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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 final}

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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

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[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.

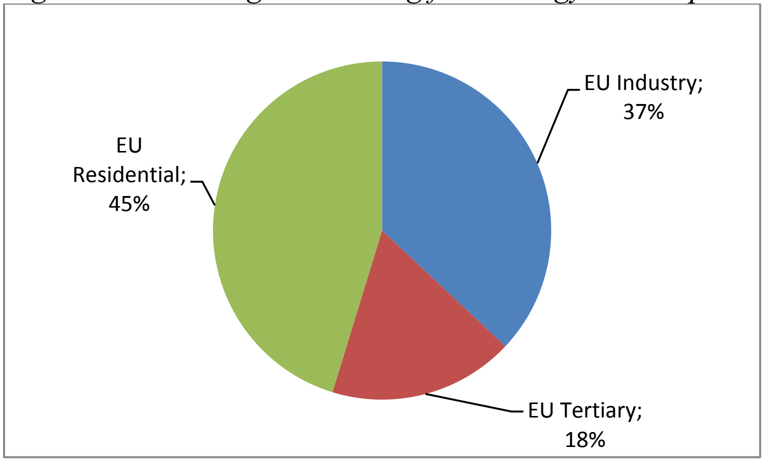
[5] IEA, (2014).

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

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[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

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[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.

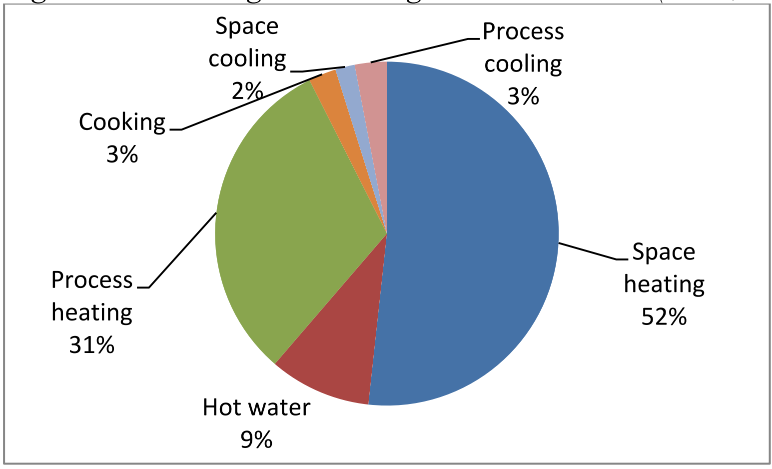
range of the potential demand goes from 100 to 174 Mtoe, demonstrating the high expected increase but, at the same time, the uncertainty attributed to the future cooling demand. Kemna (2014) estimates that the potential space cooling demand is 42.1 Mtoe, less than half of which is fulfilled. In 2020 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.

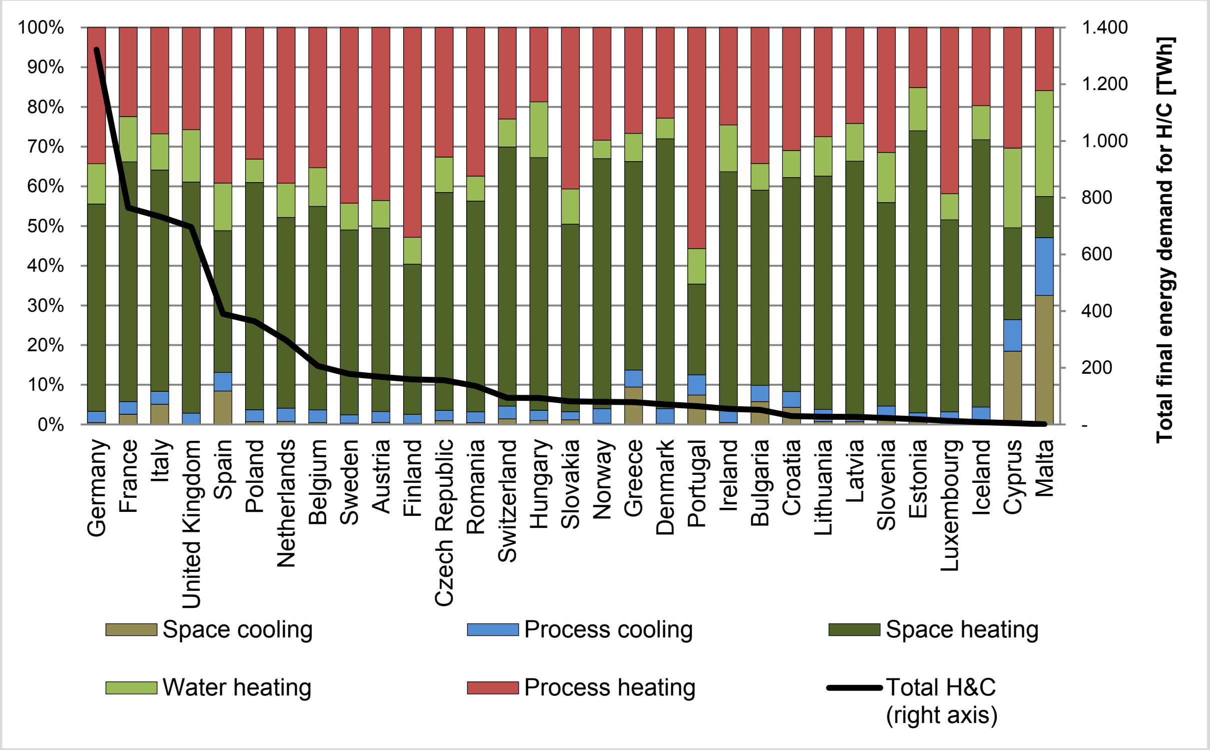
Figure 2-2: Heating and cooling end-uses in 2012 (Mtoe, %)



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.

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[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

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[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.

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[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)

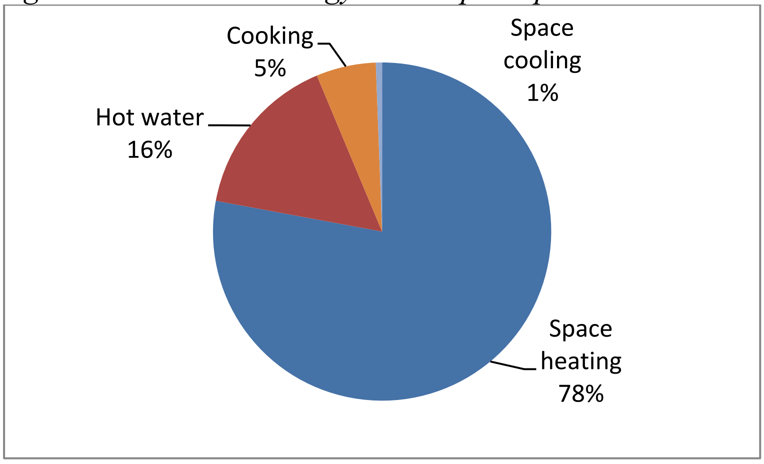
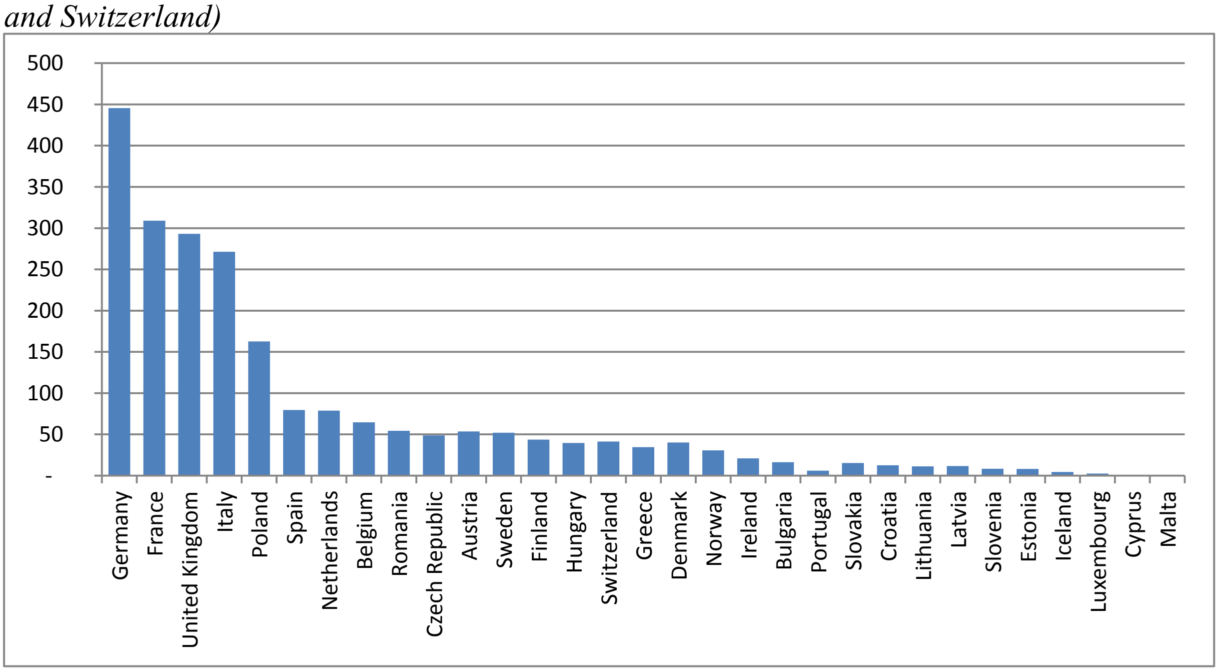


Figure 2-5: Space heating in the residential sector, 2012 (TWh, EU28 + Norway, Iceland and Switzerland)



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

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[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.

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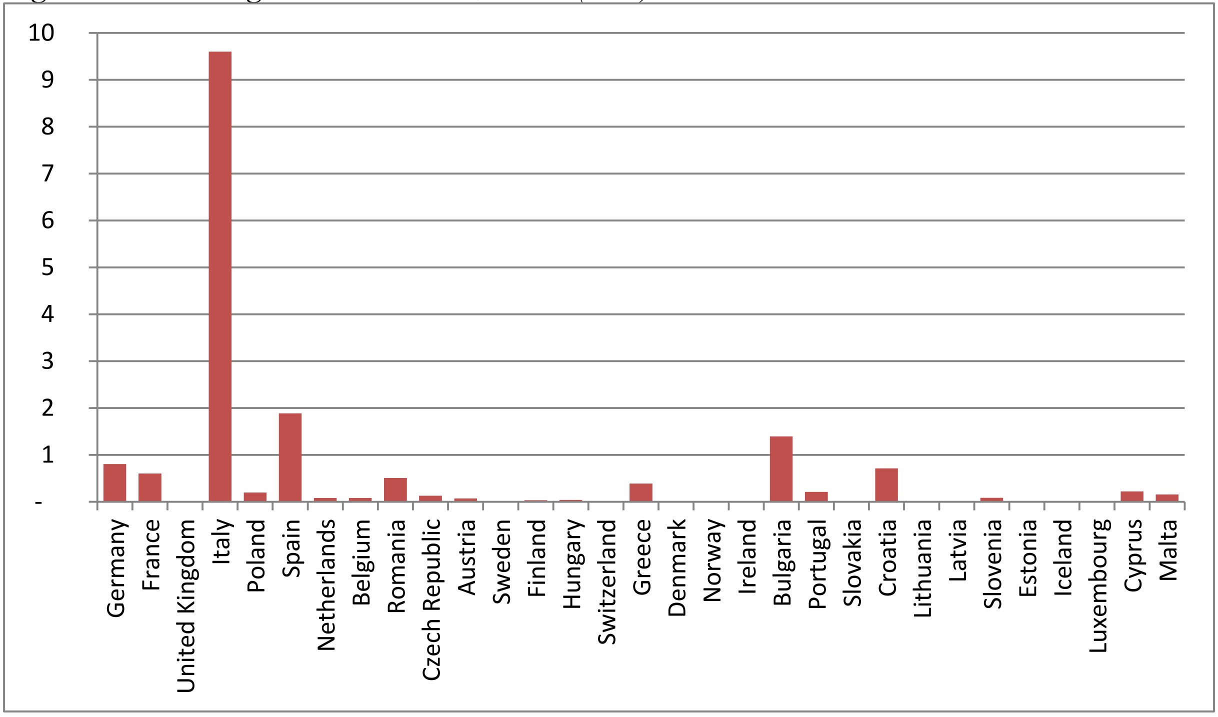
[13] "Ecodesign Impact Assessment" Study estimated the total energy consumption for water heating was 581 TWh in 2010 (175 in dedicated water heaters and 406 TWh in combination heaters).

[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.

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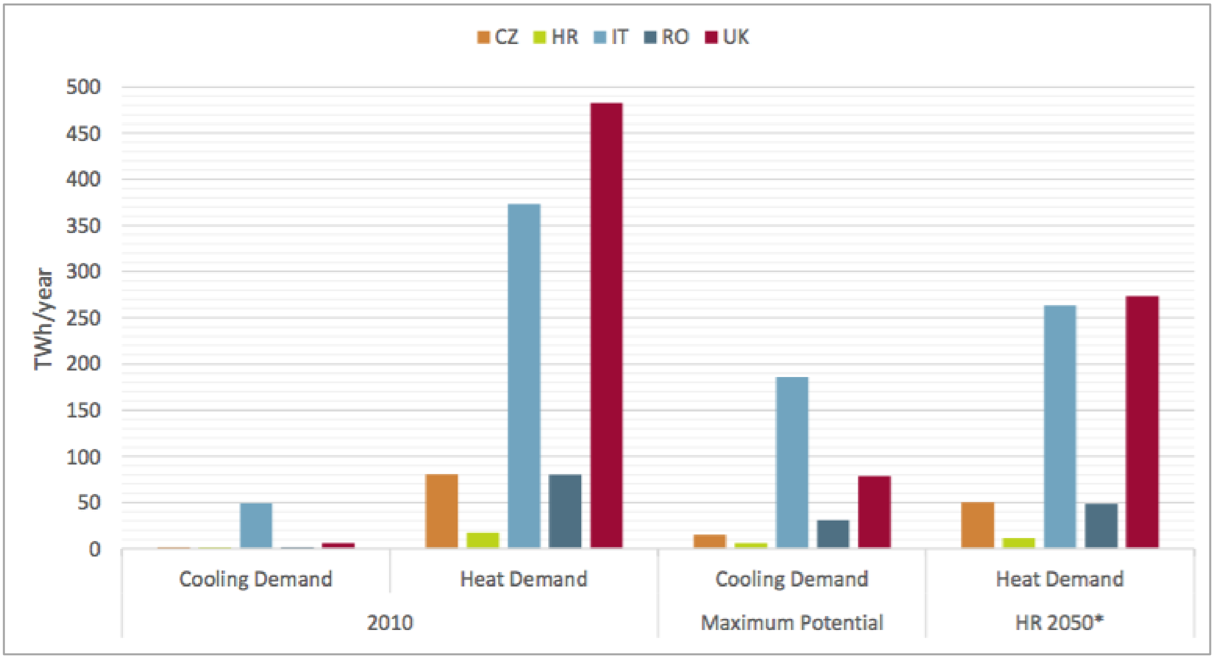
[16] RESCUE (2014), EU district cooling market and trends, 2014. Report prepared by Capital Cooling under the framework of the RESCUE project co-funded by the IEE programme of the EU.

[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).



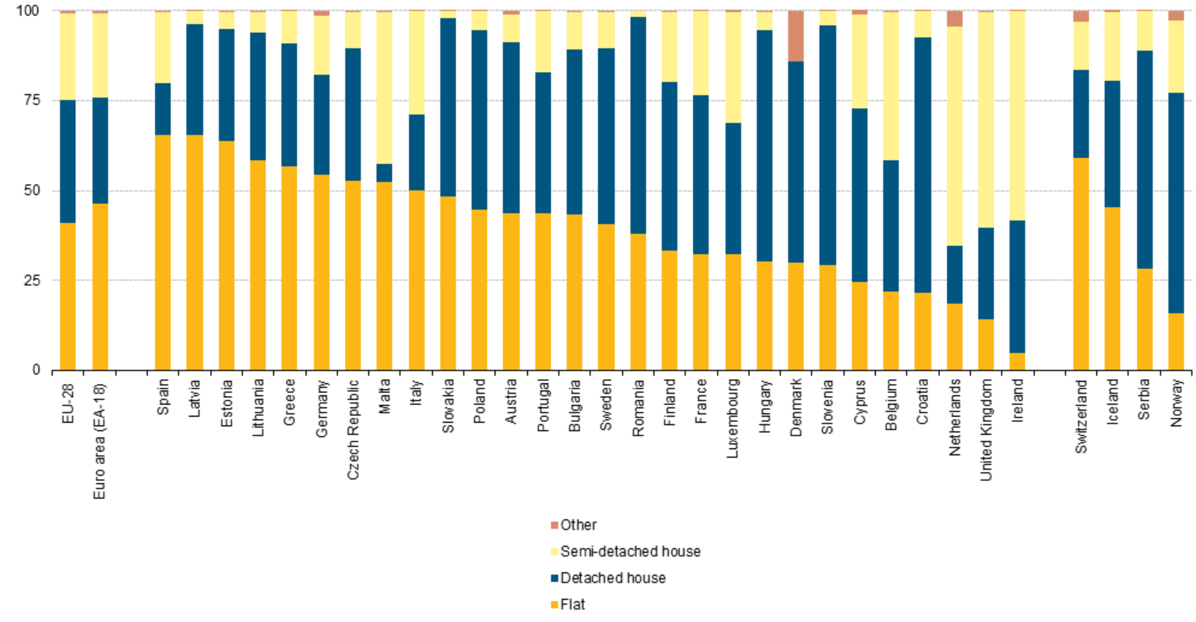
CZ = Czech Republic, HR = Croatia, IT = Italy, RO = Romania, UK = United Kingdom. Source: STRATEGO 2015. The HR 2050 is the heat roadmap 2050 scenario that includes energy savings.

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 %).

