of providing heat or process steam continuously and at all temperature levels. Additionally, certain types of biomass heat are cost competitive with fossil fuel alternatives, even without the need for subsidies. Large-scale biomass heat units for industrial applications are already capable of reaching high thermal efficiencies. The advantage of the industrial CHP units is the presence of an existing heat market, which in many cases is not subject to seasonal demand variations, as is the case with district heating networks. In addition, large-scale industrial units have a higher degree of fuel flexibility, which could allow for the mobilisation and effective utilisation of biomass resources that remain mostly unexplored, such as many types of agricultural residues, or waste derived fuels, though there could be (economic and environmental) limits as to the sourcing radius of particularly low-density biomass resources that need to be considered in the context of large-scale plants. Load flexibility, a key issue in large scale fossil fuel-fired units, can also be increased from biomass utilisation, e.g. by direct or indirect co-firing. R&D needs for industrial biomass applications are targeted towards increasing the fuel flexibility, use of new energy carriers, like thermally treated biomass fuels, as well as increasing the electrical efficiency component of the total CHP plant efficiency, leading to higher availability rates.

The exploitation of the potential of biomass to cover industrial heat demand will also depend on sustainability and resource availability conditions taking into account competing demands from traditional uses (e.g. food and feed), other energy uses (electricity, transport) and novel uses (biomaterials).

Geothermal

Different geothermal technologies can be useful for industrial applications, in particular to provide heat in the low temperature range. In the medium temperature range (95-250°C), geothermal energy can provide heat above 95°C from deep geothermal resources and from high-enthalpy geothermal resources.

4.3.3 Deployment of existing best available technologies

A wide range of efficient and renewable heating and cooling solutions are available and already successfully applied. However, the market share of these technologies is still low and even the most established cost-effective technologies face low diffusion rate or barriers to market up-take.

Barriers to the deployment of efficient and renewable technologies are strongly dependent on their technical and market maturity. However, there are common causes hindering wider diffusion, and these additionally create a feedback loop that slows the progress towards higher levels of technical and market maturity. The lack of awareness, information and knowledge regarding the availability, benefits and technical applicability of these technologies characterise all users groups: domestic, public, tertiary and industrial consumers alike. The lack of trained installers, builders, architects and developers hinders bringing these solutions to the customer. Another key and equally important factor is the widespread lack of access to financing instruments, as the installation of a new, efficient and renewable heating and cooling system – be it in households, the tertiary or the industrial sectors, or in district systems –, almost always entails large up-front capital investments, even if the result is lower operation costs over the lifetime of the equipment. Overall these barriers are symptomatic of missing or incomplete markets for heating and cooling and call for policies that address them with various economic and market-based instruments, such as strengthened energy and carbon price signals[102], fiscal measures (e.g. taxes), public procurement, standardisation, and the use of public investment in energy infrastructures and buildings to stimulate the development of markets.

The lack of awareness, information and knowledge manifest in strong consumer preferences for choosing only mainstream technologies, well established in markets. Only a few efficient and renewable technologies fall in this category, these being mainly condensing and biomass boilers. Consumers are still reluctant to buy other solutions, even if already well tried, such as heat pumps, with the exception of a few national markets. This highlights the needs for better information and trained professionals to improve consumer awareness.

Another well-known barrier for the uptake of new efficient and renewable heating and cooling technologies, especially in buildings, is the so-called “split-incentive” dilemma. For example, rental property owners have little incentive to invest, if their tenants pay the energy bill. Conversely, the tenant may not be interested in investing in renewable or highly efficient heating or cooling system either, as they may move out of the building before recovering their investment via reduced energy costs. For tenants, the decrease in energy costs due to energy efficiency improvements can be structured to offset the rental price increase, and this practice is already happening in few countries across the EU. Another possible approach to overcome this barrier is for the property owner to borrow the money from the local authority but the loan is paid back by the tenant via the local taxes.

One specific bottleneck that reduces the actual market uptake of the most efficient technologies is represented by the technical installation and maintenance of heating and cooling systems, in which installers and architects (in the design phase of renovation or new built) play a major role. The installers especially play a key role when it comes to the market deployment and wider commercialisation of highly efficient technologies and are regarded as “market makers” for many technologies, i.e. intermediaries bringing together the technology

[102] The EU ETS already establishes a carbon price signal for the installations that fall under it.

and the user. In retrofit applications on existing buildings, small scale installers of conventional heating and cooling systems often act as “gatekeepers” between suppliers of products and building owners. In cases of equipment failure, the building owner may follow a least-cost approach, rely on the installer’s advice or proceed with whatever option can be supplied and installed immediately to minimise downtime. If the installer is also offering a maintenance contract on heating and cooling equipment, they would not usually be inclined to recommend the installation of non-conventional products, including solar heating systems. Better training, incentives for smaller installers to follow courses, certification, using technical consultants as a go-between, easier-to-learn streamlined environmental legislation, new business models with rentals and energy services contracts, boiler inspection tracking the need for replacement before breakdown are some of solutions that can overcome these barriers.

Demand for space heating and cooling technologies is strongly driven by the evolution of the building sector and by the investment cycles in industry. Decarbonisation of buildings is a large opportunity for the increased market up-take of renewable and efficient heating and cooling technologies, because consumers buy or replace their heating and cooling systems usually together with the buying of a new home or office, or when they refurbish existing buildings. The Energy Performance of Buildings Directive (EPBD) requires high energy performance standards to be applied for new construction and refurbishment and these are key opportunities for commercialisation of efficient and renewable heating and cooling technologies, as these represent cost-optimal improvement solutions in the building newly built or refurbished. These opportunities are however often missed for multiple reasons. In general there is low consumer awareness or a lack of trained installers, builders, architects willing to bring these solutions to their consumers. Often the possibility of introducing a low carbon (new) solution is overlooked or considered too late in the construction process of buildings and plants or in urban planning. In cities, the planning of key infrastructure is rarely coordinated with other urban planning aspects that could be used to deploy renewable energies and energy efficient heating and cooling, e.g. when building refurbishment programmes are implemented. Sustainable energy programmes targeting the decarbonisation and energy efficiency of buildings and the heating and cooling supply are often overlooked during the urban design phases. Often decisions on infrastructures and buildings at municipal or other levels take place without any consideration of the feasibility of long term sustainable solutions and without performing a Life Cycle Cost analysis to assess the long-term cost-competitiveness of a portfolio of options. In addition, new built and refurbishment rate of buildings are low, around 1% and 1.4% per annum, respectively, which is not conducive to a more rapid diffusion of these technologies. Linking the energy efficient renovation of existing EU building stock with the deployment of efficient and new heating and cooling technologies is strategic and critical to make heating and cooling efficient and decarbonised. This is even more so in light of the fact that 75% of the Europe’s buildings are inefficient, being constructed with minimal or no energy performance requirements in building codes and their great majority will remain in use beyond 2050. Buildings today represent close to half of the EU final energy consumption.

Ultimately, the modernisation of the current heating and cooling equipment stock depends largely on the lifetime of the installed capacity and by the rate and quality of renovation of buildings. These are also affected by EU and national regulations. Important EU level regulation promoting efficient and renewable heating and cooling are the EU Energy Performance of Buildings Directive, the Renewable Energy Directive, the Energy Efficiency Directive and the EU eco-design and labelling framework.

It is important to recall that, from 26 September 2015, the Ecodesign Directive will apply to space heaters (including heat pumps and fossil fuel boilers), combination heaters (for both space and water heating), water heaters and water storage tanks. All these products will have to meet minimum requirements for energy efficiency and maximum sound power levels, or be banned from use. The minimum energy efficiency levels for both space heaters and water heaters will be raised from 26 September 2017 (tier 20, while maximum sound power levels will be lowered on 26 September 2018). Additionally, from September 2018, some fossil fuel products will have to meet maximum NOx (Nitrogen Oxide) emissions levels. The legislation also covers 'packages' of space heating and water heating products (for example, an air-to-water heat pump, temperature controller and solar thermal system). As a consequence of the entering into force of these requirements, the most inefficient boilers (low-temperature) would be banned from the market. For heating boilers, the new EU Energy Label and Ecodesign regulation will show consumers and operators – for the first time – efficiency ratings of not only single technologies, but also hybrid packages with renewables. Industry and NGOs hope that this would drive innovation forward in new buildings, but at the same time warn that the improvement of the far larger existing market should not be forgotten – phase out scheme might be a solution.

A study from Ecofys (2014) investigated the drivers of the innovation behaviour through surveys and interviews with manufacturers. It was emphasised that the best conventional heating products on the market, condensing boilers, are nearing their maximum potential for burner efficiency. Therefore, a relatively large percentage of R&D is going to innovative (renewable) technologies such as heat pumps and solar water heaters, yet these technologies are currently only a niche market.

Since the non-condensing boilers will be phased-out of the market, this will lead to a lower innovation focus on those technologies. In the short term, Ecodesign will therefore spur companies to improve their low-end products to the levels acceptable under the Ecodesign requirements by incremental innovation to products that are already widely available. To this end, some companies have to adapt their products through incremental technological innovations and making new combinations of technologies to match the Ecodesign requirements. In the long run, energy labelling is expected to act as a driver for innovative (renewable) technologies requiring innovation of the more radical type. Companies also indicated that the Ecodesign regulation is likely to have a bigger impact on companies focusing on Southern and Eastern European markets, rather than on companies focusing on the North-Western and Central European Market. In the latter, there is already a large market for high efficiency products, whereas in the Southern and Eastern European market, there is less demand. The role of strong regulation is well illustrated by the UK case, where, as shown in the table in section 2, the penetration rate of A class condensing boilers is the highest in Europe due to consistent policies to push the replacement of old, inefficient equipment.