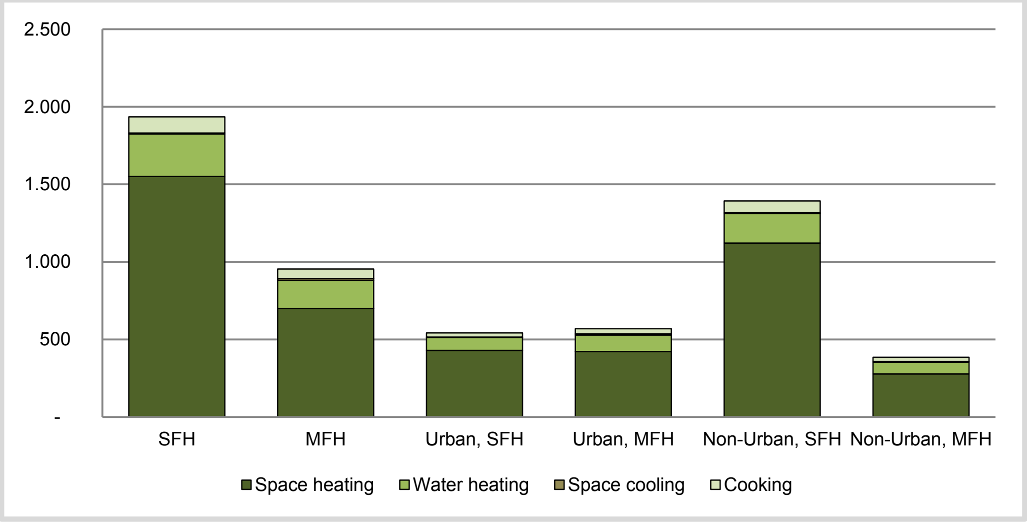
Figure 2-8: Distribution of population by dwelling type, 2013 (% of population)



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

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[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)

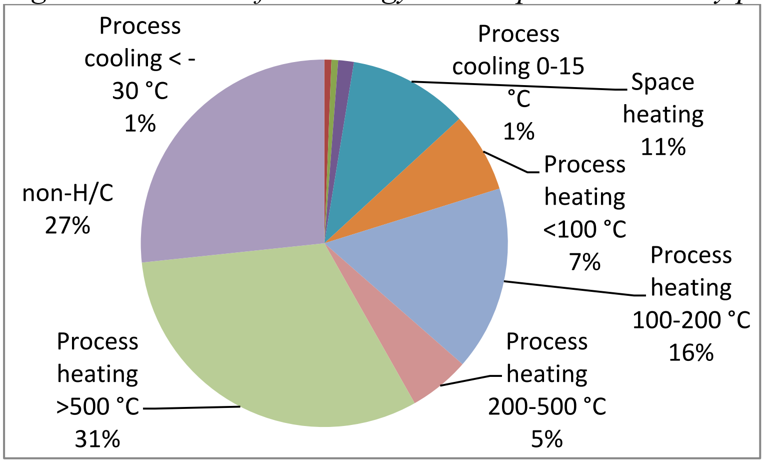
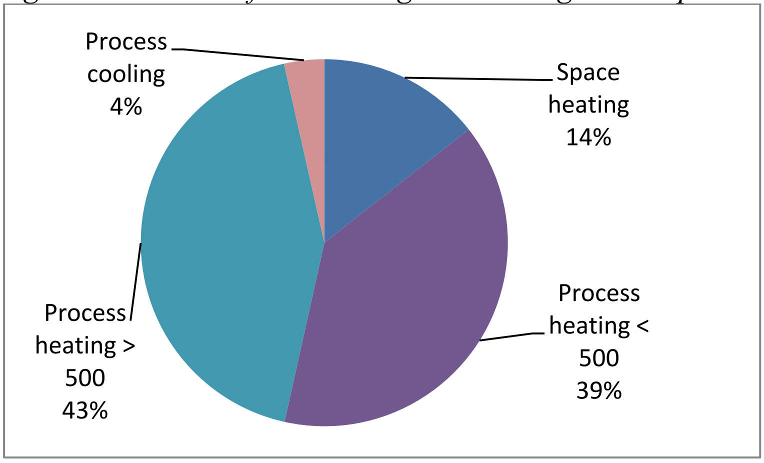


Figure 2-12: EU28 final heating and cooling consumption in industry per end-use (2012)



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].

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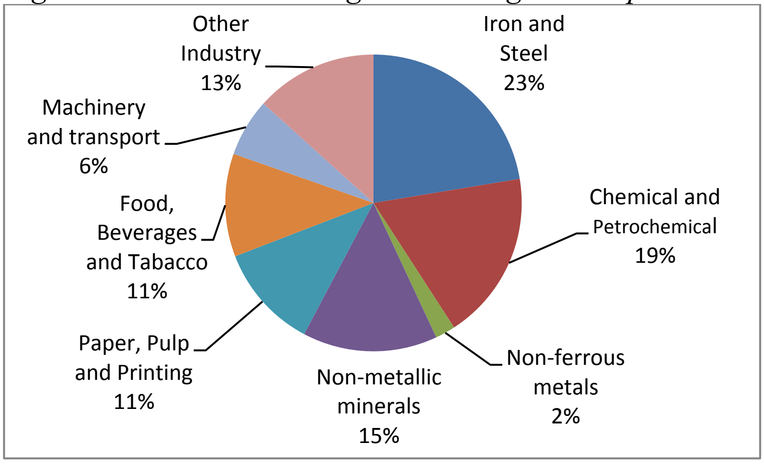
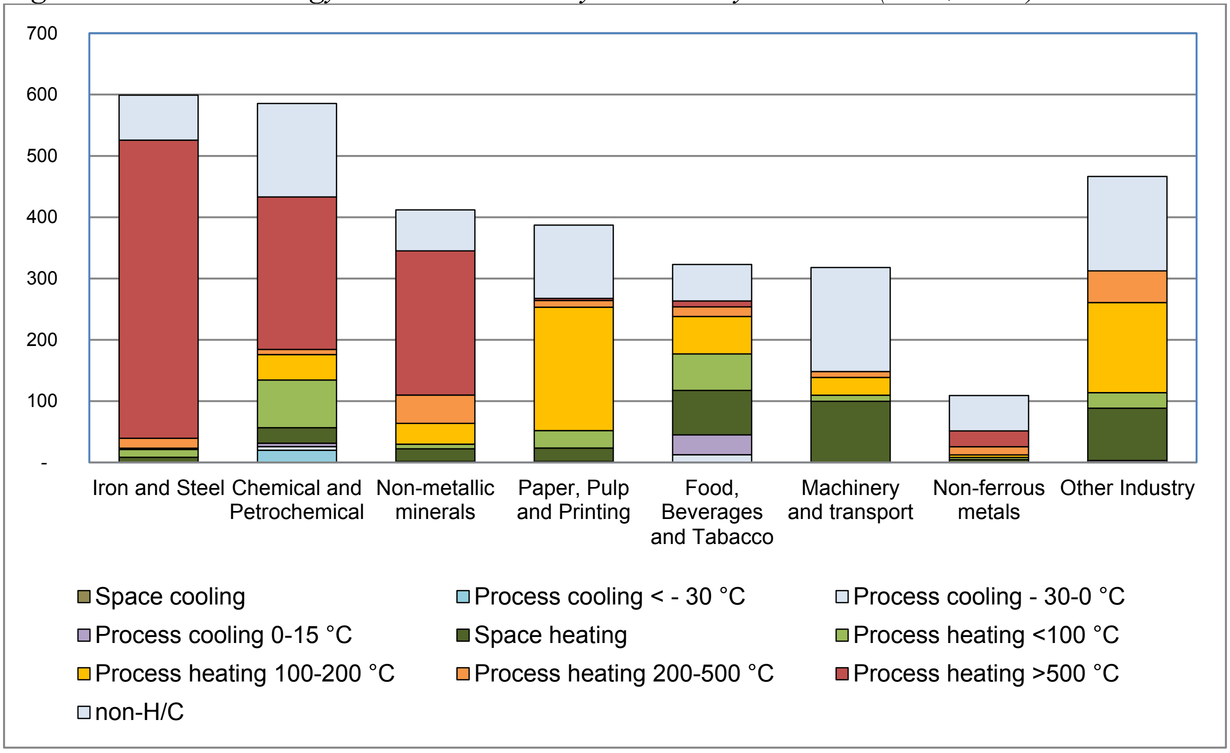
[22] The energy intensive industries included here are: i) iron and steel, ii) non-ferrous metal, iii) chemical, iv) non-metallic mineral products and v) pulp and paper; vi) food, drink and tobacco, vii) textile, leather and clothing, viii) ore extraction, ix) engineering and other metal industries. 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.

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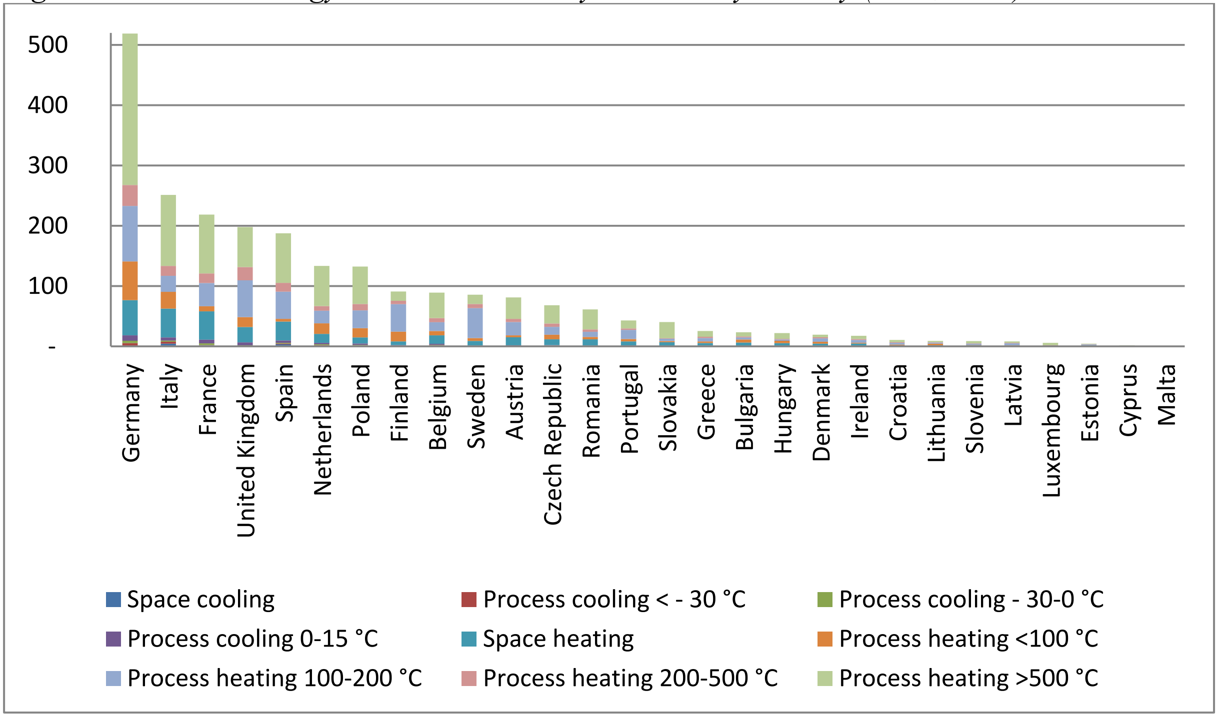
[23] The percentages presented here are with reference to the total final energy demand of the respective sector. Process heat % excludes electrical heating and HVAC. Electricity % includes electrical heating and HVAC (note that non-ferrous metal has very high electrical heating consumption). Process 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)

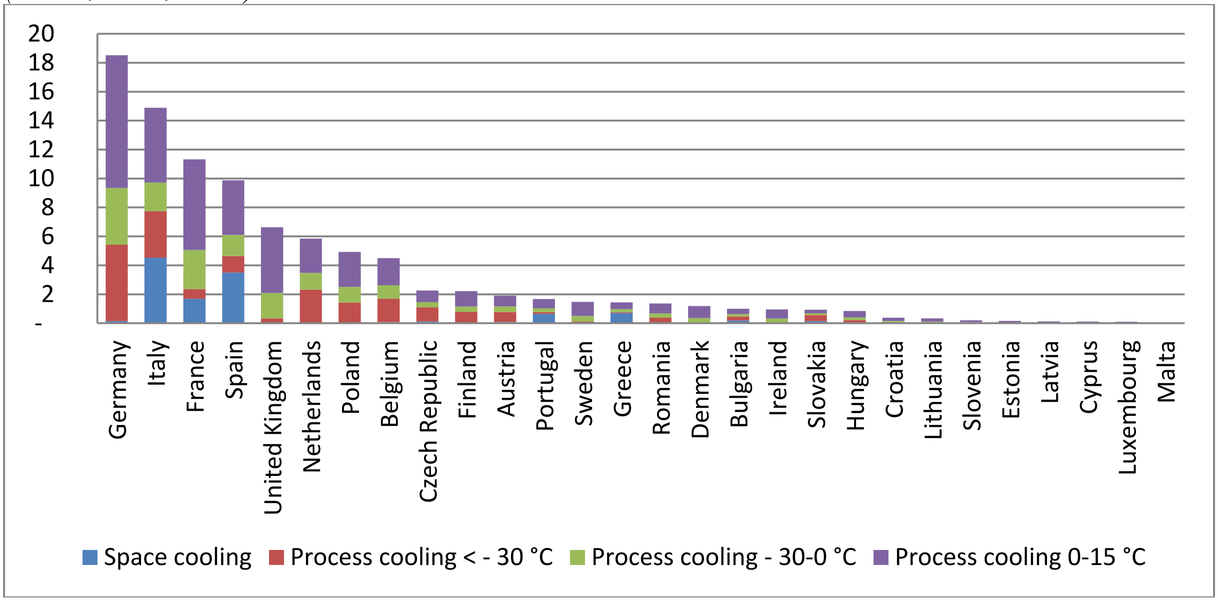


Process cooling between 0°C and 15°C amounts to 53% of the total process cooling demand in Europe and this highlights the importance of the industrial food cool supply along its supply chain. Additional requirements for the food industry with respect to freshness, reduction or complete avoidance of the 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.

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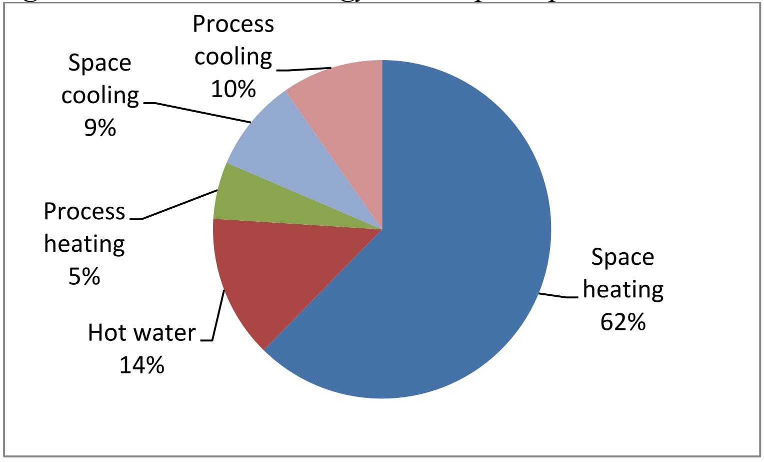
[24] Ibidem.

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.

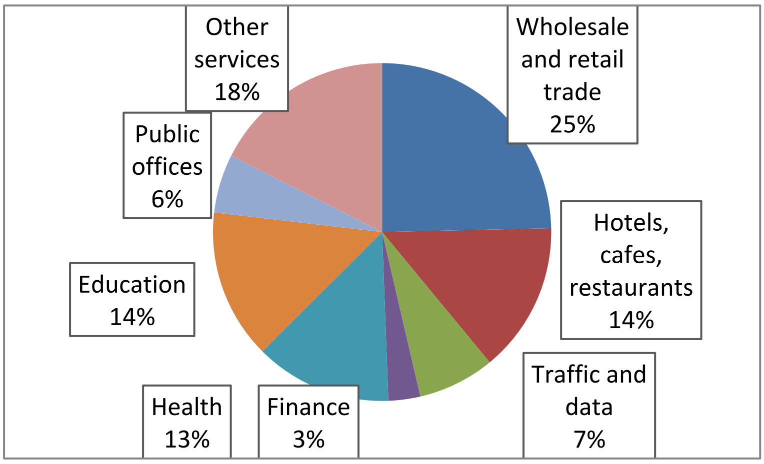
Table 2-4: Service sector grouping and sub-sectors

	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.

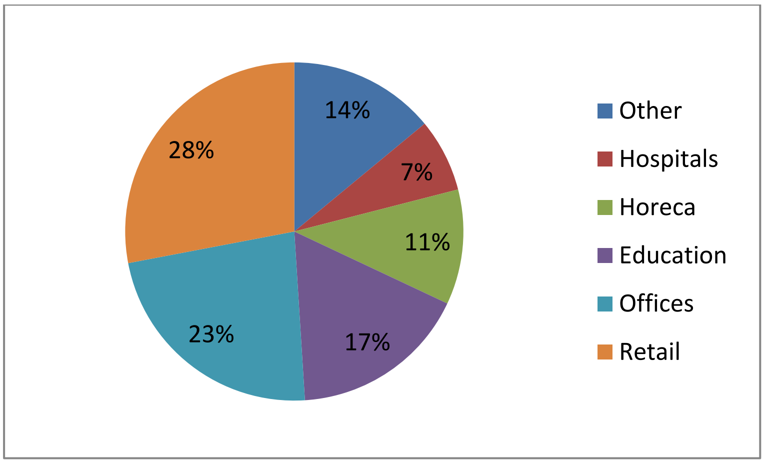
Figure 2-18: EU 28 heating and cooling consumption in services per sector (2012)



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].

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[25] Tait Consulting (2015).

[26] BPIE (2011) Europe's buildings under the microscope.

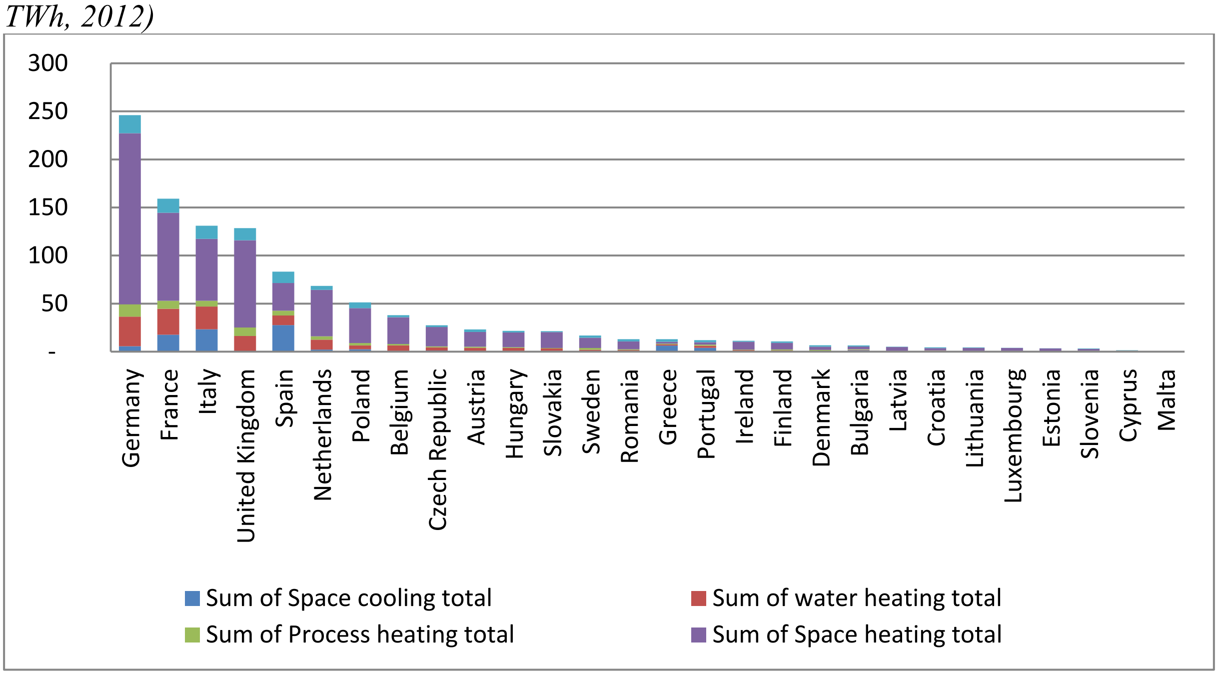
[27] Ibidem.

[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)



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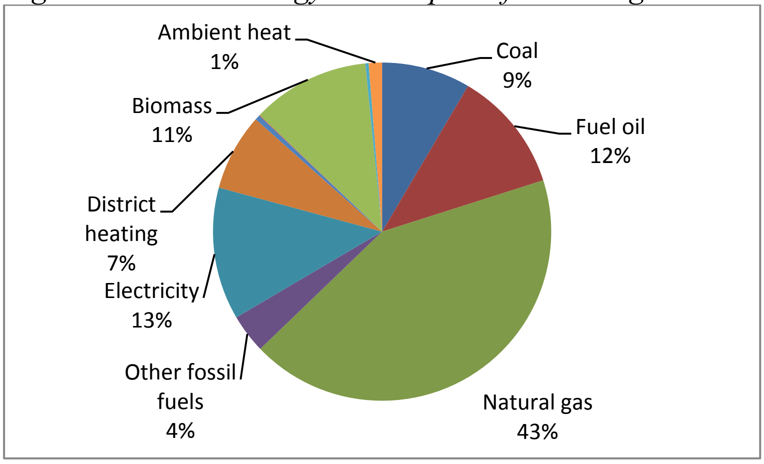
[29] In the UK, an average employee working in this industry occupies 9.7m^2 of workspace. In 2012, this sector employed approximately 3.15 million people in Europe. Assuming that each person worked in an office, the office space used by the sector was approximately 30.6 million m^2 of space. Studies 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.