Heating and cooling systems always represent a large, often lifelong investment for consumers and enterprises. This is even more so, in the case of many new renewable and efficient low carbon technologies, because many of them has not yet reached larger industrial scale production volumes and/or use more complex, materials and technologies of higher capital intensity, which on the other hand significantly reduce operation costs over the lifetime of the equipment. To bring down the costs of technologies necessary for the energy transition and for bringing many solutions to scale, supportive EU and national regulatory frameworks and the availability of financing instruments have proven effective to accelerate the buy-in of consumers. Access to financing energy efficiency and renewable energy investments have still, however, many barriers, especially for households and SMEs.

The public sector has a key role in accelerating the transition towards more energy efficient and decarbonised heating and cooling systems through their ability to spend, e.g. via public procurement, and their many different roles as regulators, administrators of public assets and infrastructures, as well as coordinators of the various stakeholder actions. They often have a role as public planners, developing also heating and cooling plans. They can facilitate financing and design and implement dedicated financing instruments, through e.g. supporting the implementation of concrete projects and operate energy and building infrastructures. However, they often lack appropriate skills and financial or human resources. It is therefore key to help regional and local administrations to acquire the skills and capacities needed to take a more active role along the many dimensions of deploying new, efficient and renewable heating and cooling solutions in buildings and industry.

At EU level, the Intelligent Energy Europe (IEE) programme launched in 2003 has and is still supporting a number of EU wide projects addressing the non-technological barriers hindering the market uptake of efficient and renewable heating and cooling solutions, including through building capacities and skills in public authorities. Support for these activities continues under the EU Horizon 2020 programme. Transfer of the knowledge resulting from such IEE and Horizon 2020 projects to all relevant actors is important, not the least to ensure optimal use of the significant funding from the European Investment and Structural Funds for investments in this area.

4.3.4 Technological innovation and R&D

IEA (2015) estimated that, of the additional investment in RD&D needed to reach the 2050 decarbonisation goals, around 60% will be required to support accelerated R&D efforts to improve performance and reduce the cost of existing technologies, with the balance for demonstration projects.

R&D can focus on reducing system costs and improving performance as well as optimising existing technologies for heating and cooling applications and for some of the most promising market segments. Large-scale demonstration projects of energy-efficient and low/zero-carbon technologies are needed to help reduce technical and market barriers by providing robust data to evaluate their performance in each market segment.

Industrial innovation faces different interlinked challenges. These fall into three main groups: 1) an uncertain economic and policy outlook that can make it difficult to justify investment in innovation, 2) the need to manage risk, and 3) the need to balance collaboration with protection of knowledge (IEA, 2015). The relative importance of these challenges depends on the phase within the R&D process at which the technology or process stands. For instance, basic research and laboratory-scale tests tend to be less capital-intensive but they typically involve more incertitude as the technology principles have not been proven yet. Throughout these initial phases of R&D, cross-sectoral international collaboration and information sharing may be critical for a project's success, as they can accelerate the research learning process and reduce the associated incertitude levels. Low-carbon industrial innovation can face additional challenges, such as the difficulty of penetrating a market dominated by a small number of widely used process technologies. This is especially relevant when environmental benefits are undervalued, when growth prospects are only moderate, or where it is difficult to track environmental impacts along the value chain, as in highly diversified markets (e.g. multiple production routes and final uses for plastic-based products).

Risk is also inherent to innovation projects because they aim to develop and deploy completely new processes or products. Thus, risk management becomes critical to make research and innovation projects viable. Final decisions on investment depend on many factors, but two stand out: uncertainty intensity and capital intensity. Investors have different levels of risk tolerance and perception throughout the different phases of the R&D process. Financing early phases of research tends to be more uncertainty-intensive, with less chance that the estimated return on investment is met because technology performance or product benefits are yet to be proven. The design and development phase builds on successful results from previous research activities, lowering the level of uncertainty when performing relevant investment risk assessments. Finally, the commercial demonstration stage, although characterised by greater capital intensity, has a more manageable risk because prior pilot-scale trials have provided a basis for considerable confidence in the new technology or product benefits. While uncertainty intensity decreases as R&D advances, capital intensity tends to increase, mostly because of the gradual process of scaling up. A decision to invest in innovation hinges on what balance between uncertainty intensity and capital intensity the investor can accept.

The EU research and development Framework Programmes and Horizon 2020 have already contributed to introduce new technologies, bring down their costs and help their wider market up-take. These efforts need to be continued to help technologies reach market-readiness and secure the needed levels of research, development and demonstration.

Support will also come from the European Structural and Investment Funds (ESIF)[103]. In particular, for the 2014-2020 period EUR 45 billion are allocated to investments supporting the shift towards a low-carbon economy[104], EUR 44 billion for research and innovation, and EUR 63 billion for enhancing the competitiveness of SMEs. Smart Specialisation Strategies, which are a pre-condition for ERDF funding for research and innovation, identify key investment priorities for Member States and regions. Energy is one of the most widely chosen priorities. The Commission in 2015 launched a platform to assist Member States and regions in the uptake of the Cohesion Policy funds[105] for sustainable energy, including for research and innovation[106]. The impact of Horizon 2020 can be further enhanced through the development of synergies with ESIF investments[107]. Examples could be the development and equipment of R&I infrastructures, the transfer of knowledge and technologies resulting from Horizon 2020 or ESIF projects to companies that can develop them further through ESIF funding. ESIF can also be used to help deploy innovative solutions resulting from Horizon 2020 or ESIF, e.g. through public procurement.

[103] ESIF include the European Regional Development Fund (ERDF), the Cohesion Fund (CF), the European Social Fund (ESF), the European Agricultural Fund for Rural Development (EAFRD), and the European Maritime and Fisheries Fund (EMFF).

[104] The investment priority 'supporting the shift towards a low-carbon economy in all sectors' includes areas such as energy efficiency, renewables, high-efficiency cogeneration, smart grids, sustainable multimodal urban transport, and research and innovation in these areas.

[105] Cohesion Policy funds include the ERDF, CF and ESF.

[106] http://s3platform.jrc.ec.europa.eu/s3p-energy

[107] http://ec.europa.eu/regional_policy/en/information/publications/guides/2014/enabling-synergies-between-european-structural-and-investment-funds-horizon-2020-and-other-research-innovation-and-competitiveness-related-union-programmes

The European Technology Platform on Renewable Heating and Cooling (RHC-Platform) identified in its Research and Innovation Roadmap the R&D activities that are needed to achieve the RHC-Platform 2020 objectives. The Roadmap is based on Technology Roadmaps developed by each of the four RHC panels (Solar Thermal, Geothermal, Biomass, and Cross-Cutting) finalised in 2014[108].

− **Solar thermal**

Solar thermal energy has a high potential for renewable heating and cooling in Europe, but today only generates about 20 TWh of heat, which corresponds to less than 1% of the heat demand in Europe[109]. For solar thermal, a focus on the three following 'pathways' is suggested for technological development until 2020:

1. Solar Compact Hybrid Systems (SCOHYS) are compact heat supply systems including both a solar heating source and a backup heating source (based on bioenergy, heat pumps or fossil fuels), with a solar fraction of at least 50% in the case of domestic hot water. Improvement of solar hot water systems by integrating solar collectors in building components, by using alternative materials and by developing standardised kits and plug-and operate systems are also recognized as an R&D priority by IEA.

2. The Solar-Active-House (SAH) provides a solution towards achieving the goal of the 'nearly zero-energy building'. With a good, but not high-end insulation, the energy required to meet the residual heating demand can be provided by solar thermal energy. The SAH roadmap pathway focuses on cost reduction as well as the optimisation and standardisation of the technology for Solar-Active-Houses with about 60% solar fraction; the aim is to develop Solar-Active-Houses as a competitive solution for nearly zero-energy buildings.

3. The SHIP (Solar Heat for Industrial Processes) roadmap pathway enables the sector to tackle the vast untapped potential in all industrial applications with process temperatures up to 250°C i.e. both low and medium temperature applications.

Research, development and demonstration support to solar heating and cooling technologies have different levels of maturity. Whereas solar domestic hot water technology is relatively mature, solar cooling is currently in the demonstration/preindustrial phase and, therefore, has significant potential for improvement. Compact seasonal heat storage is still in the early development phase: in order to make very high solar fractions in solar space heating possible, continued development is crucial. Hybrid solar assisted systems and PV-T systems offer promising potential but are still in the demonstration phase. Long term, sustained and substantially greater research, development and demonstration (RD&D) resources are needed to improve designs and accelerate cost reduction in order to bring novel solar heating and cooling concepts to market. For solar cooling, IEA identifies the need for increasing thermal

[108] The RHC-Platform is an initiative officially endorsed by the European Commission since October 2008, gathers over 700 research and industry stakeholders to define a common strategy to increase research and innovation for renewable heating and cooling. The Biomass Panel of the RHC-Platform published the Strategic Research Priorities for Biomass Technology in April 2012.

[109] The actual amount of solar generation may be larger, as energy statistics only account for active solar thermal production. Passive solar thermal systems are already widely used but are not reported in energy statistics as they are considered to be part of the building design.