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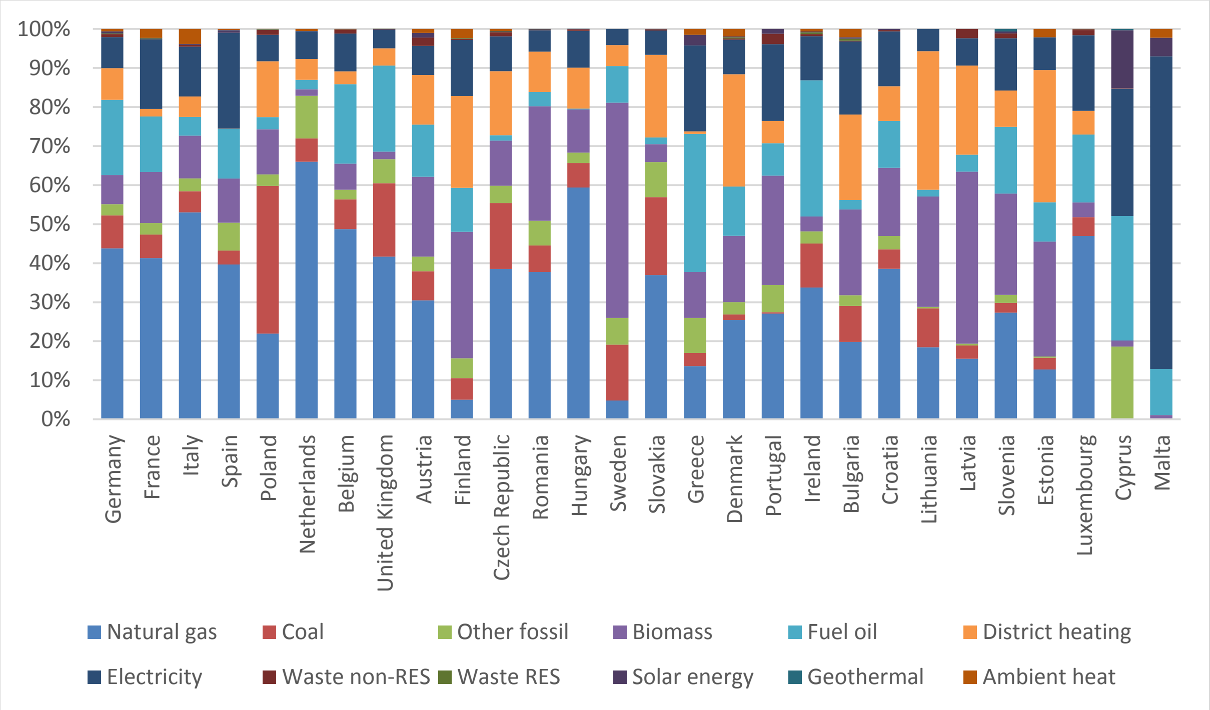
[30] This overall share does not take into account the energy carrier used to produce electricity and in district heating.

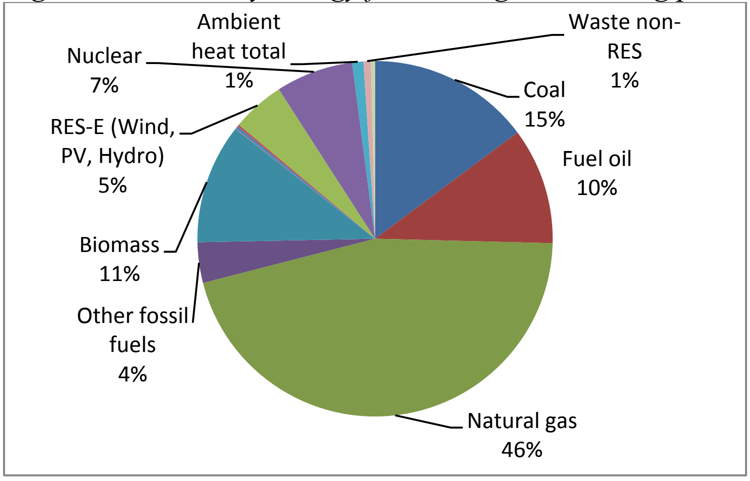
[31] The following sources remain each below 1%: solar, geothermal, renewable waste, non-renewable waste, other.

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,

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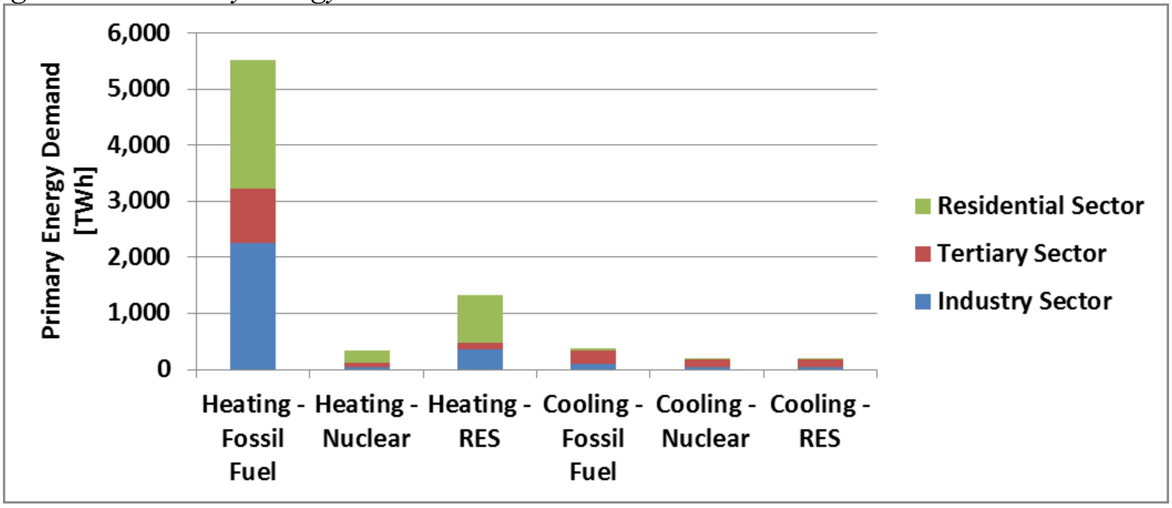
[32] Both nuclear energy and renewable energy are used for electricity generation which in turn is used for heating and cooling.

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].

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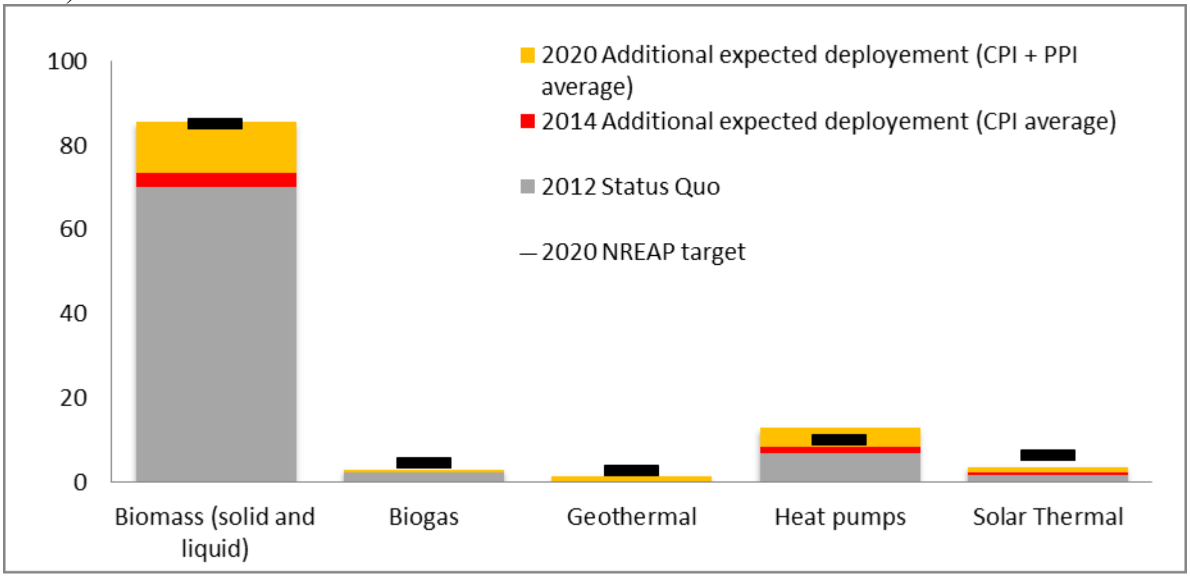
[33] COM(2015) 239 Final.

[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

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[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].

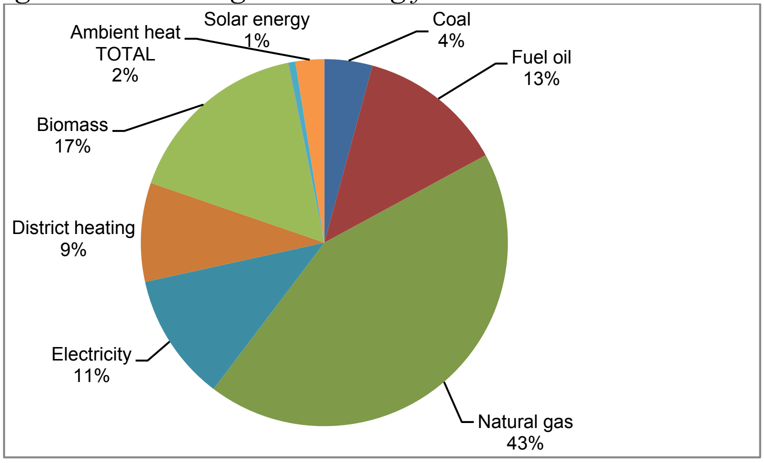
3.1. Fuel mix in buildings

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

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[42] Renewable energy in Europe – approximated recent growth and knock-on effects, EEA 2015.

[43] European Energy Security Strategy, COM (2014) 330.

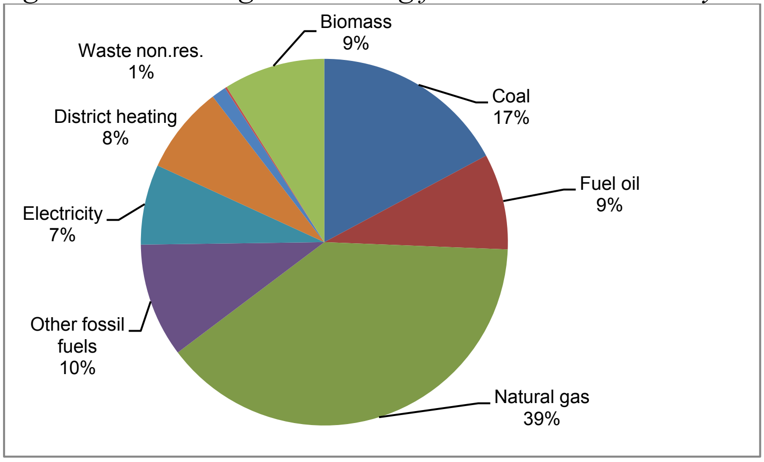
[44] Distance to 100% in the total is due to rounding.

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.

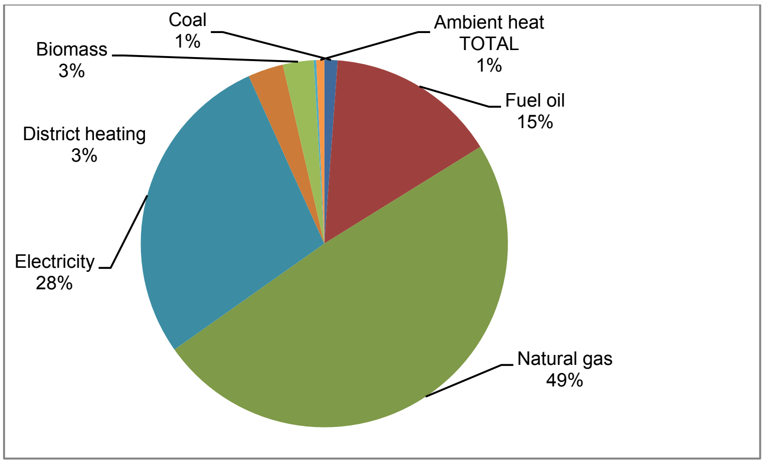
Overall, fossil fuel supplied heat in 2012 represent 75% of the final energy consumed for heating and cooling in industry, to which the share of fossils fuels in electricity and district heating should also be added. Coal with 17% still plays an important role in industrial heating. Renewables (biomass) 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

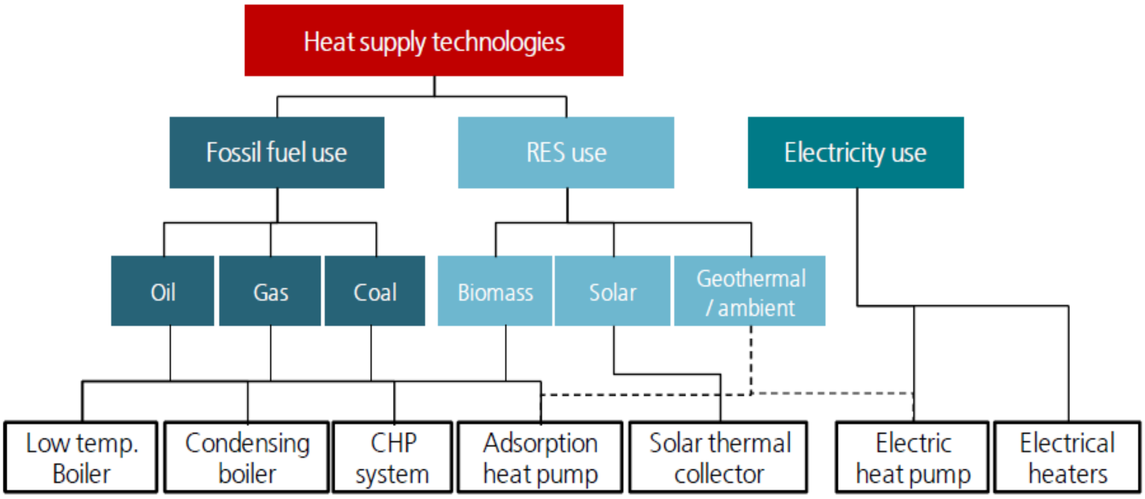
A wide range of technologies can be used to supply heat and cooling for buildings. Boilers are the most commonly used technology. They can be operated on natural gas, oil, coal and bioenergy. Boilers can be of different efficiencies. The currently most widely used standard boilers have an efficiency 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.

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[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.

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[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

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[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.

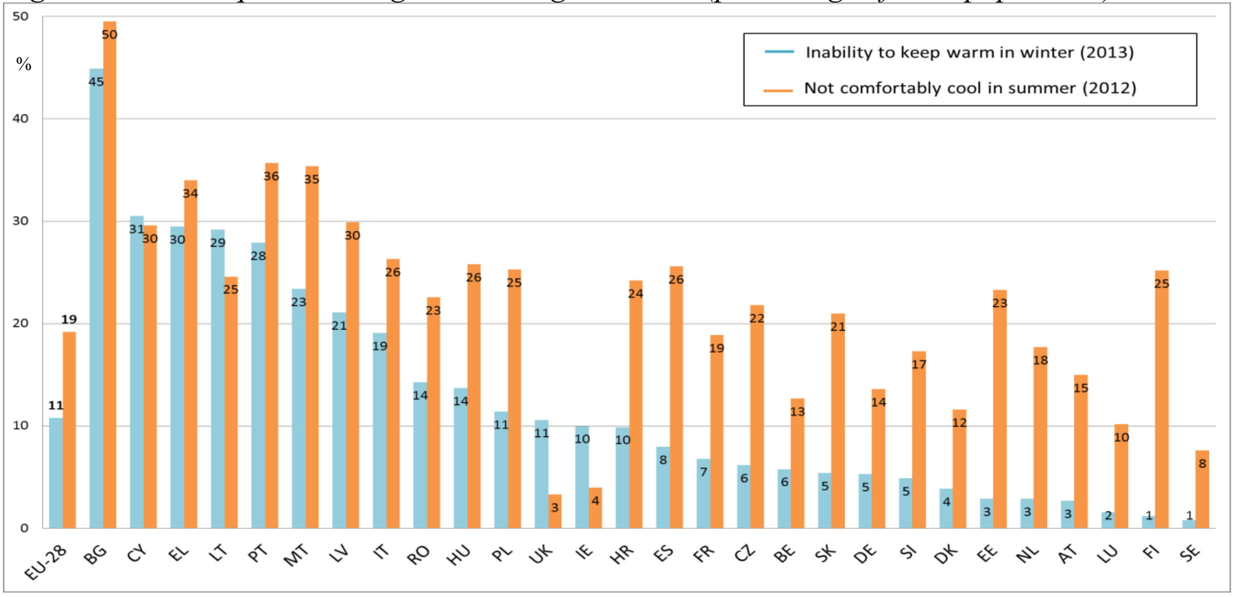
[51] Insight_E (2015) 'Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures'. Available at: http://ec.europa.eu/energy/en/news/energy-poverty-may-affect-nearly-11-eu-population

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

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[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

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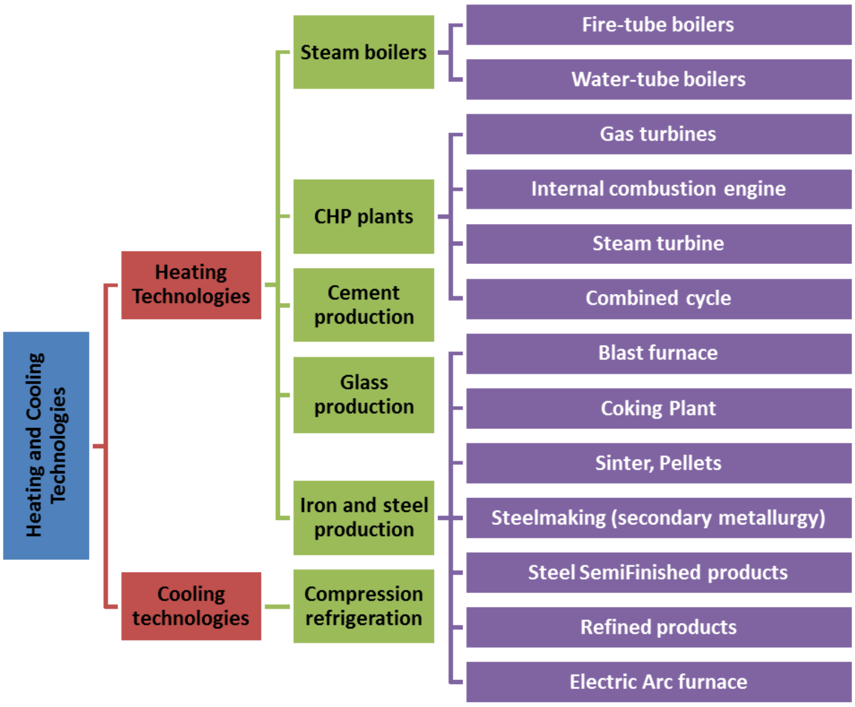
[58] Insight_E (2015) 'Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures'.

[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.