COP and COPel (overall electrical efficiency), through further development of new cycles, optimized heat rejection systems, reduced parasitic consumption and new storage concepts; by development of small-scale solar thermal driven cooling products for small commercial buildings, and for single and multi-family dwellings; and by developing standardised kits and plug-and-play systems.

Apart from their possible contribution to passive building design, building envelopes will need to become solar collectors themselves, so both the performance of collectors and their direct integration into buildings needs to be improved. This should lead to the development of multifunctional building components which act as elements of the building envelope and as solar collectors. Planning regulations will need to protect solar access to integrated solar collectors (which will in some cases be on vertical surfaces) to avoid performance reductions due to shading. The development of new components for use in collectors – such as plastics, functional coating of absorbers (optimised to resist stagnation temperatures and new polymer materials that resist deterioration from UV exposure – should help to reduce the life-cycle cost and improve the economics of solar thermal systems. On-site installation challenges and maintenance work are sometimes seen as bottlenecks to the increased deployment of solar heating equipment.

- **Biomass**

According to the Biomass Technology Roadmap four selected value chains need to be addressed:

- Advanced biomass fuels replacing coal, fossil oil and natural gas in heat and CHP production (advanced fuels). Sustainable, innovative and cost-efficient advanced feedstock production and pre-treatment technologies for different biomass sources need to be developed to meet the quality requirements for thermally treated biomass, bio-oil and biomethane[110] production[111];
- Cost-effective micro and small-scale CHP for the residential sector and small industries;
- High efficiency large-scale or industrial steam CHP with enhanced availability and increased high temperature heat potential (up to 600 ºC) (High efficient large-scale or industrial CHP), and

[110] Biogas typically refers to a gas produced by the anaerobic digestion or fermentation of organic matter including manure, sewage sludge, municipal solid waste, biodegradable waste, energy crops, agricultural residues (straw, catch crops, etc.) or any other biodegradable feedstock. In many CHP units located in remote areas with no potential heat user, the heat produced is only partly used, or wasted. This inefficiency in energy use is a bottleneck in current biogas production, causing macroeconomic and microeconomic losses and challenges in the context of overall increasing land use competition. There are many different solutions to use this “unused heat”, including micro district heating networks, injection of the heat into the district heating network, installation of biogas-pipelines to satellite-CHP units, heat use in nearby greenhouses, cooling, drying, etc. A further solution to overcome this problem of “unused heat” of biogas plants is to promote the upgrading of biogas to biomethane with adjacent injection of the biomethane in the natural gas grid. Once the biomethane has entered the natural gas grid, it can be easily stored and consumed at any place with natural gas grid access.

[111] The estimated fast pyrolysis-oil output in 2020 could reach 3 Mtoe in Europe which represents about 10% of the mineral oil currently used for heating (approximately 30 Mtoe/year) and corresponds to a greenhouse gas reduction of almost 2 million tons CO^2 equivalent compared to natural gas. Bio-oil has also the advantage of guaranteeing high fuel flexibility: a wide variety of different feedstock can be processed in the pyrolysis process,

and more than 45 different types have already been tested at pilot scales, including wheat straw, rice husk and other food industry residues, bagasse, sludge, tobacco, energy crops, pruning and many more. However, the type of biomass used influences the bio-oil yield and quality. Woody biomass is typically the type of biomass that gives the highest bio-oil yields.

- High efficient biomass conversion systems for polygeneration

As regards, industrial applications of biomass, main technological challenges are the increase of fuel flexibility for large-scale combustion / co-firing / gasification processes, especially to be able to use more complex and low cost biomass fuels (e.g. agricultural residues, lingo-cellulosic crops and waste recovered fuels/sludge). The other identified challenges to overcome to increase the use of biomass in industrial processes are the following:

(1) Maintain high operational electrical efficiency, close to nominal, for variable feedstock and/or variable load;
(2) Increase steam parameters and/or heat medium temperature;
(3) Address catalyst deactivation issues and PM emissions in flue gas cleaning systems with increasing share of biomass;
(4) Identify new ash utilization options;
(5) Reduction of particle and gas emissions of the biomass combustion process.

It is important to take into account that, because of the geographically scattered nature of the feedstocks, biomass conversion technologies cannot be developed at large-scale on a stand-alone basis; the entire value chain – from feedstock to end products – needs to be taken into account for successful implementation. Different types of R&D projects are required to implement the strategic research priorities for biomass technology: applied research and development activities are needed to develop and optimize specific elements for the demonstration of the different value chains.

- **Stationary fuel cells**

Stationary fuel cells (FC) is an emerging CHP application that in some use segments is ready for commercialisation and can achieve attractive prices.

Stationary fuel cells for decentralized power production in CHP mode can supply heating and cooling in smaller buildings with micro-CHP fuel cells, in larger commercial buildings with fuel cells up to 400 kW and industrial heat and electricity with larger high temperature fuel cells up to several MW. These latter industrial larger scale applications are still in the research phase.

Stationary fuel cells are able to store domestic renewables at a virtually unlimited scale. They reduce primary energy consumption by approximately 25%, greenhouse gases emissions by up to 80% and pollutants and particulates to almost zero. With further development, they will also be able to provide high temperature heat for industrial purposes.

As a distributed power generation form, stationary fuel cell CHP systems exhibit high energy efficiencies with electrical efficiency of around 60% and overall efficiency of more than 90%, while avoiding transmission losses. Fuel cell micro-CHP offers primary energy savings of 24% compared to using condensing boilers[112]. Stationary fuel cells using several fuel cell technologies are also able to operate in reverse (electrolyser) mode and thus store electrical energy in hydrogen for later use, e.g. when no renewable electricity is available or additional energy is needed.

- **Geothermal**

[112] http://www.fch.europa.eu/sites/default/files/FCHJU_FuelCellDistributedGenerationCommercialization_0.pdf

For shallow geothermal, the Research and Innovation Roadmap identifies as a goal to improve the performance and the market penetration of ground source heat pumps, as well as achieving a decrease in their cost. For deep geothermal, promising areas are the development of smart thermal grids with the building of new district heating and cooling networks (Geothermal District Heating & Cooling, with ca. 5 €-cent/kWh, is one of the most competitive energy technologies), optimisation of existing networks, and the increase of new and innovative geothermal applications in transport, industry, and agriculture.

As regards industrial geothermal applications, the development of these requires the support for a range of R&I actions and programs to enlarge our understanding of deep geothermal resources (and to mitigate the financial risks inherent in these types of projects), improve and decrease the cost of deep drilling, and also improve the surface systems.

- **Cross-cutting technologies**

In addition to specific pathways and direction which are specific for each of the four sectors represented in the RHC platform, the roadmap identifies the need for cross-cutting technologies, which are considered necessary to exploit synergies among renewable energy production, distribution, and consumption. Cross-cutting technology enhances the thermal energy output of RES systems, improves the system output, or allows RES, such as aerothermal energy, to be used in building-specific applications. Four key energy technologies or applications have been identified that fit the definition above: District Heating and Cooling, Thermal Energy Storage, Heat Pumps and Hybrid Renewable Energy Systems and priorities with generic impact on RHC applications in the residential sector.

5. FOCUS ON SPECIFIC SOLUTIONS FOR HEATING AND COOLING

5.1. Linking buildings and industry: the use of waste heat

Reusing waste heat is a known and emerging energy efficiency measure to increase the overall efficiency of a heat system inside an industrial plant or within a site helping internal process improvement. In addition, it can be part of heat integration and energy cascading, when waste heat is recovered and exported outside the plant or site to nearby heat users, such as by providing space heating to residential consumers through district heat.

Few studies have estimated the potential for waste heat and exploitation of waste heat remains limited. Industrial and power generation installations produce large amount of waste heat as a by-product. Most of this waste heat is currently dissipated unused in air and water. A few countries utilise a small portion of this waste heat from industrial plants, nuclear and other electric power plants through feeding the waste heat into district heating and cooling systems that supply buildings. Waste heat can also be used for cooling through absorption chillers, more details about that are given in Section 6.

Stratego (2015) calculated the EU total waste heat potential to be 11.3 EJ (270 Mtoe), an order of magnitude that could cover the EU's entire heating needs in residential and tertiary buildings[113]. The sources considered included large scale (above 50 MW) thermal power generation fuel combustion plants, fuel supply and refineries, and industrial facilities within six significant energy-intensive industrial sectors: chemical and petrochemical, iron and steel, non-ferrous metals, non-metallic minerals, paper, pulp and printing, and the food and beverage sector. The report also considers Waste-to-Energy facilities. The calculation did not take into account European nuclear facilities, which reject approximately 6.7 EJ, although in some Member States some district heat facilities utilise waste heat from nuclear plants. The study established waste heat potentials for all 28 EU Member States. The ratio of excess heat to primary energy consumption in industry is between a third and half for each Member State. Seven Member States (France (7%), Germany (23%), Italy (11%), the Netherlands (5%), Poland (8%), Spain (6%), and the United Kingdom (12%)) account for the major share of the total excess heat availabilities.

Studies (Persson 2015, Werner 2014) show that sequential energy use or energy cascading can maximise the use of waste heat from industrial and power plants by first using higher exergy heat[114] in industrial plants' internal processes and feeding the remaining low energy heat (below 120°C) into DHC networks. Under current and emerging technologies (Organic Rankine Cycle, heat pumps) useful heat and electricity can be extracted from heat of as low a temperature as (60°C). Furthermore, heat content of waste water in urban sewage systems and from urban infrastructures (metro, large building complexes, e.g. shopping malls) can be extracted and utilised. Waste heat can also be used for cooling through absorption chillers and other technologies.