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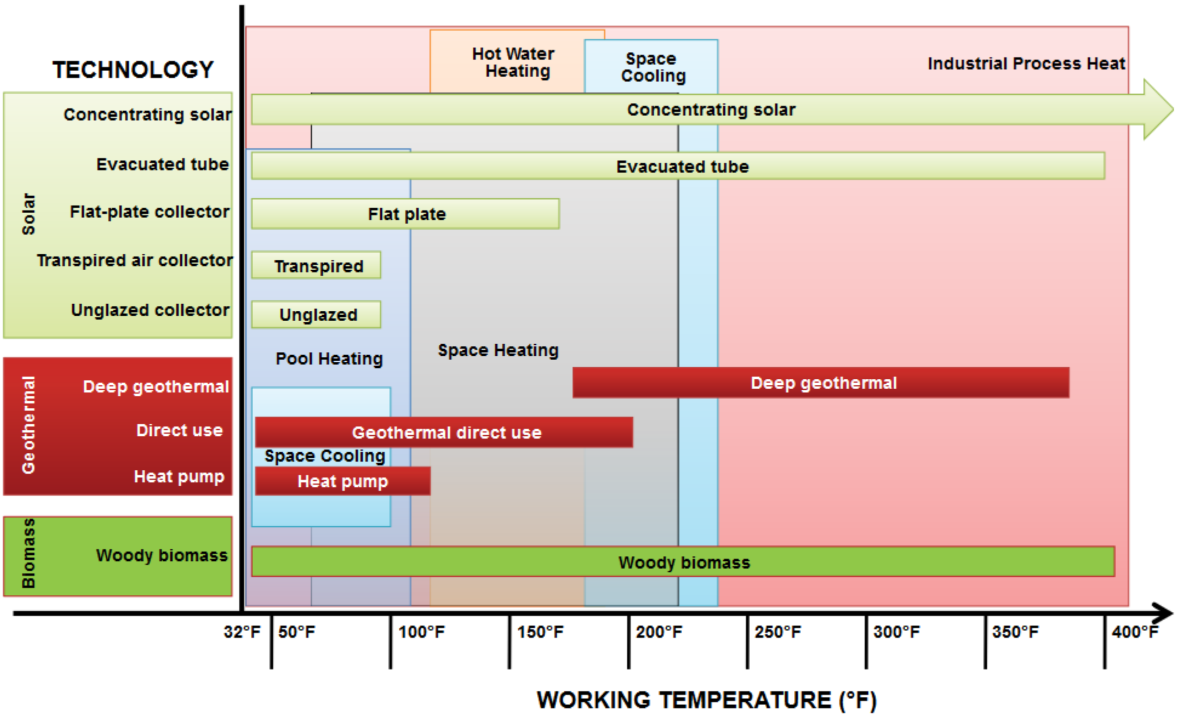
[60] See Ecodesign preparatory studies at: http://www.eup-network.de/product-groups/overview-ecodesign

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

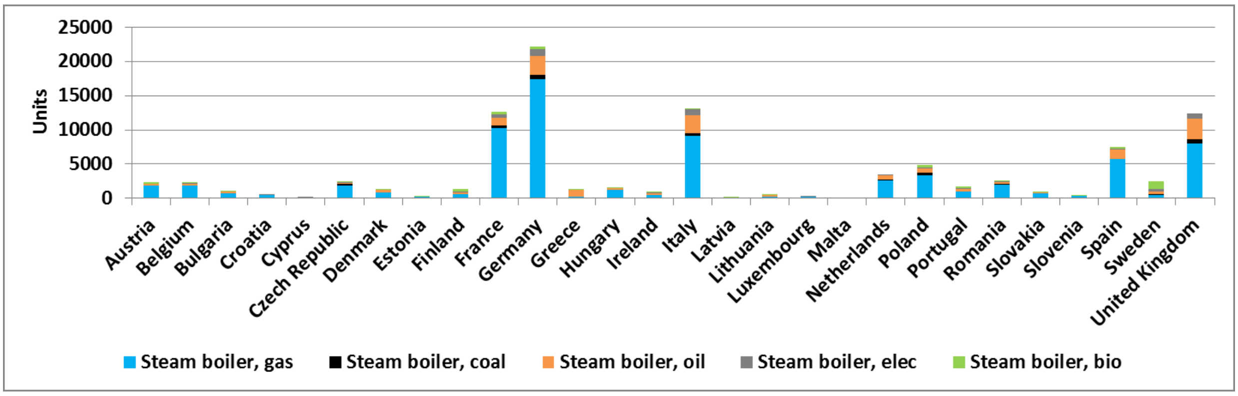


Figure 4-6: Steam boilers, number of units and installed capacity in EU-28 in 2012

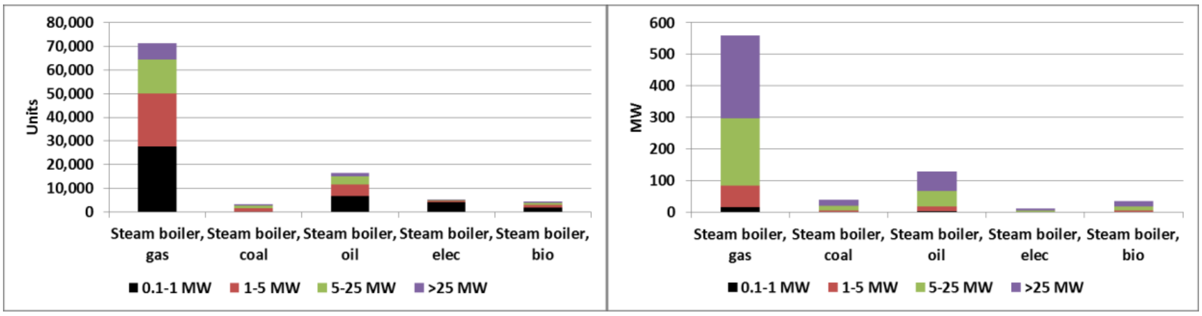


Figure 4-6 shows the number and total installed capacity of steam boilers categorised according to the fuel used and the capacity range of the unit, which could vary from 0,1 MW up to more than 25 MW. Most of the units are boilers with a capacity from 0.1 to 1 MW_{th} but their total installed capacity 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].

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[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

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[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.

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[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

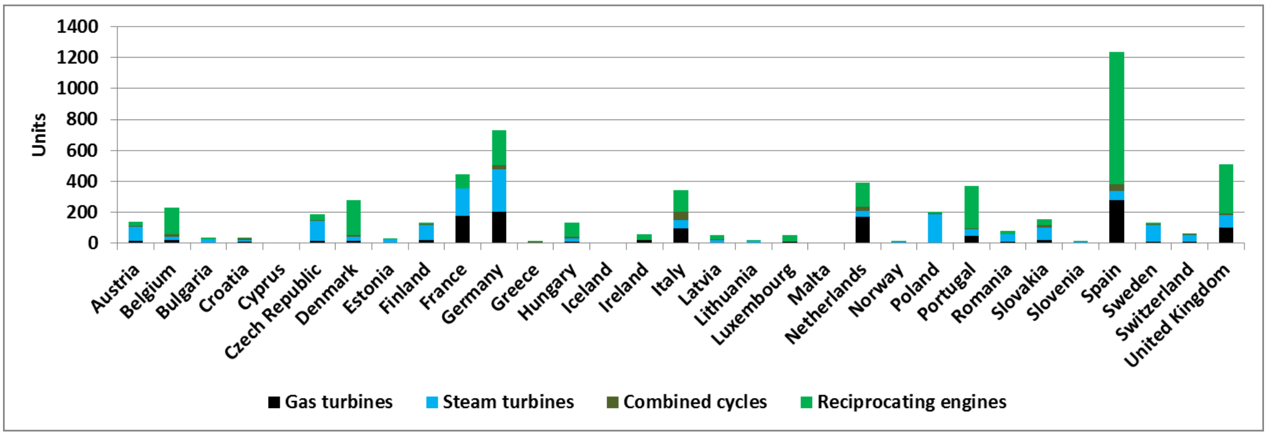


Figure 4-8: Installed CHP units according their capacity and age in EU-28^{SIN} in 2012

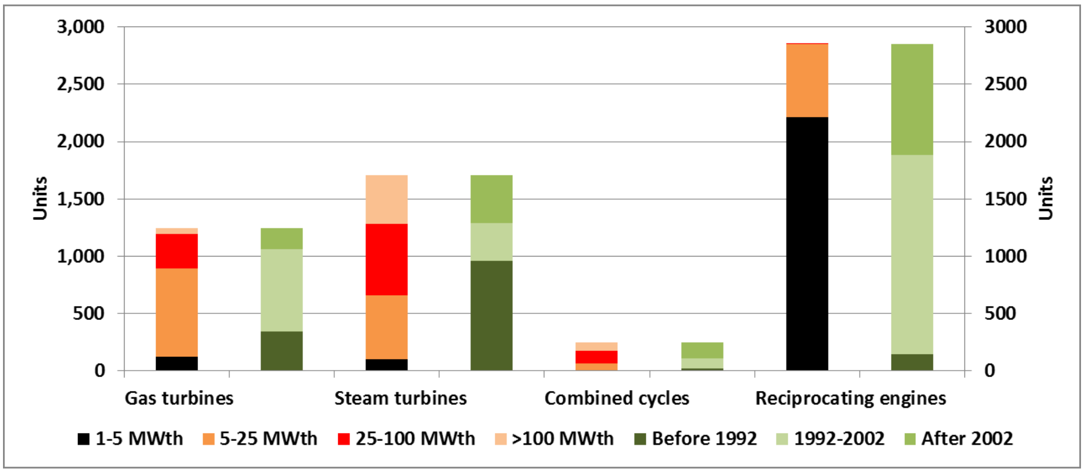
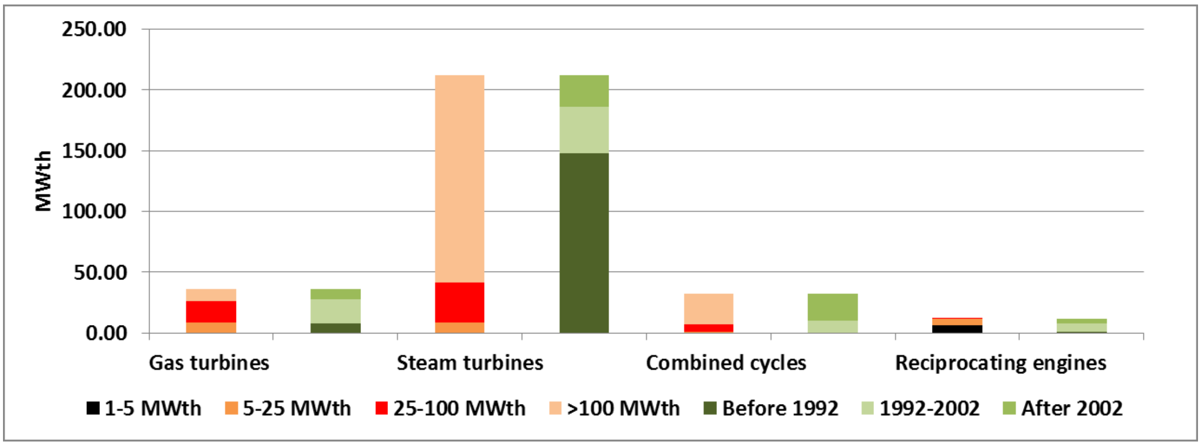


Figure 4-8 shows that reciprocating engines (CHP$_{RE}$) are mostly used for the lower capacity range. The large majority of the CHP$_{RE}$ were small units constructed after 1992 . In contrast to these numbers, the installed CHP steam turbines (CHP$_{ST}$) have mainly been constructed before 1992 and 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*).

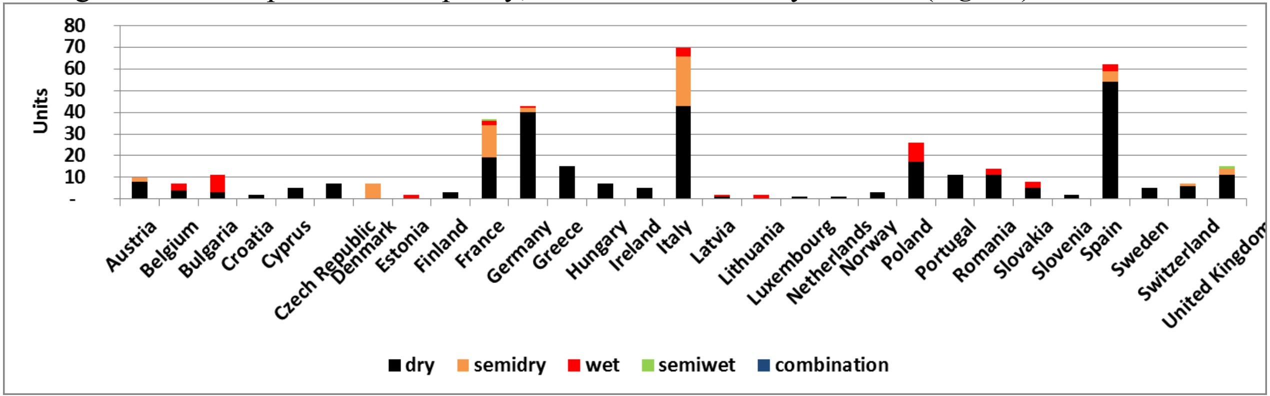


Figure 4-10: Cement production units in the EU-28^{SIN} in 2012

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[66] Fraunhofer 2015

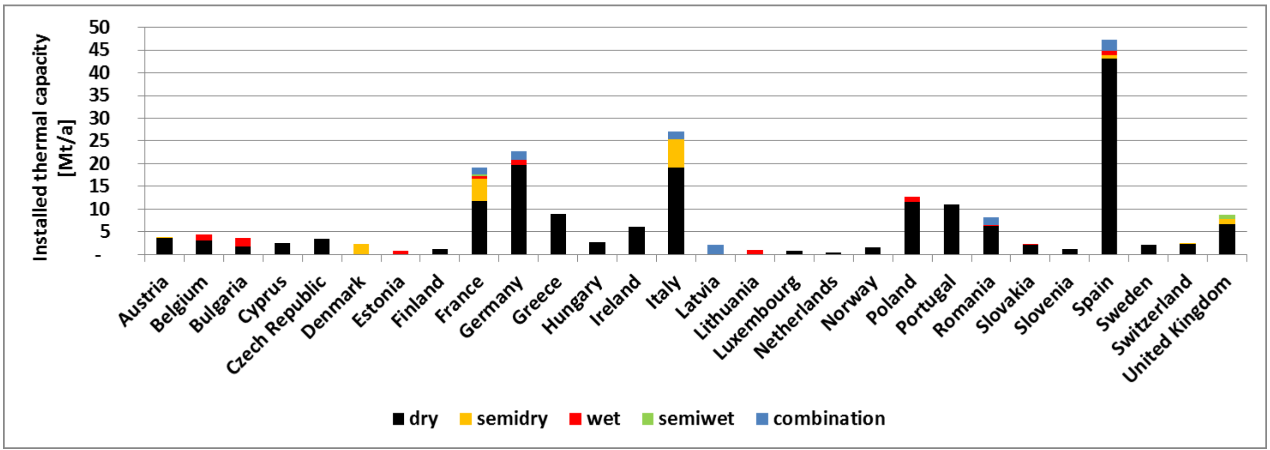


Figure 4-11: Cement production capacity in EU-28^{SIN} in 2012

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

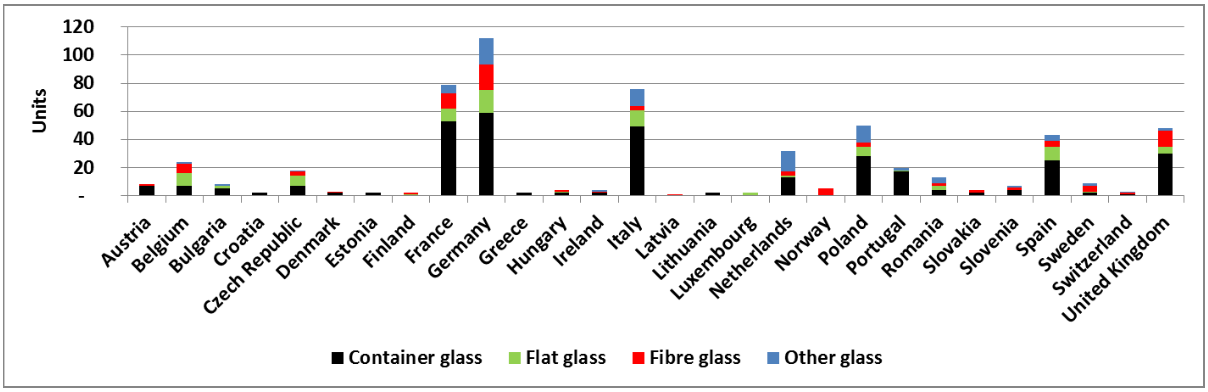
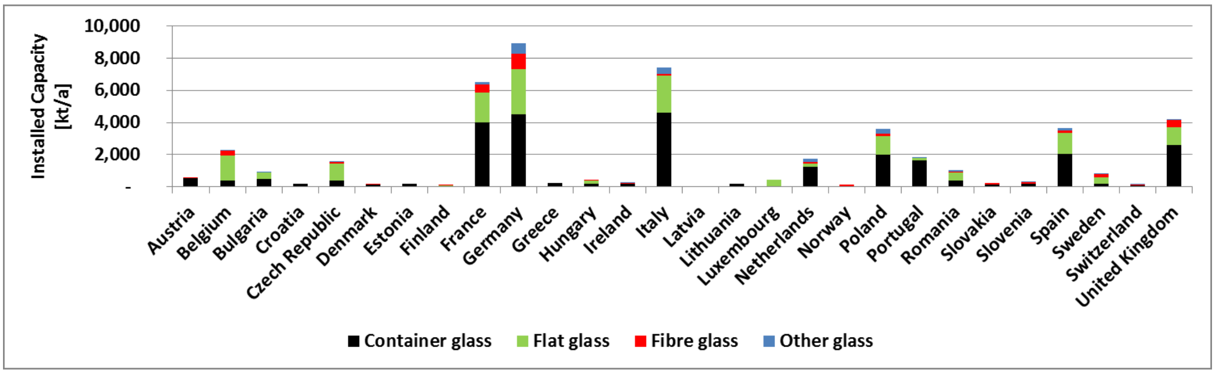


Figure 4-13: Installed capacity of glass production units in EU-28^{SIN} in 2014



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%

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[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]

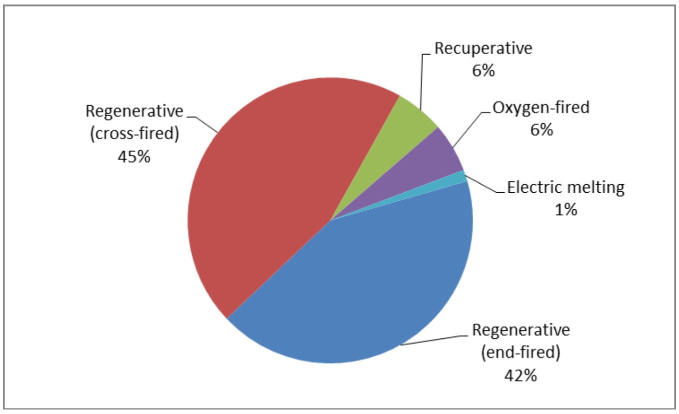

Figure 4-14 illustrates the share of regenerative furnaces for the two main glass manufacturing sectors (container glass and flat glass). Glass fibre production and other glasses types rely on more diverse technologies.

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

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[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 (

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[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.

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[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

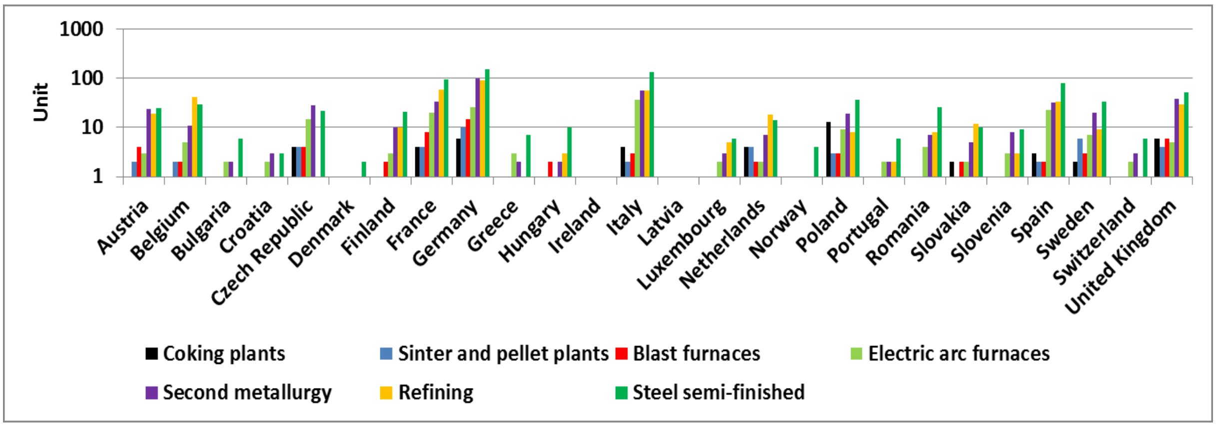


Figure 4-16: Installed capacity of iron and steel producing units in EU-28^{SIN} in 2014

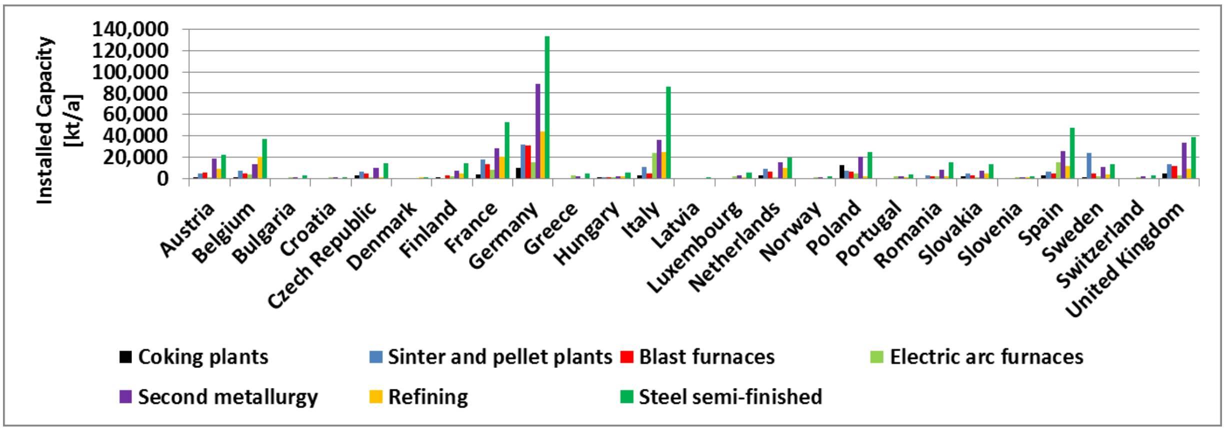
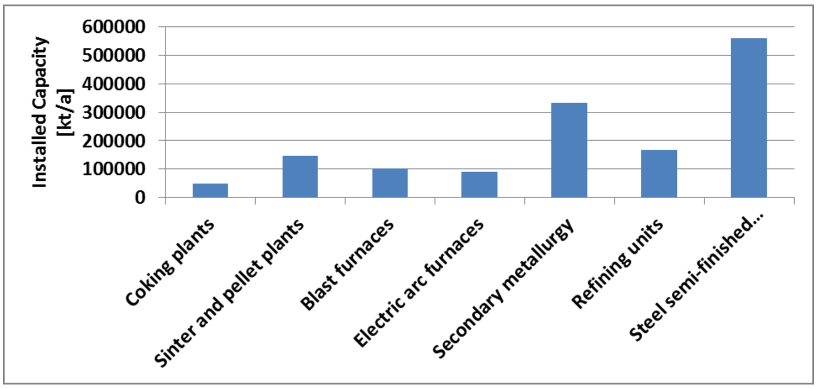


Figure 4-17: Installed capacity in EU-28^{SIN} of the different iron and steel processing units in 2014



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.

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[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

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[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

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[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

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[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

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[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).

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[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.

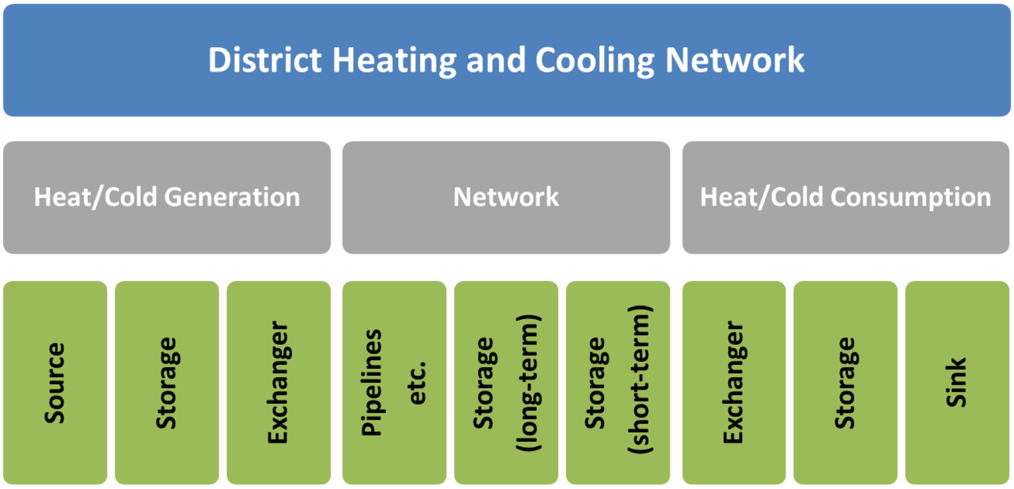
Solar heating systems combined with biomass boilers can provide 100% renewable heating systems. The combination is technically straightforward and several manufacturers already offer combined systems that are perfectly integrated and available in high performance kit systems.

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

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[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.

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[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

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[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.

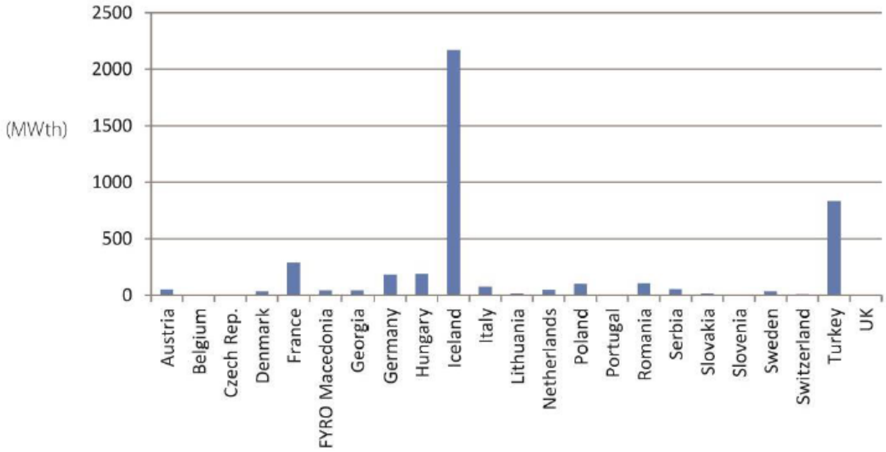
[88] An example of this is being investigated in the Smart Cities and Communities project CELSIUS. http://celsiuscity.eu/ . Project co-funded by the Framework programme 7 of the EU.

[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

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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

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[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 m^2) (RHP 2015). Most of these systems are pilot plants with a relatively

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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

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[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.

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[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

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[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

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[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

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[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.

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[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

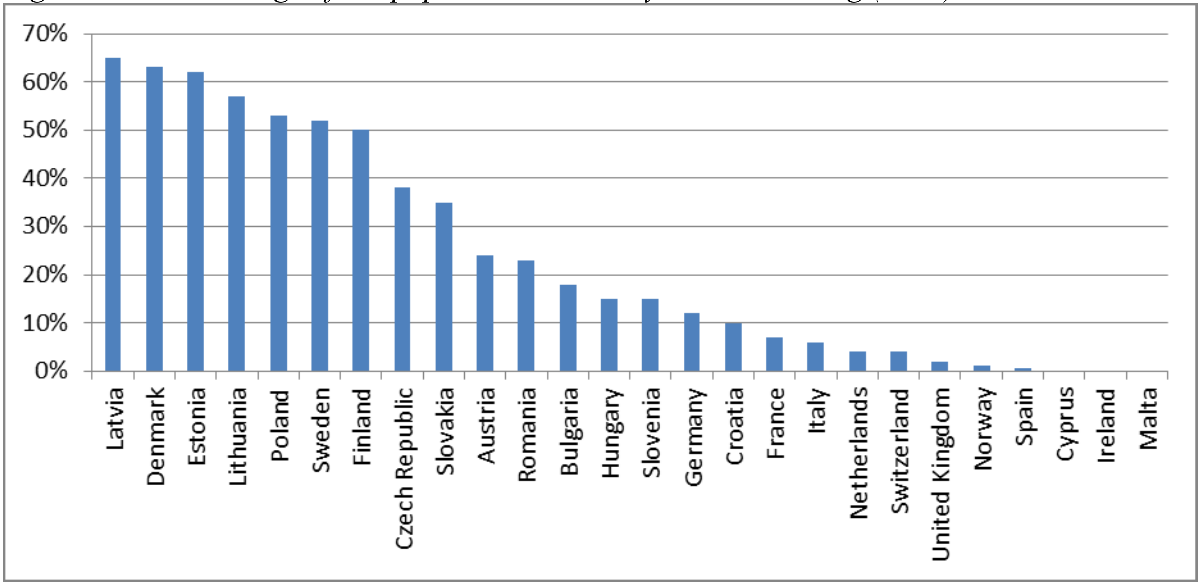
Heat Generation

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]

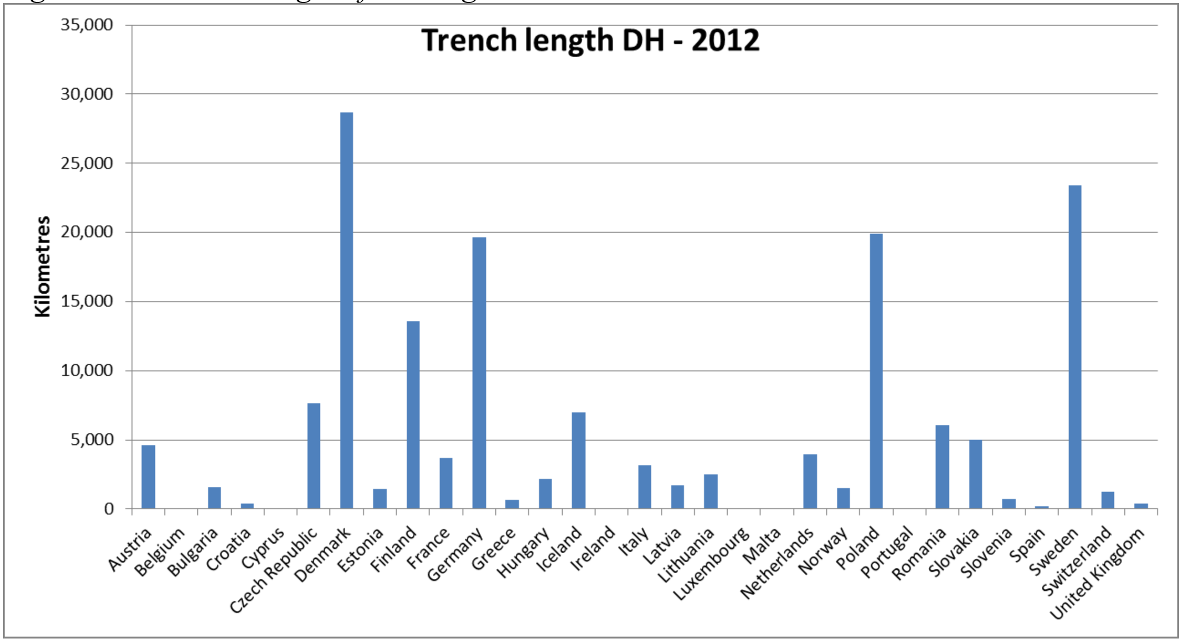
Figure 5-1: Percentage of the population served by district heating (2013)



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}



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[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

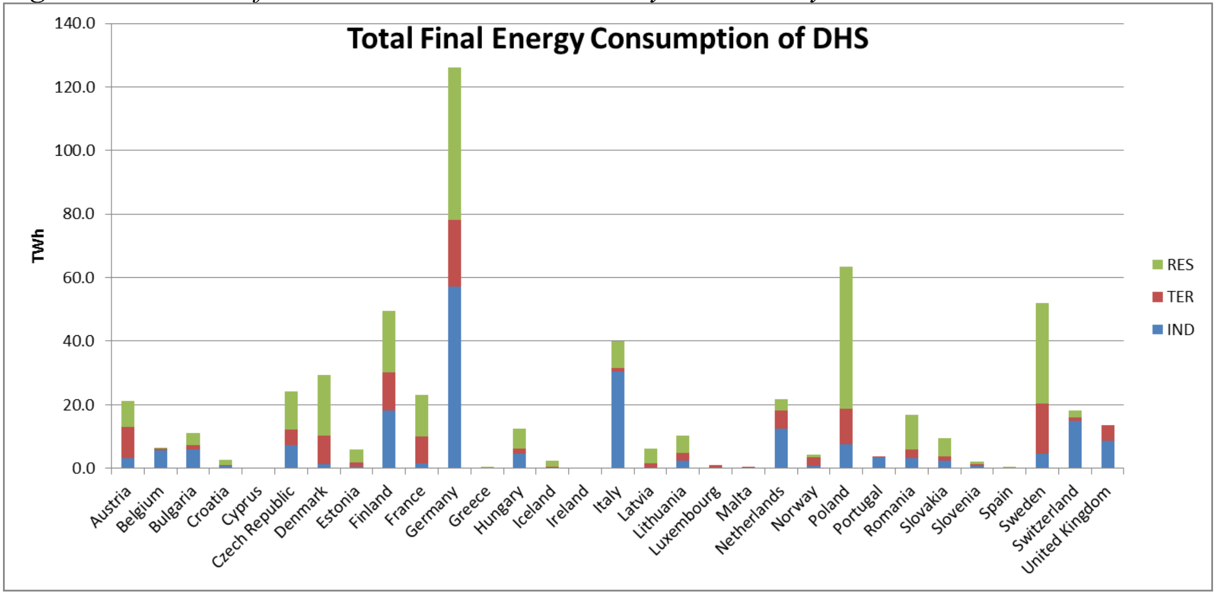
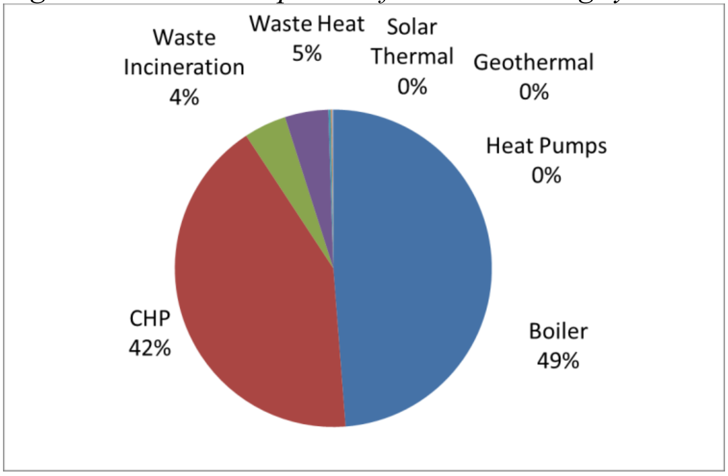


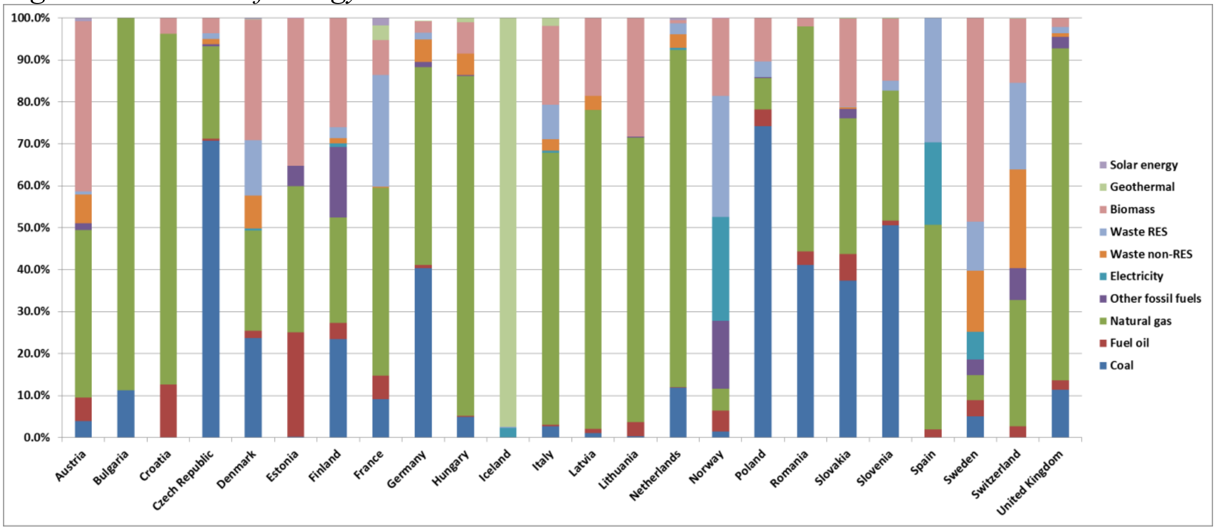
Figure 5-4 shows the share of the installed power of heating applications in DH systems (DHS) of the EU-28^{SIN}. The available data is not complete but allow identifying the most common applications, which are boilers, followed by CHP, waste heat recovery applications and waste incineration plants. 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%).

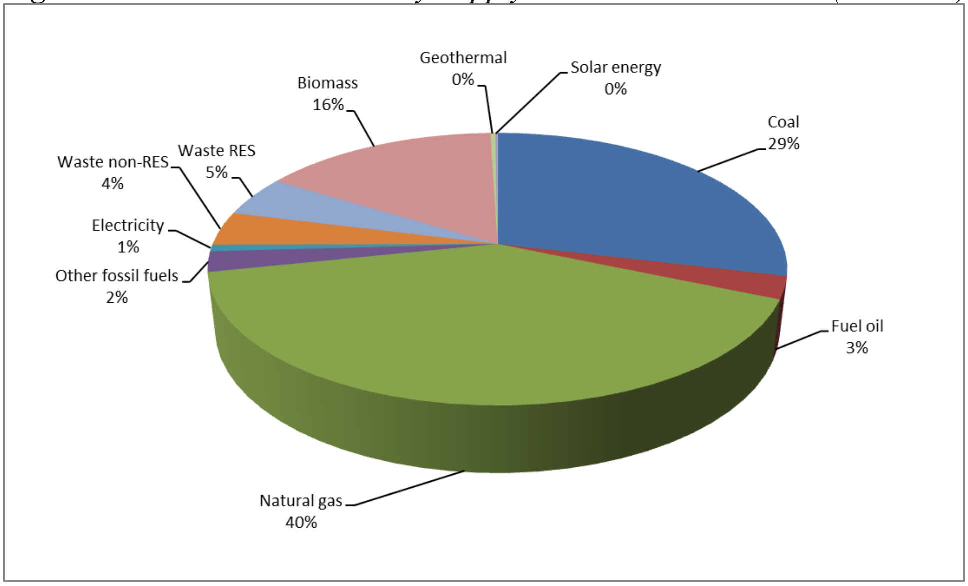
Figure 5-5: Share of energy carrier in DHS in 2012



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.