The enabling technology for waste heat recovery is a heat or cool distribution systems (thermal networks) in centralised heating/cooling systems and larger thermal networks that connect the waste heat source with buildings and industrial plants.

[113] Quantifying the Excess Heat Available for District Heating in Europe, Stratego, Background Study 7, 2015.
[114] In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.

Cities produce a large amount of solid and liquid waste that currently is largely left unused. Waste and sewage water contains thermal energy that can be recovered and distributed to buildings through central and district heating systems. The unrecyclable part of municipal waste is already used in Waste-to-Energy Plants to produce heat and/or electricity; however the potentials for W-t-E are far from being exploited fully in the EU.

The recovery of waste heat from waste and sewage water is an emerging practice that is already used in many European cities based on already established and mature technologies. The extension of this practice to its full economic potential could substantially contribute to the reduction of primary energy demand and decarbonisation and help reduce the EU's import dependence, increase security of supply and the resilience of its local and national energy systems against external supply crises and price shocks. Waste sources of heat can also be used to generate cooling using heat driven chillers. As the efficiency of conversion heat driven chillers is low relative to electrical chillers, the driving heat needs to have a lower price for this to be competitive. This is why heat driven chiller solutions can be found in cities having access to waste energy. Examples of cities where absorption chillers are used in the district cooling plants are Barcelona, Gothenburg, Vienna, Halmstad and Copenhagen. In most of the cases district cooling schemes uses a combination of sources and it is precisely this flexibility what allows to obtain very high efficiencies when used in the right applications.

Table 5-1 The potentials for generated heat energy from wastewater for the EU-28 capital cities (Source ThermoWatt)

		Inhabitants [thousand]	*Mass flow [m^3/day)*	*Energy potential [MW]*
Austria	Vienna	1 599	565 684	**137**
Belgium	Brussels	1 000	353 774	**86**
Bulgaria	Sofia	1 246	440 802	**107**
Croatia	Zagreb	779	275 590	**67**
Cyprus	Nicosia	214	75 708	**18**
Czech Republic	Prague	1 171	414 269	**100**
Denmark	Copenhagen	502	177 594	**43**
Estonia	Tallinn	392	138 679	**34**
Finland	Helsinki	560	198 113	**48**
France	Paris	2 181	771 580	**187**
Germany	Berlin	3 388	1 198 585	**290**
Greece	Athens	796	281 604	**68**
Hungary	Budapest	1 696	600 000	**145**
Ireland	Dublin	472	166 981	**40**
Italy	Rome	2 554	903 538	**218**
Latvia	Riga	735	260 024	**63**
Lithuania	Vilnius	553	195 637	**47**
Luxembourg	Luxembourg	83	29 363	**7**
Malta	Valetta	209	73 939	**18**
Netherlands	Amsterdam	739	261 439	**63**
Poland	Warsaw	1 693	598 939	**145**
Portugal	Lisbon	529	187 146	**45**
Romania	Bucharest	1 927	681 722	**165**
Spain	Madrid	3 100	1 096 698	**265**
Sweden	Stockholm	762	269 576	**65**
Slovakia	Bratislava	425	150 354	**37**
Slovenia	Ljubljana	268	94 811	**23**
United Kingdom	London	7 429	2 628 184	**635**

5.2. District heating

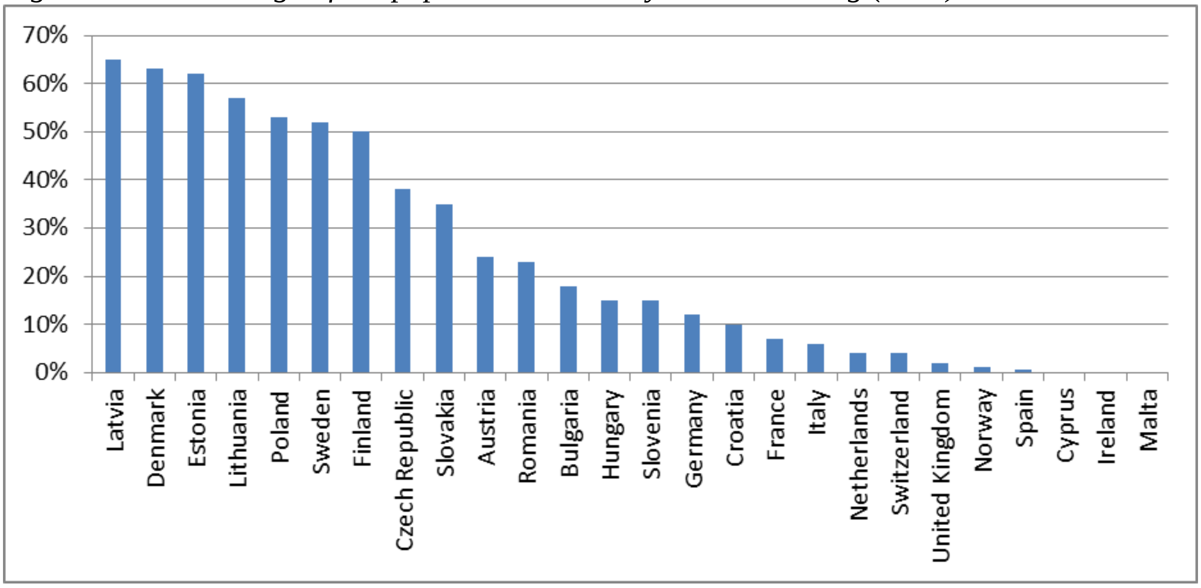
Heat Generation

District heating provides 9% of heating in the residential sector, 10% in the service sector and 8% of industry's heat needs.

There are more than 10,000 district heating (DH) systems in EU-28^{SIN} which supply around about 8 % of the Europe's total demand for heat. In the EU-28 ^{SIN}, district heating is supplied by CHP, waste-to-energy plants, industrial processes and other kind of heat generators.

Today, approximately 70 million EU citizens are served by DH systems.[115] 140 million EU citizens live in cities with at least one DH system.[116]

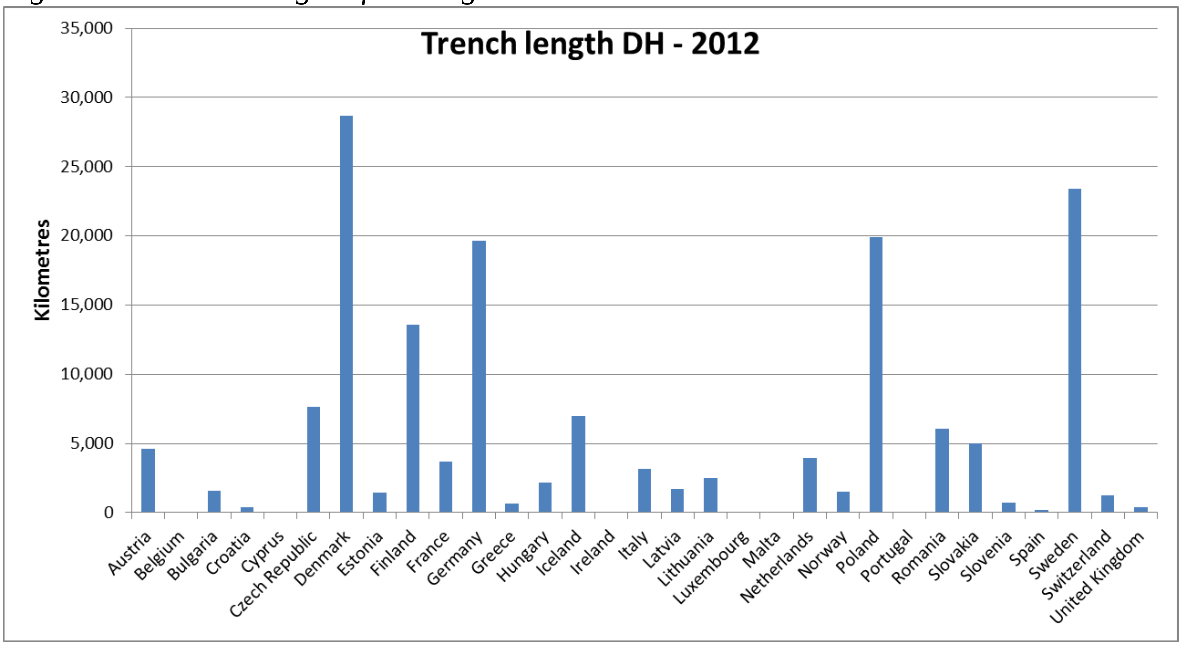
Figure 5-1: Percentage of the population served by district heating (2013)



Source: Commission services using data supplied by Euroheat and Power

There are more than 150,000 kilometres of district heating in the EU. Denmark, Sweden, Poland, Germany and Finland have the highest length of DH network in the EU-28[SIN] with around 65 % of the total length. The country average trench length ranges from 1 km to around 150 km. This mean there are in some countries lots of (small) DH networks and in other countries a lower number of (big) DH networks. For example, Slovakia has over 2,000 DH networks according to a trench length of approximately 5,000 km.