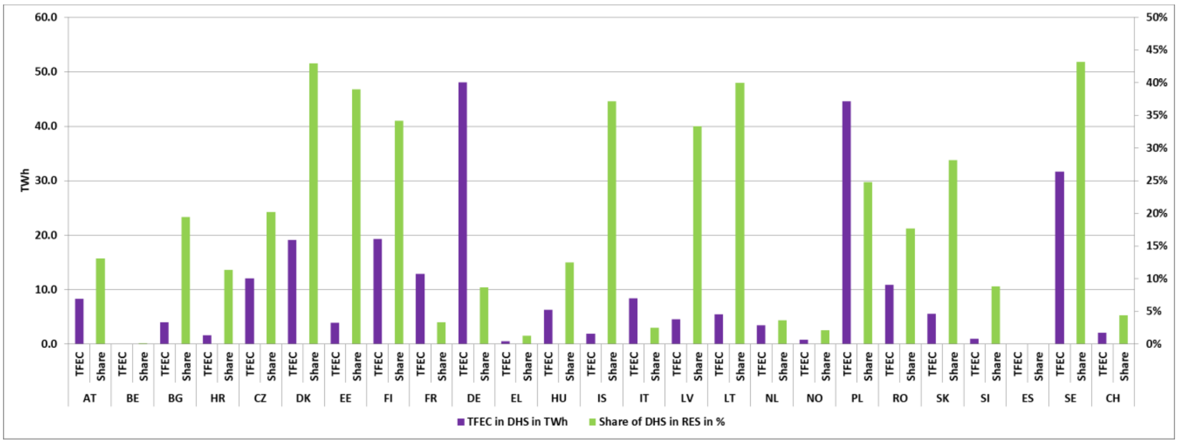
Figure 26: District Heat Primary Supply Sources in EU28 2012 (606 TWh)



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]

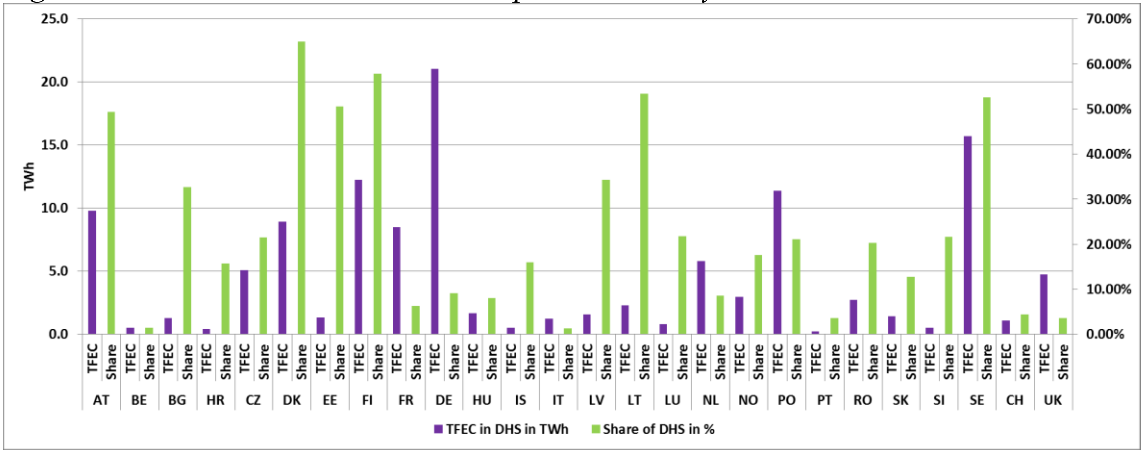
If we look at the situation of district heating by sector, the situation is again different across countries. In the residential sector, the most important countries in relation to the total final energy (TFE) consumption are Germany followed by Poland and Sweden. These three countries are generating 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]



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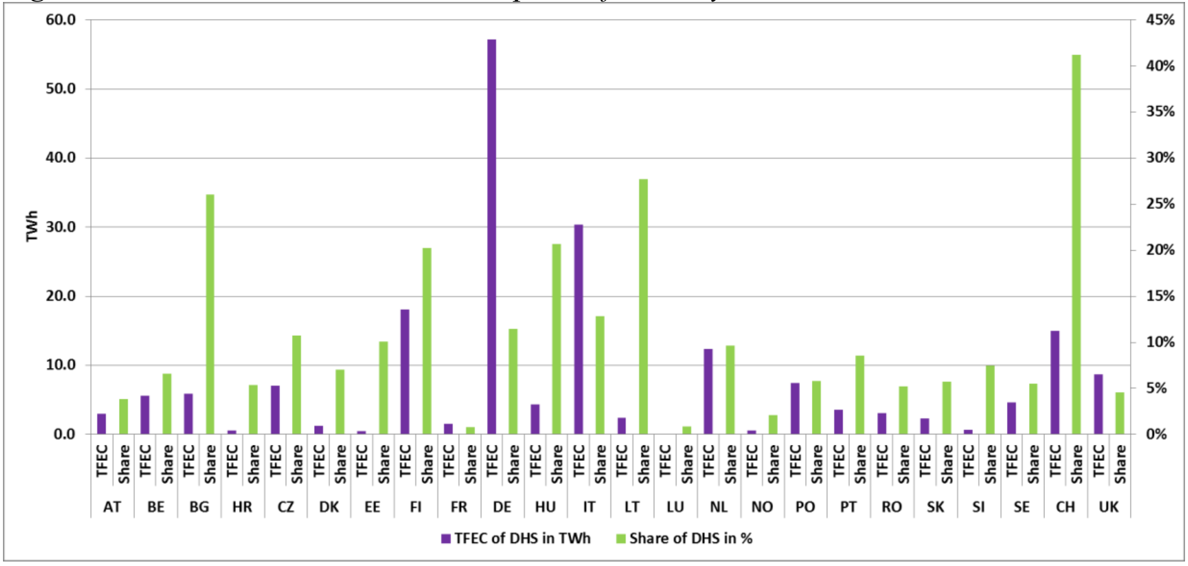
[117] Euroheat and Power (2015): "District Heating and Cooling – Country by Country – Survey 2015", Status: 2013

[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.

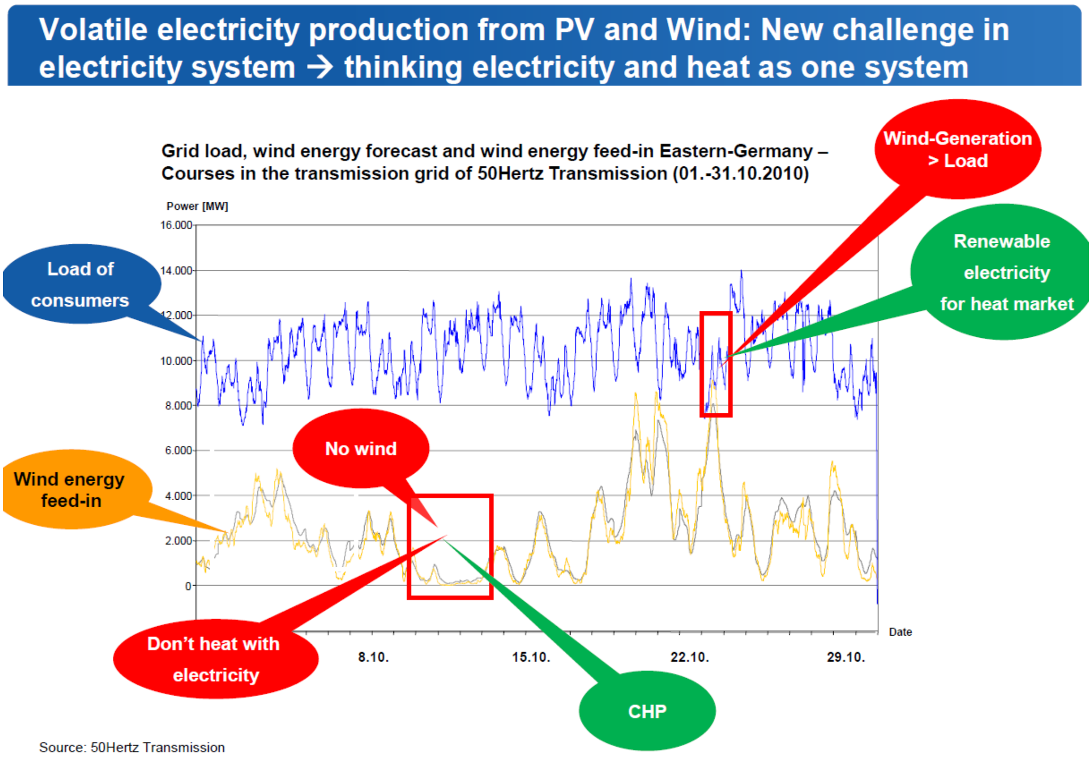
Flexibility is achieved by making demand flexible and through energy storage. Currently demand response and demand management are the most established demand flexibility solutions. However, this flexibility is limited by the demand in the current electricity system, which even if shifted to the time 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.

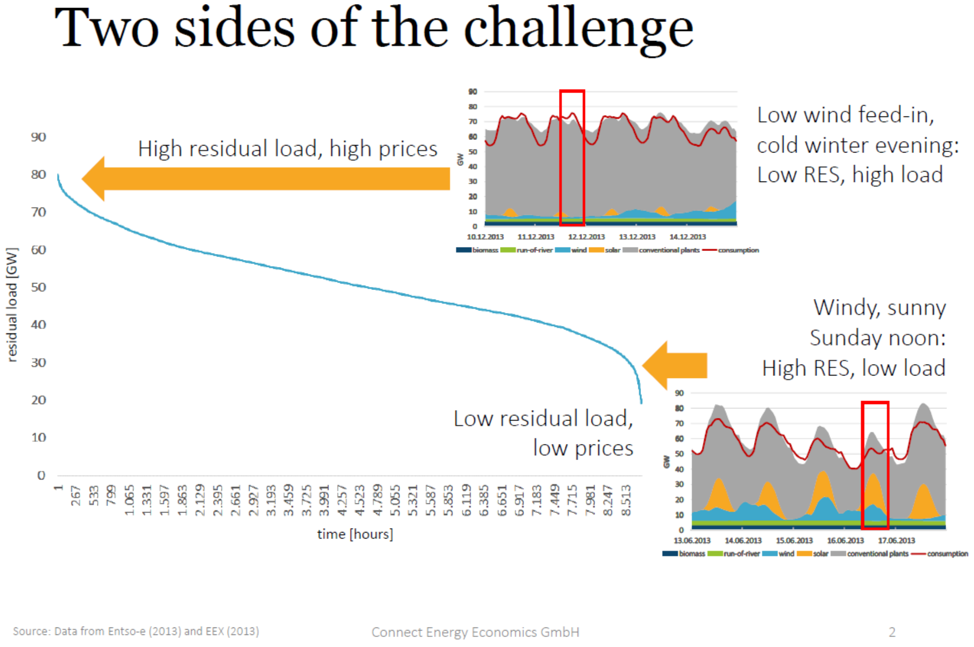
For storage to become part of a renewable based energy system, storage also need to be recognised as an economically viable solution and a necessary component of balancing strategies that will be needed in the frame of the transition to more sustainable European energy transmission, distribution and 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



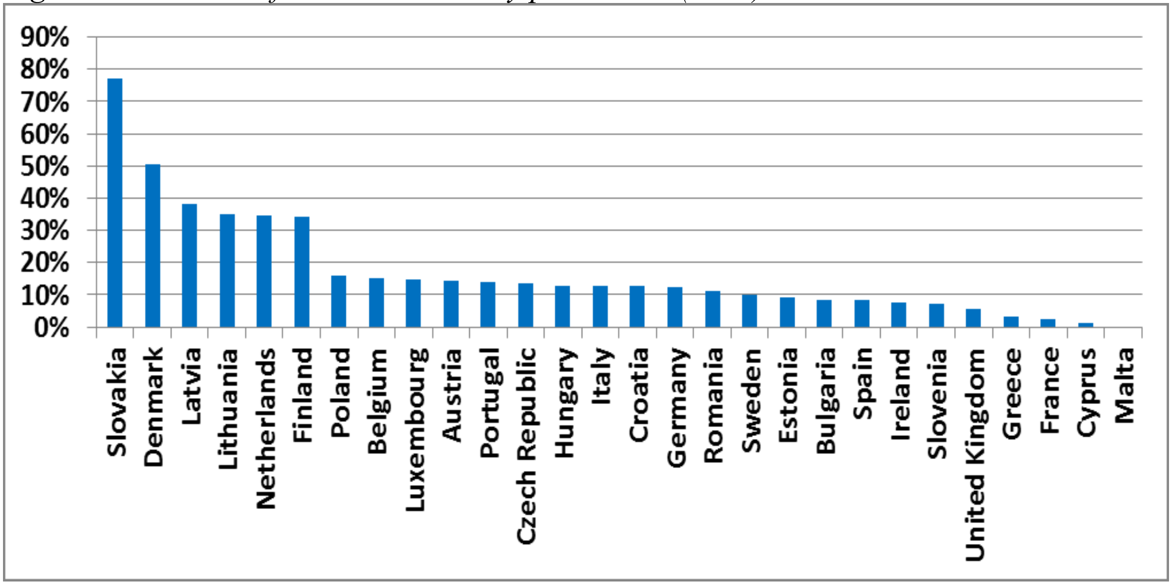
During the hours with low residual load, electricity prices ought to be low, as supply is relatively high compared to demand. In such situtions the heating sector would benefit from using cost efficient renewable electricity. Another benefit of the heating and cooling system is that it offers large quantities 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.

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PART 2/2

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 final}

Contents

6. FOCUS ON COOLING TECHNOLOGIES

6. FOCUS ON COOLING TECHNOLOGIES[1]

6.1. Cooling needs in the residential sector

The two main uses for cooling in the residential sector are for preserving food quality in household refrigerators and freezers and for space cooling using portable and/or fixed air conditioners. Since household refrigerators and freezers are not included in the scope of the analysis of this Staff Working Document, this section focuses on the needs related to space cooling.

The EU market for space cooling equipment is considered to be only mid-way towards saturation and so the high growth rate is likely to be sustained to beyond 2030 into properties that had previously not had space cooling. Sales of residential air conditioning units were estimated at just over 3 million units per year in 2010, rising to 4.5 million by 2030 (ARMINES 2008). Italy, Spain, Greece and France together account for the majority of EU sales; Italy and Spain account for over half of EU sales by installed capacity (ARMINES 2008). This matches with the data on final energy consumption for cooling purposes presented in Section 2. Through efficiency improvements anticipated from measures such as the EU Ecodesign minimum requirements and energy labels, consumption is projected to fall to by 40% to 51 TWh_e by 2030[2].

Around 80% of residential cooling capacity is provided by room air conditioners of the single split type (one indoor unit and one outdoor unit joined by refrigerant pipework) with multi-splits providing just over 10% of the capacity (single outdoor unit with two or more indoor units, ARMINES 2008). Window-mounted units account for only around 2% of sales and capacity, in contrast with US market where window units account for a significant proportion. Moveable air conditioners (that often need to have an air duct hose fed out through a window) account for 10% or less of EU sales and capacity (ARMINES 2008).

Key opportunities to reduce demand arise from better thermal performance of the building envelope and lower heat gains through glazing – these factors may be addressed through building regulations and through an energy label for windows that is currently at draft stage[3] which takes account of solar gain. Thermal performance of buildings has to be carefully balanced: much improved insulation for winter conditions can lead to excessive indoor temperatures in summer where internally generated heat (lighting, electronics, cooking) cannot be adequately dispersed. This has been noted in the UK and has given rise to health and safety concerns, particularly for the elderly. It is important to recognise that local climate and building use can be as important as product characteristics. Building design that includes natural ventilation and solar shading has the potential to reduce significantly demand in some regions of the EU, but due to the very low renovation or replacement rate of residential buildings, the effects and impacts will be gradual over time.

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[1] This Section is based on Tait Consulting (2015 - ongoing), “Equipment for refrigeration and air conditioning in the EU: technology, energy consumption, trends and opportunities”, (Service Contract ENER/C3/2015-603), J. Tait for DG ENER.

[2] These figures are outcomes of the VHK Ecodesign Impact Accounting (EIA) study of May 2014. This study provides a harmonised dataset and calculation methodology for all equipment within scope of EU Ecodesign and Energy labelling measures.

[3] The preparatory study for windows was completed in June 2015; a consultation forum considered a first draft implementing measure in September 2015.

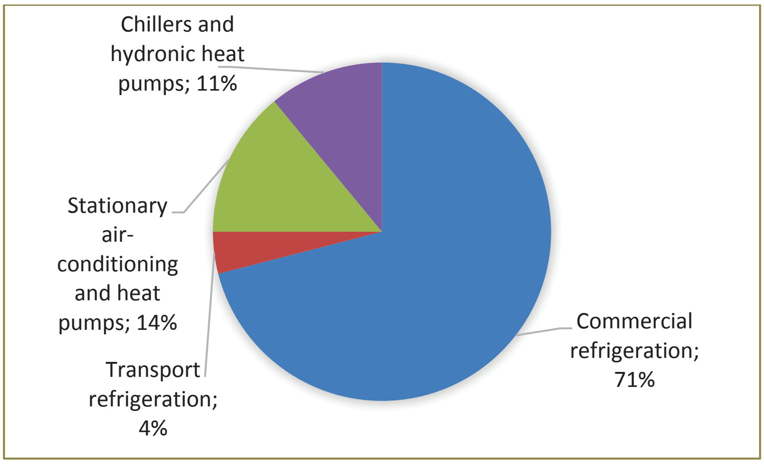
Residential buyers have been able to inform their purchase decisions for room air conditioners of <12kW using the EU Energy label since 2003, although minimum requirements only came into force in 2013.

6.2. Cooling needs in the tertiary sector, including ‘services’.

In strict statistical terms, the tertiary sector comprises the NACE[4] sub-sectors G to S - those that have significant cooling demands are shown in Table 6-1.

Figure 6-1 shows how the total tertiary sector cooling energy for 2010 splits across the equipment types. The majority of refrigeration and air conditioning equipment used in the tertiary sector is of a mass-produced type, with a significant minority bought as integral or plug-in type needing no special expertise, and the majority of the balance built up in a modular fashion from standard units such as condensing units, remote display cabinets, fan-coil units, packaged chillers etc.

Figure 6-1. Cooling only energy consumption in the tertiary sector, split by equipment type at 2010.



Refrigeration has a vital role to play in reducing post-harvest and post-manufacture losses through preserving foodstuff and beverages by refrigeration or deep-freezing. It therefore makes an important contribution to food security in developed economies such as the EU and, increasingly, in developing countries. It is vital to preserve both food safety and food quality. Refrigerated storage is also important to smooth out the seasonal fluctuations in agricultural production to further increase food security. The losses of food arising due to lack of adequate refrigeration have been estimated at 9% of production for developed countries such as the EU (and typically 23% for developing countries) (IIR 2009). Reliance on safe food transport and storage rises with increased urbanization as the population resides further from food sources and so globally there is significant growth expected in the use of food chill-chains. In the EU, however, the food supply chain has already a highly developed refrigeration infrastructure and future growth will be low – for example a rate of only 0.24% per year is anticipated for commercial refrigeration in food retail for the EU (JRC 2014).

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[4] NACE rev. 2.0, for explanation of NACE see: http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC.