Figure 5-2: Trench length of existing DH networks in EU-28 [SIN]



[115] Fraunhofer (2015).
[116] Euroheat and Power (2013): "District Heating and Cooling – Country By Country – Survey 2013"

At EU Level, DH systems are mostly used in the residential sector (45 %), followed by the industrial sector (34 %) and the tertiary sector (21 %). District heat consumption in 2012 was 576 TWh. There are differences among the Member States. In some countries, DH systems deliver more heat to the industry (e.g. Germany, Italy, etc.) and in others the residential sector is the main heat consumer (e.g. Poland, Sweden, Denmark, etc.).

Figure 5-3: Share of DH in the residential, industry and tertiary sector in 2012

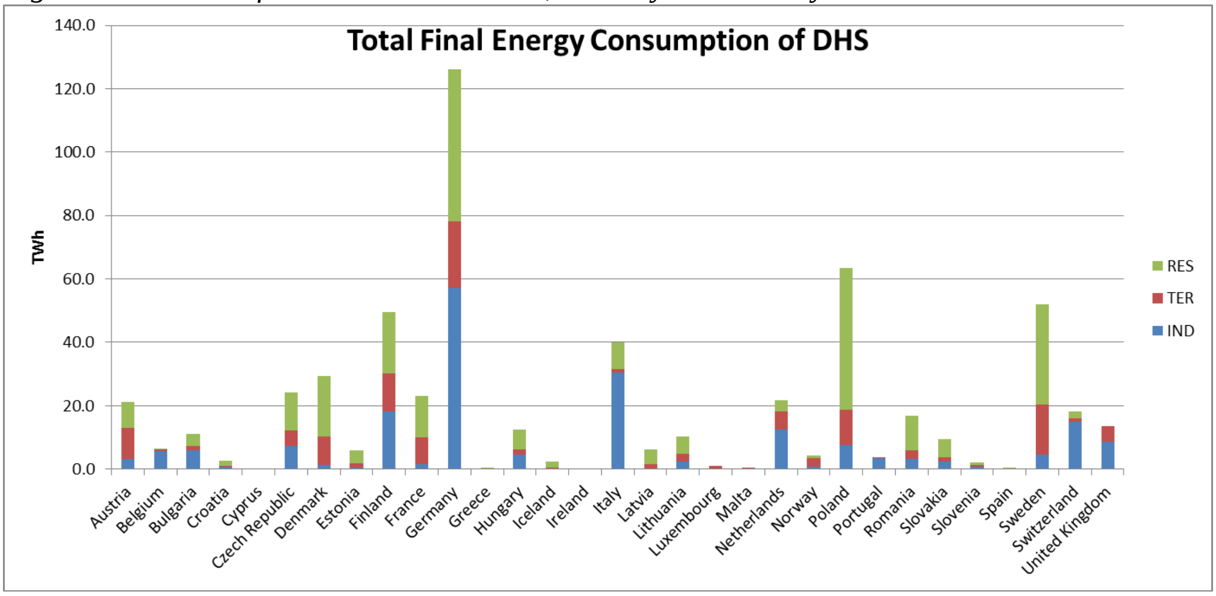
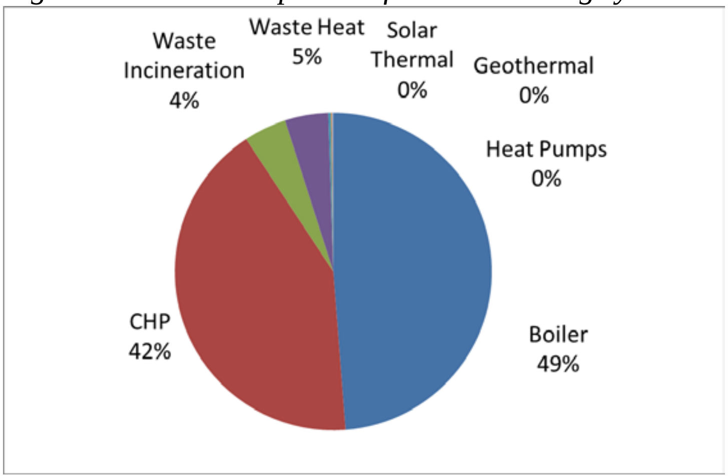


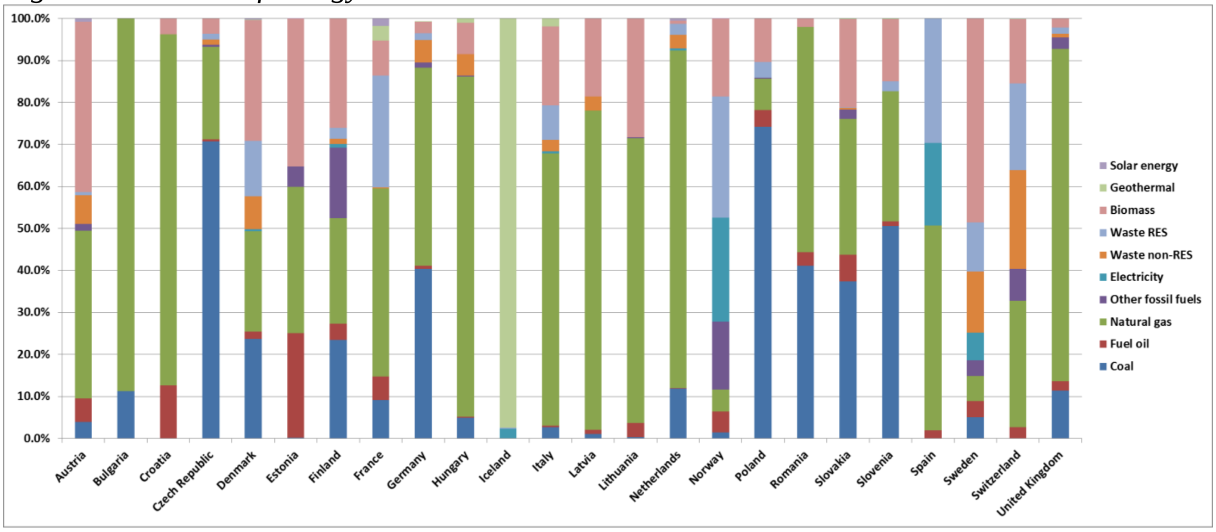
Figure 5-4 shows the share of the installed power of heating applications in DH systems (DHS) of the EU-28^{SIN}. The available data is not complete but allow identifying the most common applications, which are boilers, followed by CHP, waste heat recovery applications and waste incineration plants. The installed capacity also includes peak production units, which may operate only a few hours per year.

Figure 5-4: Installed power of district heating systems in EU-28^{SIN} of 247 GWth in 2012



The energy supply composition for district heating is very country-specific. Nevertheless, it can be noticed that fossil fuels (mainly natural gas and coal) covered a share of between 80% and 100% of the energy supply for district heating in Eastern European countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia) in 2012. Biomass played a prominent role in Sweden (49%) as well as in Austria (41%) and Estonia (35%).

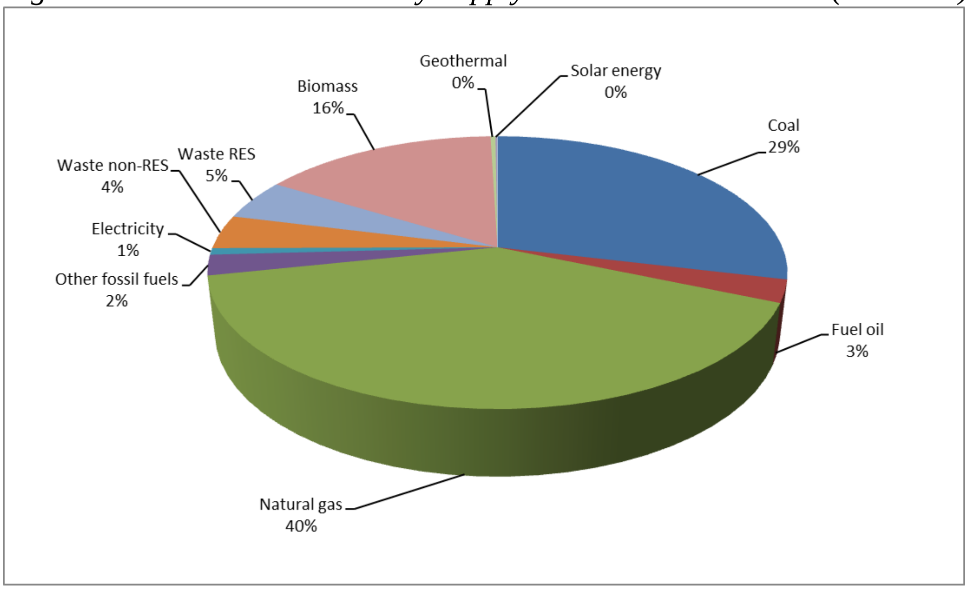
Figure 5-5: Share of energy carrier in DHS in 2012



At EU level, in 2012 the main fuel used in district heating was natural gas (40%), followed by coal (29%), with biomass (16%) only in third place. District heating integrates also electricity, including from renewable sources, local renewable heat energy (geothermal and solar thermal), waste heat and municipal waste (both renewable and non-renewable). Geothermal solar energy have very little shares and supplied 9.2 TWh (1.5%) and 0.8 TWh (0.1%) of heat, respectively, while heat pumps supplied 4.9 TWh (0.8%) in 2012.

Figure 5-6 shows the global shares of primary energy supply by district heating in 2012 in EU28.

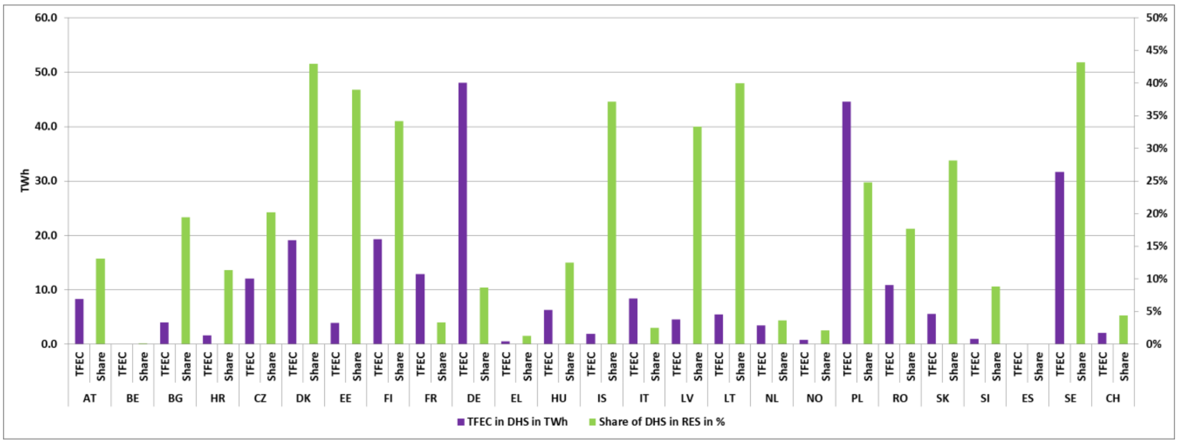
Figure 26: District Heat Primary Supply Sources in EU28 2012 (606 TWh)



Around 70% of these fuels are used in CHP plants, the other nearly 30% are direct use of renewables or other fuel for heat production only (in heat only boilers). Furthermore, the reuse of industrial waste heat (including waste heat from nuclear power plants) is around 1%.[117]

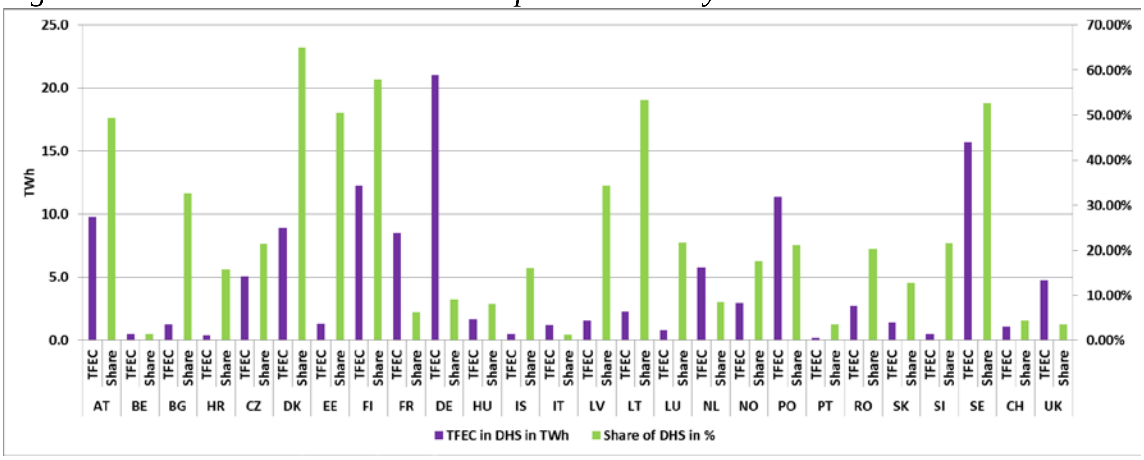
If we look at the situation of district heating by sector, the situation is again different across countries. In the residential sector, the most important countries in relation to the total final energy (TFE) consumption are Germany followed by Poland and Sweden. These three countries are generating nearly 50 % of the total final district heat energy in the EU-28[SIN]. The countries with the highest share of final energy supplied by DHS in the residential sector are Denmark, Sweden, Lithuania, Estonia and Iceland.

Figure 5-7: Total Final District Heat Consumption in the residential sector and the share of DHS in this area[118] [119]



In the tertiary sector, the most important countries for generating the TFEC are Germany, Sweden, Finland and Poland with nearly 50 % of the total energy supplied by DH in this sector (*Figure*). The highest share occurs in Denmark, followed by Finland, Lithuania, Sweden and Estonia but in contrast to the residential sector the share is far above 40 %.

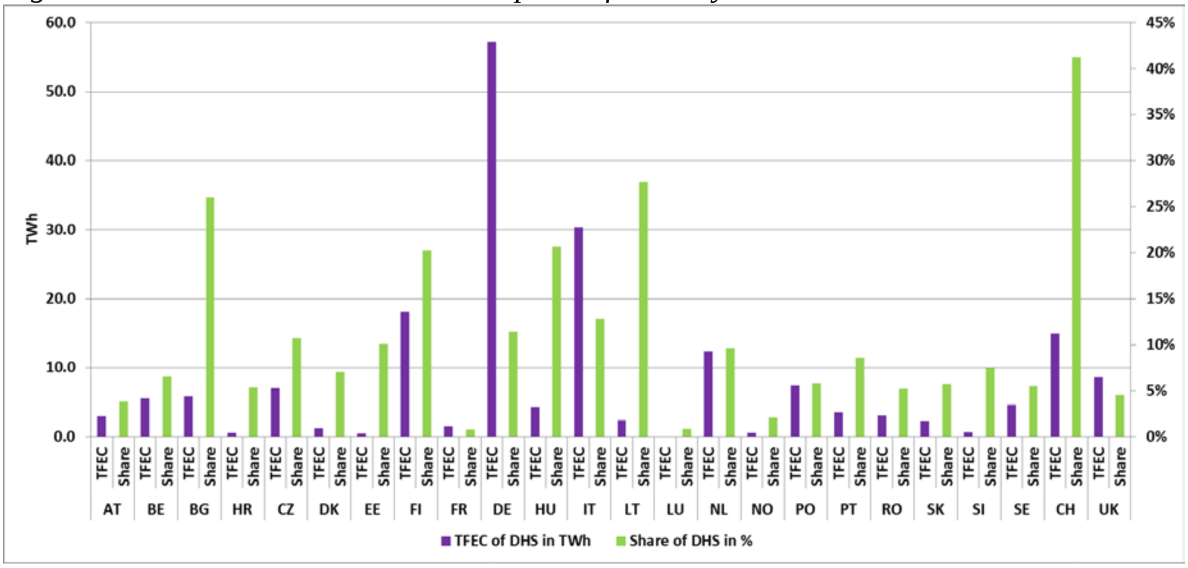
Figure 5-8: Total District Heat Consumption in tertiary sector in EU-28 [SIN]



117 Euroheat and Power (2015): "District Heating and Cooling – Country by Country – Survey 2015", Status: 2013
118 Fraunhofer 2015
119 Note: Countries which are not mentioned have no DHS or no data was available.

In industry, the most important countries in terms of total DH supply are Germany, Italy and Finland where over 50 % of the generated DH is supplied to the industrial sector in EU-28[SIN]. The share of DH in industrial sector is the largest in Lithuania, Bulgaria.

Figure 5-9: Total District Heat Consumption of industry sector in EU-28 [SIN]



Current development trends in Europe show further expansion in both traditional DH countries and countries new to DH. In the Scandinavian, Baltic and some Western European countries, DH is regarded as offering attractive economic prospects for companies and consumers and as a vehicle of decarbonisation and energy efficiency and renewable deployment. In some Central, Eastern European and Baltic countries, e.g. Romania, Bulgaria, Slovakia, Poland and Latvia, DH has a mixed situation. Old legacy systems have shrunk and/or continue shrinking due to lack of investment or unfavourable price regulation, and the ensuing low performance, negative consumer perception and disconnection trends, often combined with the impact of changes in economic structures and population. At the same time, in certain Member States and regions new efforts and policies aim to modernise, expand and initiate new DH developments in those regions, where the economics are good (in cities) in order to increase efficiency, deploy more renewable energies and keep heat prices under control.

5.3. Linking Heating and Cooling with the Electricity System

The decarbonisation of heating and cooling in buildings and industry will require utilising renewable energy sources on a large scale, coupled with the need of significant energy savings in end-energy use and energy transformation through higher efficiencies. A large part of renewable supply will come in the form of electricity from variable renewable sources (wind, solar, wave and tidal), which must be captured and used when they are available. This in many cases will not match the time when they are needed. This mismatch between the demand and the supply of energy is a marked difference with today’s energy supply system, which is designed around fossil fuels. Fossil fuels, such as oil, natural gas, and coal, can be characterised as a large amount of stored energy that can be easily made available for consumption with today's transformation technologies. They are easy to transport and store.

The high stored energy content of fossil fuels make today’s energy supply very flexible, since energy can be provided whenever it is required. Today, only bioenergy has physical properties similar to those of fossil fuels and thus could provide direct replacement. If bioenergy or renewable energies in general could replace all fossil fuels, a large proportion of the existing energy infrastructure and technologies would not need to change. The current centralised energy system, where large production facilities provide electricity or heat, can only accommodate up to 20-25% wind power or solar power. To enable covering a large portion of our energy demand with variable renewable electricity, the structure of the energy system needs to change to provide new sources of flexibility.