The energy of initial freezing or refrigeration post-harvest or post-manufacture is considered part of the industrial sector for this analysis. Considering in turn the tertiary sectors of Table 6-1, refrigeration and air conditioning demands are characterised as in the following sections.

Table 6-1. Summary of tertiary sub-sectors as defined in the NACE system and their cooling demands

NACE Sector	**Description**	**Types of demands and cooling equipment used**
G	Wholesale and retail trade	Refrigerated retail display cases for foodstuff Vending machines Walk in cold rooms Cold storage facilities Air conditioning in retail stores
I	Accommodation and food service activities	Refrigerated storage cabinets and counters Refrigerated retail display cases and beverage coolers Room and central air conditioning
H	Transportation and storage	Refrigerated trucks and vans Reefers / Iso containers Commercial cold storage facilities
J	Information and communication	Cooling for data centres
Q	Human health and social work activities	Air conditioning Cold storage for tissue samples, mortuary, medicines, chillers for scanners and other major equipment.
M	Professional, scientific and technical activities	(Specialist and scientific cooling equipment)
K	Financial and insurance activities	Air conditioning
N	Administrative and support service activities	
O	Public administration and defence; compulsory social security	
P	Education	
R	Arts, entertainment and recreation	
S	Other service activities	

Wholesale and retail trade

Refrigeration accounts for between 30% and 60% of the electrical energy consumption of a food retail outlet, plus HVAC at a further 9% - the breakdown for hypermarkets is shown in Figure 6-2. The energy intensity of these stores ranges from 700 kWh/m^2 per year for a hypermarket, up to 2.000 kWh/m^2 for a convenience store[5].

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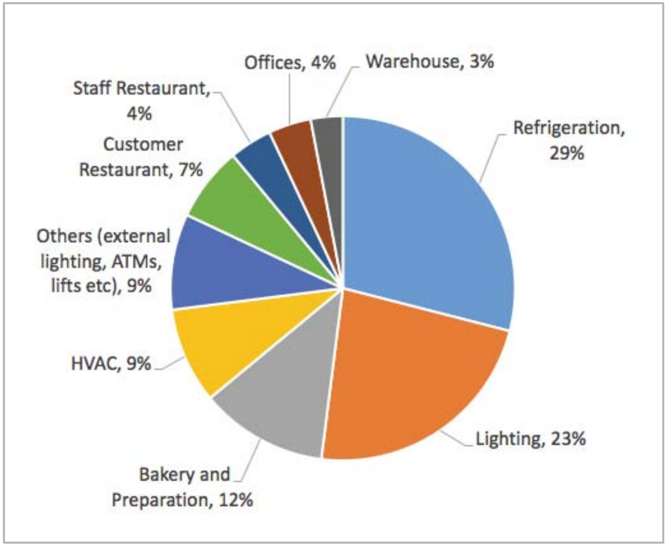
[55] Hypermarkets are generally considered those with over 5000 m² of sales area; superstores would be 1400 up to 5000 m²; supermarkets 280 up to 1400 m²; convenience stores including petrol garage forecourts generally less than 280 m² (Tassou et al. 2011).

Figure 6-2. Breakdown of electrical energy consumption in UK hypermarkets



Source: Tassou et al. (2011)

Once food reaches wholesale or retail outlets it is often stored locally in walk-in cold rooms (WICR) at the rear of the store and loaded as required for display to customers in commercial refrigerated retail display cabinets (RDCs). Medium sized WICR (20 to 100 m^3) account for half of EU WICR energy consumption, small WICR (<20m^3) for 40% and large (100 to 400m^3) for 10% (Ricardo-AEA 2012a).

Small retail stores tend to use ‘integral’ or ‘plug-in’ type RDC units for which the heat is rejected into the store environment; these also provide flexible special purpose or point of sale options for larger stores. Integral units become impractical for medium and larger stores due to excessive heat load and noise. So all but the smallest of stores use ‘remote cabinets’ in the store with the refrigeration compressors and condensers in a plant room or outside the store, joined to cabinets by refrigerant pipework. In EU food supermarkets, refrigeration is the biggest user of energy and accounts for more than 40 percent of the average store’s total energy consumption (Shecco 2014).

The commercial refrigeration market is driven primarily by purchase price of the equipment with insufficient consideration of the cost of energy use during its lifetime, despite electricity running costs accounting for between 60% and 80% of the of life cycle costs of all major types of commercial display cabinet.

This results in purchase decisions driven by short-term benefits with cost-effective energy-saving technologies having limited market penetration. The nature of the market means that base level cheap products continue to be a key offering even from manufacturers that also produce significantly more efficient and value-added products. The EU energy labels for display cabinets, vending machines, beverage coolers and ice cream cabinets are at draft status in November 2015 and once implemented will largely address the lack of efficiency performance information for buyers. Ecodesign minimum efficiency standards apply to low temperature and medium temperature condensing units from July 2016 – these are widely used in small and medium retail.

Many retail stores (food and non-food) have air conditioning systems as well. Some food stores integrate the provision of heating, ventilation, air conditioning with the food refrigeration system to improve overall system efficiency.

Accommodation and food service activities

Air conditioning is widely provided for hotels, restaurants, canteens and other food service outlets across the EU. The food service aspects add to the cooling energy consumption through walk in cold rooms (WICR) (and cellars) for food and beverage storage and through refrigerated storage cabinets in kitchens (called 'food service cabinets' in the sector). In addition, beverage cabinets used back of bar and in food service are an important sub-type of integral refrigerated display cabinet as they account for around 45% of the stock of all commercial refrigeration appliances in the EU28 in 2013 (JRC 2014) which equates to just under 60% of all integral (plug-in) display cabinets. Food service also makes use of refrigerated display cabinets in the customer facing area.

Transport and storage

Refrigerated transport is an essential link in the cold chain for perishable goods such as: perishable foodstuffs, pharmaceuticals, flowers, plants, works of art, medicines and chemical products. Frozen goods are transported at a temperature of –18°C or lower, chilled goods generally between 0°C and 15°C; some goods require controlled temperatures above 15°C such as cocoa, coffee, flavourings, certain fruit and vegetables and pharmaceuticals (IIR 2011). Currently, there are around 4 million refrigerated vehicles in service worldwide, including vans (40%), trucks (30%), semi-trailers or trailers (30%) (IIR 2011).

Articulated vehicles over 33 t are responsible for over 80% of refrigerated food transport in the UK by tonnage, with environmental impacts of diesel driven refrigeration systems equating to as much as 40% of that of the vehicle engine. Road transport refrigeration equipment is required to operate reliably in much harsher and more varied environments than stationary refrigerating equipment and so often has lower energy efficiency (Tassou *et al.* 2009). Many refrigerated trailers are of the ISO 'intermodal' type that can be used both for marine and road transportation.

Global refrigerated road freight transport is expected to grow 2.5% per year until 2030 with much higher growth of 20% per year expected in refrigerated pharmaceutical freight (IIR 2011), although this should be set in a context of a 3% drop in overall EU road freight transport (ambient and refrigerated) from 2011 to 2012 (EEA 2014). The transport of perishable food products and the equipment used to transport it is governed by what is referred to as 'the ATP agreement'[6]. This sets requirements for the thermal performance of the insulated container but not for the energy efficiency of the equipment. Refrigerated transport is also essential for international marine supply chains – ISO refrigerated containers for marine (and intermodal) transport account for around 6% of the global stock of all containers (Hofstra 2008)[7].

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[6] UN Economic Commission for Europe – Inland Transport Committee, ATP as amended 30 September 2015 – Agreement on the International Carriage of Perishable Foodstuffs And on the Special Equipment to Be Used for Such Carriage, 2003. Available from: http://www.unece.org/trans/main/wp11/atp.html.

[7] Marine use of these containers is beyond the scope of this analysis.

Commercial and industrial cold stores are generally considered to be those with over 400m^3 storage volume (below that, they are considered walk-in cold rooms). Some of these larger storage facilities provide medium and/or long term storage of perishable goods; others provide crucial hubs for buffer storage and re-allocation in complex cold chains, particularly for food.

Information and communication, including data centres

Most modern computing and telecommunication facilities run ‘close control’ air conditioning systems (CCAC) to maintain tightly controlled temperatures for the servers, which generate heat from their operation. Energy is required both for cooling and air movement (fans). ‘Close control’ air conditioning typically maintains an internal temperature within a tight tolerance of 22°C and a relative humidity of 52%. 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[8].

The explosive growth in demand for digital data and computing power over the past ten years, accompanied by need for much increased resilience and security has given rise to the ‘data centre’ as a specialised and energy intensive industry in its own right (Expert Group 2013) with a significant demand for cooling. Most of the energy used by information and communication systems is consumed by commercial data centres and servers, which consume 35% of their energy demand for cooling[9]. This is a highly dynamic sector, which is expected to expand considerably in the future, following the increase in data volumes due to the growth of mobile computing, social networks, and the spread of IT in all aspects of private and work life. This has resulted in the continuous increase in both energy densities within the typical data centre and increased cooling requirements. It has been calculated that, if no energy efficiency improvements occur, energy consumption is assumed to grow in line with market growth; *i.e.*, 2.5% per year through 2050.

The UK currently dominates the European data centre market with around 60% of market share, spread between 250-300 sites. These sites have a combined power demand of between 2 and 3 TWh per year (Intellect 2013b), implying a total EU demand of 3.3 to 5 TWh for the sub-sector. Globally, the growth in installed power[10] of data centres for 2011 to 2012 was 19% but this has slowed to just over 7% for 2012 to 2013; available data implies that the growth for the EU was 5% for 2012 to 2013[11] (DCD 2013). This average masks big differences between the member states, with Poland seeing 33% increase, UK at 9% but Spain and Italy contracting (-4% and -5% respectively). DCD attributes the slow-down in growth of installed power to the increased implementation of energy efficiency measures (in the US and Europe), plus a few other issues (DCD 2013).

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[8] Personal correspondence between Tait Consulting and Operational Intelligence Ltd, November 2015. The actual proportion varies from 50% down to 3% (the latter means zero on refrigeration but some energy for fans).

[9] There are four key processes that consume the most electricity in the data centre environment, these are: the IT load (40%); cooling and ventilation (35%), UPS and power distribution (20%) and lighting (5%).

[10] Installed power does not directly correspond with energy consumption, but is the closest proxy available.

[11] DataCenterDynamics defines Europe as including Turkey and Russia in their statistics; growth for this ‘wider Europe’ is quoted as 6% for 2012 to 2013 but data in the same publication enables a figure without Turkey and Russia to be derived of 4.9%.

A crucial aspect of data centre service is reliability and so redundancy (duplication) is essential for the services that keep the data centre running, including its cooling plant. However, there are strong business incentives for data centre operators to achieve good cooling plant efficiency:

a) Cooling accounts for between 35% and 40% of the electricity bill;
b) Equipment runs highly loaded, which usually means best efficiency for the plant, and in a largely predictable pattern and so performance can be optimized;
c) Energy efficiency is often closely associated with reliability for cooling plant and so provides dual incentive for efficiency

Unfortunately, there is likely to be a significant rebound effect from any efficiency gains due to further consolidation of distributed computing into data centres and that operators will prefer to sell any additional computer capacity that becomes available that was previously cooling capacity limited (Intellect 2013a). Whilst data centres are energy intensive, they provide that quantity of computing far more efficiently than would be achieved by distributed computing (i.e. desktops or small server rooms) and the cooling is a necessary part of achieving that efficiency.

A voluntary EU Code of Conduct for data centre operators has been in effect since 2008. It encompasses the performance of the whole data centre energy system and sets efficiency requirements for both the IT load and the facilities load (which includes refrigeration). There are several Best Practices for reducing the cooling load by use of free cooling, increasing the indoor temperature and using low energy cooling solutions. There are 110 participant organisations in the scheme across the EU plus one in the USA and one in Taiwan with over 300 data centres[12].

There are significant opportunities to reduce cooling demand for data centres and for servers more generally since there is no need for temperatures to be maintained as strictly as the service level agreements (between customer and provider) often impose (Intellect 2013a). Research by ASHRAE, that is recognised by data centre operators and server manufacturers globally, has set the safe operating temperature and humidity envelope as wide as 18°C to 27°C and published maps showing the parts of the world which can, as a result, exploit free cooling for their cooling systems, which means without mechanical cooling, only fans/pumps, and so very low energy use (Green Grid 2012) [13]. The free cooling map of 2011, reproduced as Figure 6-3, shows that in Europe 99% of locations are able to use free cooling all year; the only locations in Europe that cannot use free cooling all year are a small area in northwestern Spain (too hot), a small area in southwestern Ireland (too humid), and a small area in Sicily (Green Grid 2012).

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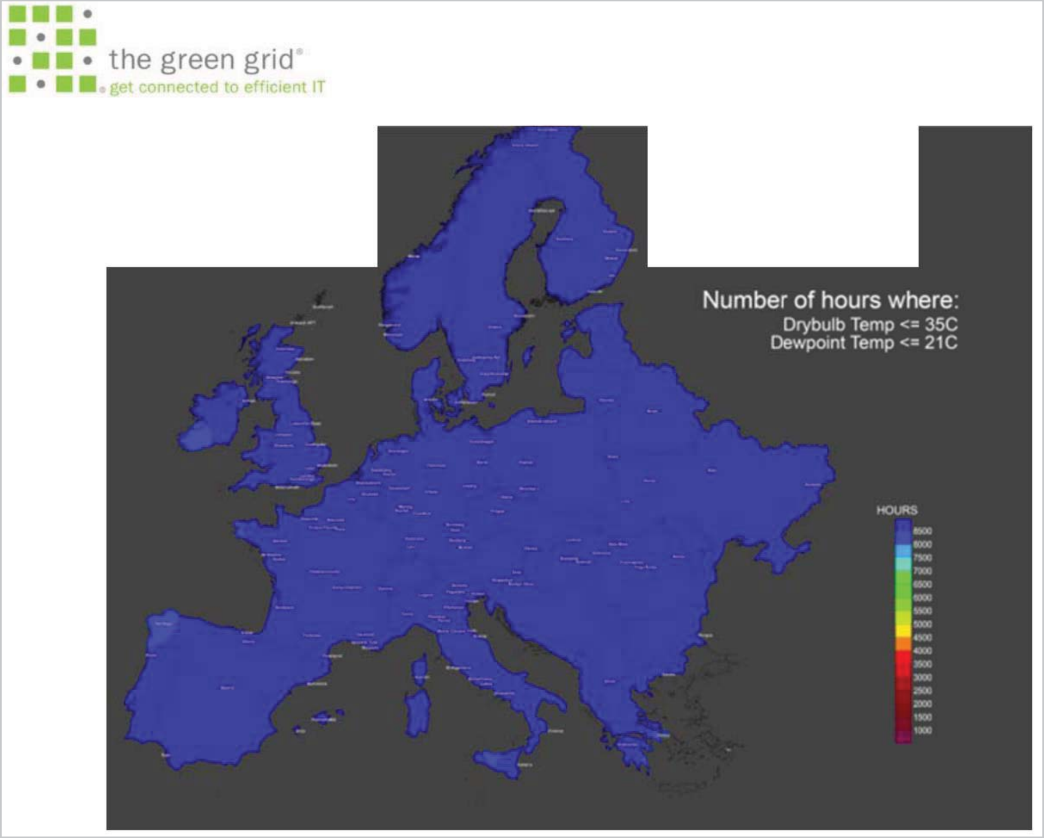
[12] See http://iet.jrc.ec.europa.eu/energyefficiency/organisation-list-short/ict_coc_dc_partner.

[13] The Framework 7 project RenewIT is focused on integrating renewable energy solutions data centres, see http://www.renewit-project.eu. The objective of the project is to develop a simulation tool to evaluate the energy performance of different technical solution integrating renewable energy sources in several European climate regions. A public RenewIT tool will be available in a web interface to help energy and IT sectors reduce the carbon footprint of planned Data Centers up to 2030.

Figure 6-3. Free Air Cooling Map for Europe, based on ASHRAE 2011 Thermal Guidelines. (Dark blue shows areas where free cooling can be used for over 8.500 hours per year)



Source: Green Grid (2012)

Barriers to improving efficiency and reducing energy demand for data centres include the large proportion of relatively old and inefficient data centres that will not be refurbished soon and the proportion of small data centres whose owners/operators lack the money and other resources to refurbish. Unfortunately, the very fast pace of IT technology development in data centres is not matched by changes to the infrastructure and buildings that they occupy[14]. It is believed that phasing out services from small and old data centres could reduce the overall energy burden if those services are provided by cloud-based servers in which major suppliers have invested heavily in the latest, most efficient technology.

Other tertiary sub-sectors with high air conditioning demand

Several tertiary sub-sectors have one cooling demand in common: air conditioning and ventilation. Air conditioning in occupied buildings provides thermal comfort to people and for tertiary buildings reduces loss of staff productivity from over-warm conditions; in high summer it can be necessary to avoid heatstroke and even premature death for vulnerable citizens including the elderly and frail. Air conditioning is the main cooling demand across buildings for:

- Offices, including for financial and insurance;
- (Retail and hotels/accommodation – included above but repeated here for clarity)
- Health and social care,
- Public administration and defence with social security,

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[14] Personal correspondence between Tait Consulting and EU code of conduct technical expert, November 2015.

- Administrative and support services,
- Education
- Arts, entertainment and recreation

The tertiary sector of Europe is about half way on its journey from negligible air conditioned space to market saturation[15] and so is likely to see at least another 15 years of ongoing growth (BRE MINES 2012). The speed of transition varies of course and markets in some southern member states are approaching saturation, while some newer states are still in the initial phases of market growth. The European market has first-time sales into both new and existing buildings and, increasingly, sales of replacement components.

Due to its age, the installed EU stock contains some systems of types that would rarely, if ever, be chosen for installation today partly due to low efficiency of design and components, in particular for systems that rely heavily on energy-intensive movement of chilled air (physical size of ductwork required for good efficiency is a major issue for all-air systems).

Some considerations about potential energy efficiency improvements can be made for the overall tertiary sectors. Opportunities to reduce demand for air conditioning in warm climates include improving the thermal performance of the building envelope, active solar shading, reduced thermal gain through coatings on glazing (and higher tolerance of occupants for warm temperatures). However, this is a complex picture encompassing several climate zones across the EU: although solar heat gains are important when sizing air conditioning systems, in many climates average levels of solar radiation are far below the peak values and annual heat gains are largely from occupants, office (and similar) equipment and lighting systems. This is especially true for deep-plan buildings and those with effective solar shading. There are opposing trends affecting these heat gains: the efficiency of equipment and lighting systems is increasing (and the consequent heat losses decreasing), partly as a result of product performance regulation; but commercial pressures are leading to more intensive use of space, increasing heat gains per unit of floor area from people and equipment. Control of solar heat gain in new and renovated buildings is imposed by building standards in most EU countries. Retrofit measures such as adding window film are possible in existing ones - but care is needed not to reduce daylighting levels, increasing the use of electric lighting. Added insulation can reduce heat gains through the building fabric, which can be important in poorly-insulated buildings in sunny climates (as can reflective roofs if added insulation is impracticable). However, in cooler climates it can increase the use of air conditioning by restricting heat loss from the building.

Totally unnecessary demand can also be reduced: there is evidence that building operators rarely prioritise energy efficiency and it is not unusual for air conditioning systems to operate for longer hours (including at weekends or overnight) than is necessary. The scale of energy wastage has been estimated as similar to that from weakness of building design or inefficient equipment. This is challenging for policy to address, although monitoring and automated control systems to manage this very well are widely available.

6.3. Industrial (secondary) sector

Cooling is required for a very wide range of process and manufacturing applications with the industrial sector. A fairly comprehensive cataloguing and estimate of total demand of

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[15] Market saturation is considered to be when there are no first-time sales to existing buildings; the process from first sales to saturation has been seen to take four or five decades.

industrial refrigeration cooling is provided for the German industrial and food sectors in a recent study for the German government (ILK 2015). Equipment used in this sector is distinguished from that of the tertiary sector as a majority is bespoke designed for a specific application from components and sub-systems. The temperature range is also much wider, with industrial systems commonly providing cooling down to -60°C and sometimes lower (the field of cryogenics generally takes over from refrigeration at below -150°C).