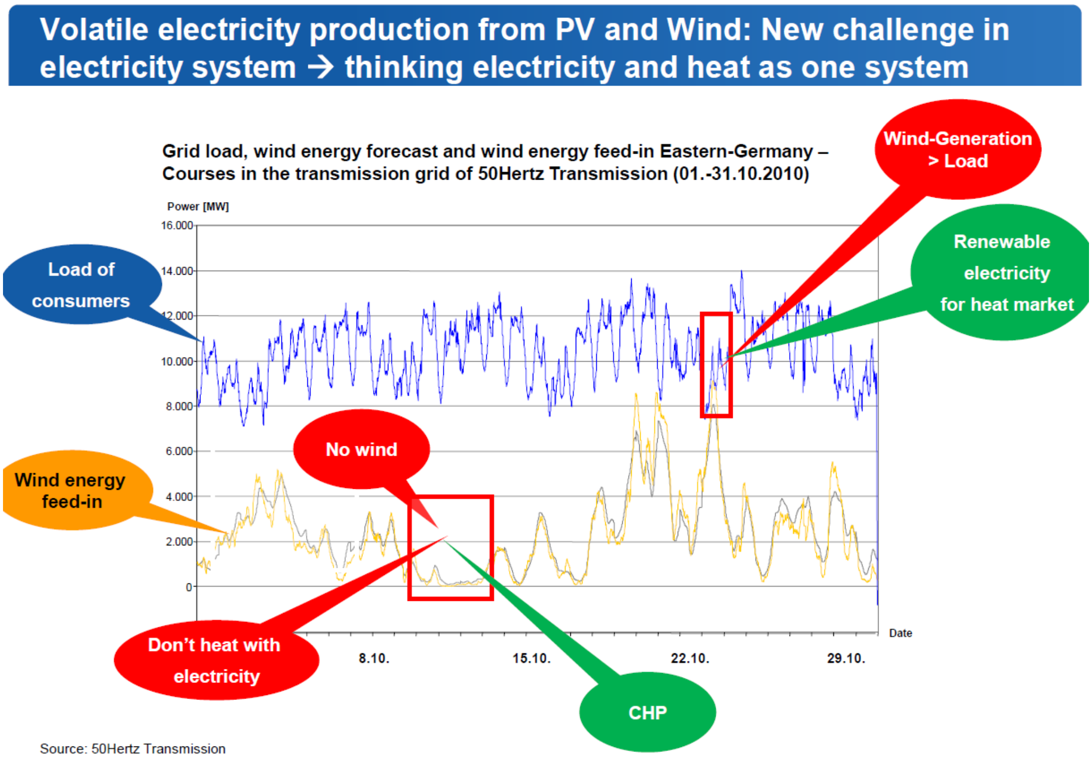
Flexibility is achieved by making demand flexible and through energy storage. Currently demand response and demand management are the most established demand flexibility solutions. However, this flexibility is limited by the demand in the current electricity system, which even if shifted to the time when excess variable electricity is available, will not be sufficient to absorb all the excess electricity, when variable electricity sources are dominant.

There are many technological solutions for storage, such as electric, thermal, gaseous, and liquid storage (an overview of storage technologies is provided in Annex III). However these technologies are not evenly developed and many emerging storage technologies are today not economically viable. Current experience and energy system modelling shows that on a unit basis (i.e. €/MWh), electricity storage is around 100 times more expensive than thermal storage. Connecting thermal storage in heating and cooling systems it with variable electricity can provide balancing services to the electricity grid.

Increased flexibility can be achieved and with already established technologies by linking heat and cooling systems with electricity systems. This creates additional demand, as buildings' heating system or district heating and cooling could absorb excess renewable electricity through e.g. heat pumps or electric heater, and by providing thermal storage. When the share of variable electricity is further increased, i.e. to 65%–97%, further flexibility may be needed and can be created by linking the transport sector with electricity grids, through e.g. electric vehicles.

There are already real applications for the linking of heat and electricity systems to create the flexibilities needed to integrate large amount of variable renewable electricity. The figure below shows one example from East Germany, where load and wind in-feed for one month are shown, indicating how these interactions could work. The curve on top shows the load, while the yellow figure shows the in-feed of wind power. Towards the end of the month, the feed-in of wind is higher than demand for electricity, conversely this renewable electricity need not be curtailed, but either exported or used in the heating (or transport) sector. Earlier in the month, there is hardly any in-feed of renewable electricity, making it likely that prices are high, which provides a business case for running cogeneration units delivering heat and electricity at the same time.

Figure 5-10: Example from a transmission grid in Eastern Germany



Another way to show this interaction is with the residual load duration curve. Here, in the figure below, the in-feed of variable renewable electricity is subtracted from the load providing a *residual* load curve, meaning the load that needs to supplied by other technologies, or in case negative, consumed. The hours with the highest residual loads are sorted from left to right.

5.3.1 Energy Storage

Energy storage is slowly recognised as an essential component of the future energy system, in particular the electricity market, where variable renewable electricity and thermal energy supply sources dominate the fuel mix. The need for energy storage arises because variable renewable electricity and heat must be used when it produced, otherwise it is lost. Storage can help to time shift demand and match variable supply with the variation of electricity and heat or cooling load. Storage is therefore a flexibility instrument that needs to be available as a balancing service together with other balancing and flexibility instruments, such as demand management and demand response, thermal district heating and cooling systems and additional interconnections.

Smart buildings when linked to smart electric grids, and equipped with smart heating/cooling systems, smart appliances and building automation, can provide additional demand, including energy storage capacities alone or as part of district heating and cooling networks. Heat pumps in buildings are also key technologies to absorb excess variable energy for supply or for storage.

Storage has many essential benefits within a renewable based energy system. It is central to enable the forecast integration of massive amounts of variable renewable electricity and can help stabilise the grid and ensures security and reliability of electricity supply. Today energy storage is only marginally used in the EU energy system, mainly in the form of large hydrogenation and pumped hydro facilities. Other technological solutions are emerging, such as thermal storage, battery storage and are already applied in some national and local energy systems. A number of storage technologies are at R&D, demonstration or experimental phase.

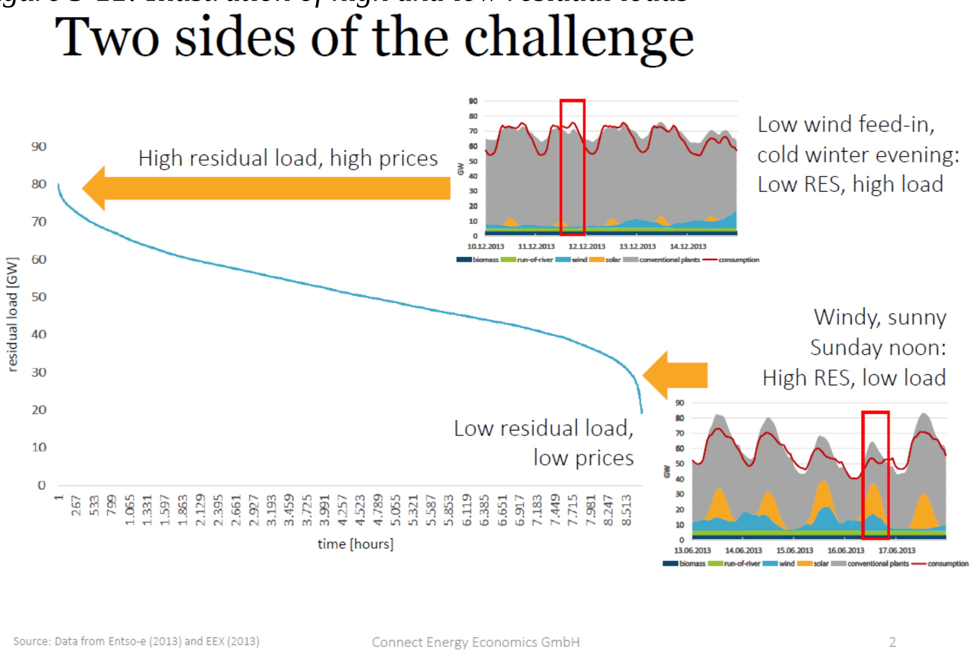
For storage to become part of a renewable based energy system, storage also need to be recognised as an economically viable solution and a necessary component of balancing strategies that will be needed in the frame of the transition to more sustainable European energy transmission, distribution and supply systems. In addition to further technological development to reduce the cost of the various storage solutions, storage needs to become part of the market regulatory framework allowing it to participate in electricity and the heating and cooling supply on equal footing with other balancing and flexibility mechanisms, such as responsible suppliers and demand response agents.

Storage today faces a number of challenges which includes high storage cost, lack of stable and clear framework conditions, high grid access fees; immaturity of many storage technology and control system.

The benefits of storage, those of cogeneration and district heating and cooling stem from synergies created between the heating and cooling, electricity, buildings and industrial sectors. These benefits and synergies can be best understood and exploited if heating and cooling is not looked at in isolation, but together with the other components of the energy system, electricity, industry, buildings and transport under an integrated approach to increase available energy efficiency and renewable deployment options at reduced costs.

Creating these new flexibility sources require transforming the structure and the composition of today's entire energy system, and the heating and cooling within it. Due to its size, any decarbonisation and demand reduction will have a decisive role on the success and cost of the EU energy transition toward a low carbon, efficient and sustainable energy system.

Figure 5-11: Illustration of high and low residual loads



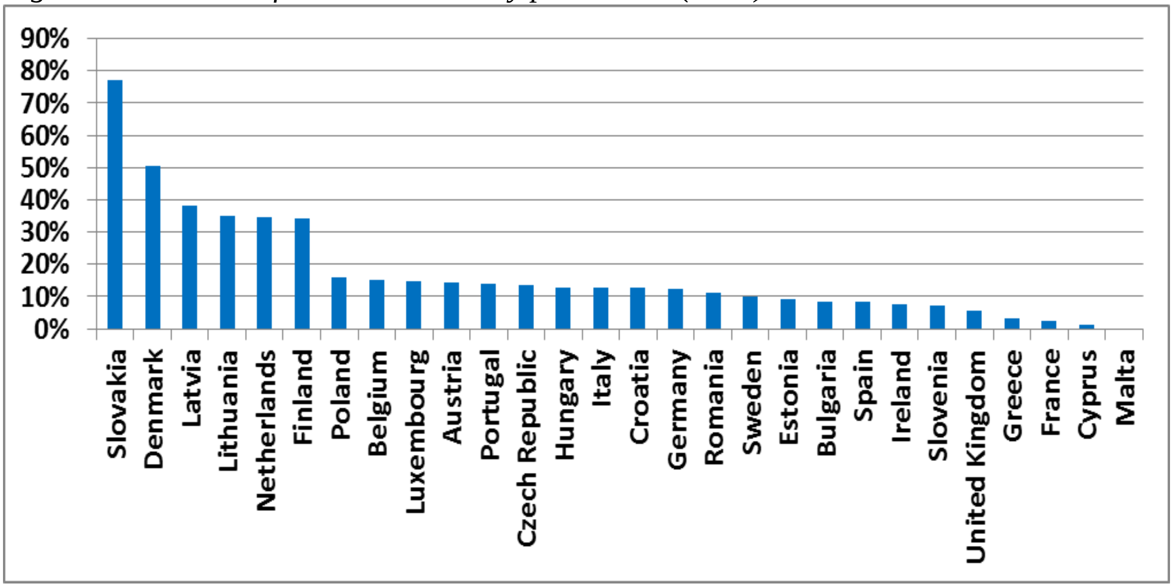
During the hours with low residual load, electricity prices ought to be low, as supply is relatively high compared to demand. In such situtions the heating sector would benefit from using cost efficient renewable electricity. Another benefit of the heating and cooling system is that it offers large quantities of cheap storage options. In a low carbon renewable based linked system, there are also hours when variable electricity is not available to cover the heat and electricty load. Cogeneration has proved to be a cost-efficient option to provide the missing elecricity and heat supply with high transformation efficiencies and low carbon emissions.

Current experience and analysis underpinned with modelling show that cost-effective and proven components of a linked system of heating/cooling and electricity are district heating networks, large scale heat pumps, thermal storage and cogeneration, alone or as combined technologies. Smart energy networks and smart buildings, advanced demand management and demand response would help fully develop this flexibility. Smart electricity grids are needed to connect flexible electricity demands, such as heat pumps and electric vehicles, to variable renewable resources, and can be connected to liquid air and liquid nitrogen production facilities to store electricity for cooling. Smart thermal grids (District Heating and Cooling) can effectively connect the electricity and heating sectors, which enables thermal storage to be utilised for creating additional flexibility and to recycle heat losses in the energy system through e.g. cogeneration. Further in the future, Smart gas grids can connect the electricity, heating, and transport sectors. This enables gas storage to be utilised for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be utilised. This is important because, while thermal storage is around 100 times cheaper than electricity storage, it is around 100 times more expensive than gas and liquid storage.

5.3.2 High-efficiency Cogeneration

The combined generation of heat and electricity (cogeneration or CHP) is a more efficient way of producing electricity and heat, but also cooling , simultaneously. The efficiency of cogeneration can reach 90% or above, which implies significant primary energy saving potentials above the current efficiency of Europe's power generation fleet. In addition, cogeneration often also reduces electricity grid losses, as it is generally built next to its consumers, supplying on-site electricity and heat or supplying consumers through electricity distribution grids.

Figure 5-12: Share of CHP in electricity production (2013)



Modern cogeneration can save on average 30% of primary energy compared to the separate generation of the same amount of electricity and heat. European legislation has been promoting the expansion of high-efficiency cogeneration since the 2004 Cogeneration Directive (2004/8/EC). The Energy Efficiency Directive (2012/27/EU), which repealed the Cogeneration Directive as of 5 June 2014, has strengthened the regulatory framework for cogeneration. The Energy Efficiency Directive integrates all substantial provisions of the Cogeneration Directive but contains a wider range of instruments. These target the build-up of district heating and cooling systems to secure heat demand and heat consumers; a strengthened role of cogeneration in electricity markets, in particular balancing markets and demand response. The Directive aims also to ensure that cogeneration is used in power generation and industrial installation whenever this is economic. The main instruments are national comprehensive assessments, which should identify potentials for high-efficiency cogeneration together with efficient district heating and cooling; and a mandatory cost-benefit analysis obligation on the economic viability of CHP for power and industrial installations above 20 MW. Under the Energy Efficiency Directive, primary energy savings from cogeneration count towards the EU 2020 20% energy efficiency target.

Due to the significant primary energy savings it brings, cogeneration has an important role to play in Europe's efforts to make heating and cooling and electricity production more efficient and decarbonised. As a "side" benefit cogeneration also has a role to increase security of supply, reduce carbon emissions and increase the competitiveness of the industrial and energy transformation sectors.

Cogeneration technologies has been improved and the palette of technological solutions widened through R&D&I supported by EU research policies. CHP today is more flexible and integrate more and more renewable and cutting edge technologies. Flexible and decentralised cogeneration can be an important element in providing new sources of flexibilities needed to deploy variable renewable electricity at a large scale and is now part of national heating strategies to decarbonised energy supply. National strategies and the pathways they modelled demonstrated the benefits of linking heating and cooling with electricity systems to help match variable renewable heat and electricity supply with electricity and heat loads. Cogeneration can be one of key component of such integrated, linked systems. Flexible cogeneration can produce electricity, when variable electricity is not available, and either help store the heat produced or, in units that can operate flexibly, increase their electricity generation through reducing heat production.

The now decade long experience with cogeneration under EU directives and policies, has resulted in a better understanding of the benefits and the evolving role of cogeneration at EU level. This also reflects the technological advancement of cogeneration technologies, which today are more flexible and integrate more and more renewable and cutting edge technologies. There is an increasing recognition that cogeneration has added benefits in the context of making the EU heating and cooling sector more efficient and decarbonised. Recent national strategies on heating and cooling and supporting analysis of the possible pathways to energy system decarbonisation have recognised that cogeneration can be an important element in providing the flexibilities needed to deploy variable renewable electricity at a large scale.

These pathways demonstrated the benefits of linking heating and cooling with electricity systems to help match variable renewable heat and electricity supply with electricity and heat loads. Instrumental to this are district heating networks, large scale heat pumps, heat storage and cogeneration, alone or as combined technologies. The "smartisation" of energy networks and buildings, advanced demand management and demand response would help fully develop this flexibility. An energy system composed of smart electric grids, smart buildings equipped with smart heating and cooling systems and building automation, cogeneration units with or without district heating and cooling networks, can provide additional demand or energy storage capacities to utilise surplus variable electricity, when this is abundant and cheap. Flexible cogeneration is a natural component of such future linked systems as it can produce electricity, when variable electricity is not available, and either help store the heat produced or, in units that can operate flexibly, increase their electricity generation through reducing heat production.

5.3.3 Passive and active technologies to integrate and control heat and cool supply in buildings and industries

There are innovative technologies that help integrate and control within buildings the heat and cool supply and demand. These include new materials in buildings and the building envelope to reduce or regulate the heat or cool load. Cooling and heating floors, direct radiant cooling in the roof and window technologies that reduce at will the heat or cooling demand through e.g. variable thermal transmittance modulated by electric currents are examples of such technologies. Passive building systems, including e.g. passive solar thermal heating or cooling, are important emerging solutions that can help correctly dimension the heating or cooling supply equipment in buildings and industries. These passive solutions have the potential to provide highly efficient alternative heating and cooling systems but require the further development and deployment of proper design and technical solutions adapted to the conditions of a specific consumer site.

5.3.4 Smart thermal and electric networks

There is still significant research need to develop and mainstream new and innovative district energy networks that are able to supply low-energy buildings and take advantage of very low temperature heat sources (low temperature or 4th generation district heating). These thermal energy networks can offer new opportunities for the recovery of sources of thermal energy in urban contexts which are currently being wasted. Distribution and piping solutions (e.g.

insulation, materials) and the integration with buildings are particular elements in need of attention.

The smartisation of thermal and electric networks is an emerging area, and the interface with consumers, including smart (white) appliances, smart heating and cooling and control systems, substations, and smart micro-grids need either wider consumer adoption in case of proven technologies (e.g. modern thermostatic radiator valves) or further focus for development, deployment and cost-reduction, if they are still in the development phase, e.g. 'predictive controls' to optimise energy consumption and establish better interaction with smart electric and thermal grids.