Applications for industrial refrigeration include:

- Food processing applications, such as rapidly cooling cooked food, blast freezers and continuous spiral and tunnel freezers, fresh milk and cheeses, beverages, production of coffee and ice cream, removing heat of fermentation from beer and other beverages;
- Cooling printing machines;
- Cooling plastics and rubber moulding machinery;
- Industrial chilled or frozen warehouses are used on-site in the food manufacturing sector. Industrial cold stores would generally be considered as those over 400m3 in size – below that would be considered walk in cold rooms. Food is typically frozen at between -20°C and -30°C, with higher fat content foods requiring the lower temperatures;
- Freeze-drying and freeze-concentration of foodstuff, pharmaceuticals and chemicals;
- Production of flake ice for fish and other food preservation and industrial applications including for use on small fishing vessels (trawlers over 15 metres tend to have on-board ice making plant, Expert Group 2013);
- Gas liquefaction in the chemicals sector;
- Soil freezing for the building sector;
- Chemicals processing for cooling of reactor vessels, reducing humidity, condensation of gases;
- Ice rinks (leisure application but very much industrial type plant)

There is also space cooling used on industrial sites for offices and production areas, but this is negligible in comparison with the demands for process and storage.

A long list of incremental improvements to adopt best practice approaches, techniques and components could add up to a significant overall increase in efficiency of future systems. Two EU projects have examined opportunities in detail:

- The COOL-SAVE project[16] looked at energy efficiency improvements to refrigeration systems in the food and drink sector.
- The ICE-E[17] project provided information and tools to industrial and commercial cold store operators, designers and users to help them reduce the energy consumption and carbon emissions from their stores.

Both of these have provided insight into the complexity of improving efficiency and the many measures and approaches that can be applied to achieve it. Measures in that list include:

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[16] Development and dissemination of cost effective strategies to improve energy efficiency in cooling systems in food and drink sector (COOL-SAVE). See http://ec.europa.eu/energy/intelligent/projects/en/projects/cool-save.

[17] Improving Cold storage Equipment in Europe (ICE-E). See http://www.khlim-inet.be/drupalice/ and http://ec.europa.eu/energy/intelligent/projects/en/projects/ice-e

- Reduction of cooling requirements by free cooling for some of the year or to achieve some of the cooling stage
- Better sizing of plant to match cooling demands
- Better control strategies including head pressure, defrosts and temperature settings
- Better component selection, particularly compressors and heat exchangers, particularly for part load operation
- Effective maintenance, for example ensuring free air circulation for heat exchangers, minimize refrigerant leakage, removing oil fouling in evaporators, matching controls to changing demand etc.

6.4. Refrigeration and air conditioning equipment categories

The refrigeration and air-conditioning equipment are common across the sectors examined in the previous sections. This section presents a classification of them and an overview of the main categories. In fact, whilst there is a very broad spread of applications for cooling, the inventory of equipment that delivers those needs can be characterised relatively simply into seven categories, according to the technology and service delivered:

1. Commercial refrigeration
2. Transport refrigeration
3. Unitary air conditioning
4. Chillers
5. Industrial refrigeration
6. Domestic refrigeration (out of scope of this analysis)
7. Mobile air conditioning (MAC, out of scope of this analysis)

This approach of the seven categories has been internationally recognised as appropriate for refrigerant inventory studies. As already noted, domestic refrigeration and MAC are out of scope of this analysis. To these categories, non-electrical cooling is to be added since it is particularly relevant to the renewable cooling perspective through the use of waste heat. The table below illustrates the subcategories for each of the main equipment categories and it is based on the classification provided by SKM Enviros (2012).

The specific technical definitions of ‘low temperature’ (LT), ‘medium temperature’ (MT) and ‘high temperature’ (HT) vary according to the type of equipment being considered, but these can broadly be characterised (at least for commercial refrigeration applications) as:

- ‘Low temperature’: a rated operating temperature between -35°C and -15°C
- ‘Medium temperature’: a rated operating temperature between -15°C and 0°C
- ‘High temperature’: a rated operating temperature between 0°C and +15°C (most air conditioning applications operate at this range)

Table 6-2. Refrigeration and air conditioning equipment categories and sub-categories. MT = Medium temperature; LT = low temperature; DX = direct expansion.

Category	Sub-category
Commercial refrigeration	Hermetic Units MT and LT
	Single condensing units MT and LT
	Multi-pack centralised systems MT and LT
Transport refrigeration	Vans and light trucks
	Large Trucks and Iso-Containers
Industrial refrigeration	Small DX LT and MT
	Medium DX LT and MT
	Large DX LT and MT
	Medium-size Industrial Chillers
	Large Industrial Chillers
	Large Flooded LT and MT
Stationary air-conditioning and heat pumps	Small portable units, cooling only (air-to-air)
	Small split systems, cooling only (air-to-air)
	Small split systems, heating & cooling (air-to-air)
	Medium split systems, cooling only (air-to-air)
	Medium split systems, heating & cooling (air-to-air)
	Large split systems, cooling only (air-to-air)
	Large split systems, heating & cooling (air-to-air)
	Packaged systems, cooling only (air-to-air)
	Packaged systems, heating & cooling (air-to-air)
	VRF systems, cooling only (air-to-air)
	VRF systems, heating & cooling (air-to-air)
Central plant chillers and hydronic heat pumps	Small - cooling only (scroll/screw, air-cooled)
	Medium - cooling only (scroll/screw, air-cooled)
	Large - cooling only (screw, air-cooled)
	Small - cooling only (scroll/screw, water-cooled)
	Medium - cooling only (scroll/screw, water-cooled)
	Large - cooling only (centrifugal, water-cooled)
	Small (domestic) - heat only, air-source, hydronic
	Medium - heat only, air-source, hydronic
	Small - reversible heating/cooling, air-source, hydronic

6.4.1. *Commercial refrigeration*

This category includes a wide range of equipment used in the food retail and food service sectors. It covers both equipment to which customers have access, for retail, and also equipment accessed mainly by the employees of an organisation (such as food service staff). The size/cooling capacity range extends from small integral ('plug-in') cabinets at 1kW up to remote condensing packs that provide cooling to dozens of retail display cabinets in a supermarket or walk in cold rooms at 200kW. Amongst manufacturers and the equipment supply sector, there is a market distinction of equipment: if it is for public access the equipment is generally referred to as 'commercial refrigeration'; if it is accessed only by employees then it is referred to as 'professional refrigeration'. This distinction is also recognised in the set up of the relevant Ecodesign and energy label regulations and draft regulations at November 2015 (see Table below).

Table 6-3. Summary of Energy labelling and Ecodesign measures (adopted or in draft) related to industrial and commercial refrigeration packaged equipment and sub-assemblies.

Equipment	Energy label applies from date (with implementing measure)	Minimum efficiency requirement applies from date (with implementing measure)	Notes
Professional refrigerated storage cabinets	July 2016 (B)	July 2016 (A)	For commercial and professional food service.
Condensing units	-	July 2016 (A)	For commercial and small industrial use.
Industrial process chillers (low temperature and medium temperature only; air-cooled and water-cooled)	-	July 2016 (A)	
Blast freezer cabinets (up to 300 kg food capacity)	-	(Information requirement only from July 2016)	For food service / manufacturing use
Refrigerated commercial display cabinets for supermarkets (virtually all types)	Proposed July 2017 (D)	Proposed July 2017 (E)	Food retail and food service
Beverage coolers (glass door refrigerated cabinets)	Proposed July 2017 (D)	Proposed July 2017 (E)	Drinks retail and food/drink service. Those with ‘pull-down’ capability
Refrigerated vending machines (virtually all types)	Proposed July 2017 (D)	Proposed July 2017 (E)	For foodstuff
Small ice cream freezers (up to 600 L net volume)	Proposed July 2017 (D)	Proposed July 2017 (E)	As used in and outside small retail stores and restaurants
Gelato ice cream cabinets	Proposed July 2017 (D)	Proposed July 2017 (E)	For serving gelato ice cream in food service
Air-cooled high temperature industrial process chillers	-	Proposed January 2018 (C)	
Water-cooled high temperature industrial process chillers	-	Proposed January 2018 (C)	

A. Commission Regulation (EU) 2015/1095 of 5 May 2015 with regard to Ecodesign requirements for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers.

B. Commission Delegated Regulation (EU) 2015/1094 of 5 May 2015 with regard to the Energy labelling of professional refrigerated storage cabinets.

C. Working document for Commission Regulation with regard to Ecodesign requirements for air heating products, cooling products and high temperature process chillers (DG ENER Lot 21). Draft due for vote at Regulatory Committee meeting of 8 December 2015.

D. Working document Commission Delegated Regulation with regards to the Energy labelling of refrigerated commercial display cabinets. In draft at November 2015.

E. Working document Commission Regulation with regard to Ecodesign requirements for refrigerated commercial display cabinets (DG ENER Lot 12). In draft at November 2015.

An important development for the commercial refrigeration equipment is the number of supermarkets installing commercial refrigeration systems using natural refrigerants. In 2013, CO_2 was in use for the main refrigeration systems in nearly 3,000 retail stores across the EU, up from just over 1300 in 2011 (all using CO_2 in its ‘transcritical’ mode) (Shecco 2014). Around 17% of 50 EU retailers participating in the Shecco survey used hydrocarbon refrigerants, often by means of hydrocarbon chillers feeding cooling to cabinets using brine or chilled water loops. A theoretical analysis backed up by laboratory testing showed a potential for CO_2 systems that use heat recovery to improve energy efficiency by over 30% compared with a conventional system when analysed for a 5.600 m_2 store (Colombo 2014).

6.4.2. Transport refrigeration

Refrigerated small vans and light trucks are used to distribute foodstuff for food service and also local distribution for retail. In recent years, home delivery of groceries is also a key application for some Member States including the UK. For these units, the refrigeration system is usually belt-driven from the vehicle engine, and so the fuel source is diesel. Large refrigerated trucks including articulated refrigerated trailers are used for national and international transportation of perishable foodstuff and also some industrial products. Refrigerated ISO containers or ‘reefers’ are used for shipping and also on articulated truck. These large units are mostly driven by their own diesel engine, separate to that of the tractor unit.

Transport refrigeration is not subject to energy efficiency requirements. In particular, ISO containers and other equipment used to transport refrigerated goods internationally would be particularly complex to regulate due to lack of clarity of ownership and their operation across EU borders.

The most common refrigeration system in use for refrigerated food transport applications today is the vapour-compression system powered by a diesel engine (IIR 2011). The manner in which the refrigeration unit is run is the basis on which equipment in road vehicles is classified, as either "dependent" or "independent": independent (or self-contained, self-powered, diesel unit): equipped with an independent heat engine which runs the compressor, both on the road and during stops; dependent (or non-self-contained, vehicle powered): such equipment is generally dependent on the engine of the road vehicle.

It is estimated that energy savings of up to 50% can be achieved in the field of refrigerated transport of chilled and frozen products (IIR 2011). Many non-vapour-compression refrigeration technologies, e.g. adsorption, absorption, liquid-gas cryogenic systems, and eutectics, have been tested.

6.4.3. Stationary air conditioners and heat pumps

This category covers four main types of air conditioner:

- Small portable units. These are small appliances that can be moved to where they are needed within a building. They are bought over the counter or through internet suppliers and do not generally require any installation expertise. These appliances are mostly used in dwellings and small commercial buildings and generally used for limited hours per year.
- Split ‘air to air’ systems and small packaged room air conditioners. These are series-produced self-contained units or systems that condition a single room – split systems have an indoor unit and an outdoor unit joined by pipework; others are self-contained such as ‘through the wall’ units. They are generally installed professionally and widely used in both commercial buildings and dwellings. ‘Air to air’ means that air inside the building is directly cooled by the evaporator and heat is rejected outside to ambient air (as opposed to a water-cooled condenser for example). They can be

cooling only or reverse cycle (or heat pump) units that can heat or cool the building – the market is moving significantly towards reverse cycle units. They are usually divided into small (c. 3.5 kW), medium (c. 7.1 kW) and large (c. 14 kW)[18].

- Medium to large packaged air to air systems. This includes medium to large packaged stationary air-conditioning systems, including roof top units and ducted splits >12 kW. This type of unit is available up to around 100 kW in cooling capacity and can be cooling only (declining sales) or reverse cycle.
- Air to air variable refrigerant flow (VRF) systems. VRF systems achieve much better part load performance than conventional on/off systems by modulating the compressor(s) speed to deliver only the required amount of cooling and/or heating. They are built up from modular system components with one or more outdoor units with multiple indoor units.

The small portable and split units are widely applied in both the residential and in the commercial sectors; others are only in commercial sectors.

6.4.4. Central plant chillers and hydronic heat pumps

These larger systems serve large numbers of rooms or an entire building by means of a large chiller of set of chillers located in a plant room which generate chilled water that is circulated to where cooling is needed (hence 'hydronic'). The most common type makes use of 'Fan coil units' located in the rooms to be cooled blow air over a heat exchanger through which the chilled water flows, but there are other ways of transferring the cooling to the rooms, via chilled beams or chilled floor etc. These can also be used for heating (heat pumps) and are generally bespoke systems designed for specific buildings, but often composed of standardised or modular component products. In Europe central systems are predominantly used in commercial buildings.

The central plant chillers and hydronic heat pumps can be divided as follows:

- Central plant chillers air-cooled cooling only. Produce chilled water for central air conditioning systems; the condenser is cooled by ambient air blown over its condenser coils.
- Central plant chillers water-cooled cooling only. Produce chilled water for central air conditioning systems; the condenser is cooled by water sprayed or flowing over its coils or via a water/water heat exchanger. The water cooling means a lower condensing temperature and so significantly better efficiency than air-cooled, but higher capital and maintenance costs.
- Hydronic heat pumps (cooling and heating) air to water. Produce chilled or heated water for central air conditioning systems; the condenser is cooled by ambient air blown over its condenser coils or uses outside air as heat source when in heating mode. Sizes in range 100 kW to 500 kW are most common.

One renewable energy technology is the ground source heat pump that can be used as an inter-seasonal heat store: heat extracted from the building during summer is stored underground for use as a heat source in winter. This technology accounts for too small a

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[18] It is to be noted that under EU Energy label and Ecodesign definitions, a 'household room air conditioner' generally refers to units of cooling capacity <12 kW.

proportion of the current EU market but is potentially important to the lower carbon future of this sector. Also attractive as it avoids or reduces the space (and cost) of external heat rejection equipment. A good example of ground source heat pumps is the UK retail store using radial boreholes to store waste heat from the store refrigeration system which is then used to supply the heating system whenever necessary (see Section 6.6).

The EPBD and associated national building codes are putting pressure on chiller efficiency and imminent EU Ecodesign regulations will remove a significant portion of the older less efficient chillers from both the comfort cooling and industrial refrigeration markets. A significant technology advance is the magnetic bearing chiller that has now been licensed by most of the major manufacturers and enables very efficient operation. This type of unit started in serving niche markets such as data centres but is now finding wider sales.

6.4.5. Industrial refrigeration

The equipment serving industrial applications can be divided into the following broad categories:

- Industrial direct expansion (DX) systems are designed such that all of the refrigerant is converted into gas by the time it leaves the evaporator which minimises the volume of refrigerant and size of pipework required. Industrial DX systems are characterised as small, medium and large sizes (20 kW, 80 kW and 300 kW nominal sizes) with each split into medium temperature (between -15°C and 0°C) or low temperature (between -35°C and -15°C). These systems use one or several large compressors, separately located condensers (often water or evaporatively cooled for better efficiency) and evaporators located directly where the cooling is required for a process (using a refrigerant/liquid heat exchanger) or a cooled space (using an industrial fan cooler unit). HFC refrigerants dominate across the size range, with ammonia used for up to 20% of larger and low temperature systems. These are often built up from modular sub-systems and major components.
- Industrial process chillers cool glycol, brine or iced water for circulation to the cooling demand. Industrial process chillers include at least a compressor and an evaporator within a "package" and may be air-cooled or water-cooled. They are designed for either high, medium or low temperature operation. Industrial process chillers are very similar to air conditioning chillers in principle and many engineering features, but are usually designed to a different price/efficiency balance point: industrial chillers often run for over 50% of the year (4,380 hours) and at 80% loading – this is in contrast to air conditioning chillers which run mainly in warm periods with low or variable loading. Investment in efficiency (e.g. bigger heat exchangers; better controls) makes much more sense for industrial chillers and this is reflected in the typical prices being up to 50% or more higher than an equivalent air conditioning chiller. Medium chillers (200kW range) tend to use HFCs in 80% of cases with the balance ammonia; larger chillers at 1 MW range tend to use ammonia in around 40% of cases. Whilst industrial chillers are usually based on a set of standard packaged products, many chillers have variants or are customized, especially for large installations.
- Flooded systems are used in around 1 MW and larger industrial systems and are designed for maximum cooling capacity through ensuring that liquid refrigerant fills the evaporators. Refrigerant is gravity fed and/or pumped around the system. Flooded

systems use larger quantities of refrigerant than DX per kW capacity but they cope with much higher loading. Ammonia is used in virtually all new flooded systems, except for some 5% or so using an HFC refrigerant for medium temperature applications. Flooded systems are generally bespoke engineered solutions.

Ecodesign minimum requirements will apply to industrial process chillers of all sizes from July 2016. The requirements are set using the metric of seasonal energy performance ratio (SEPR) that takes into account a typical annual usage pattern. Hence the regulation encourages good part-load and full load performance according to typical usage patterns.

Most energy consumed for refrigeration (but to some extent also for air-conditioning) is consumed by systems that must be designed from components and sub-assemblies, installed and then maintained. Very substantial savings can be achieved when all of those steps are done well, even without substantial additional investment in technology. Whilst minimum product efficiency standards are important they cannot properly address system design and maintenance but raising skills levels is an essential enabler. A better training on safe and effective application of the new refrigerants being ushered in by the F-Gas regulation and also codes of practice to support more effective surveys and inspections as part of EPBD and EED implementation could enhance that and bring additional benefits.

6.4.6. Non-electrical cooling

The vast majority of refrigeration and air conditioning in the EU is delivered using electrically driven equipment. The only significant non-electrical cooling technology is heat-driven absorption cooling. This operates using an absorption refrigeration cycle in which heat, for example waste heat from another process or from burning gas, drives the regeneration segment of a closed cycle series of chemical reactions. Absorption chillers have a more prominent role in Asian markets[19] where scarcity of fuel resources and poor electricity infrastructures are thought to have encouraged various governments in Asia to promote usage of absorption chillers (GIA 2011).

Absorption type equipment can typically cost up to twice as much per kW installed capacity in capital costs as conventional electric chillers. Applications of absorption cooling are:

- Gas driven refrigerators provide silent cooling for minibars in hotel rooms, boats and mobile homes/camper vans and for camping and leisure applications. Absorption driven refrigerators accounted for around 2% of the 14.3 million EU23 annual sales of refrigerators and fridge-freezers in 2012 (VHK and ARMINES 2015).
- In some industrial applications, absorption chillers can provide effective and energy efficient cooling, particularly where that heat might otherwise be wasted. It can be used with combined heat and power, referred to as tri-generation. There are EU examples of district cooling using absorption chillers and use of geothermal heat sources (JRC 2012a). Industrial scale absorption plants probably number in the low hundreds across the EU[20]. Achieved efficiency measured as a COP[21] is low (0.7 for single effect chillers; up to 1.3 for double effect) but they can make use of low grade

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[19] Japan, China and Korea account for 75% of the global market for absorption chillers (GIA 2011).

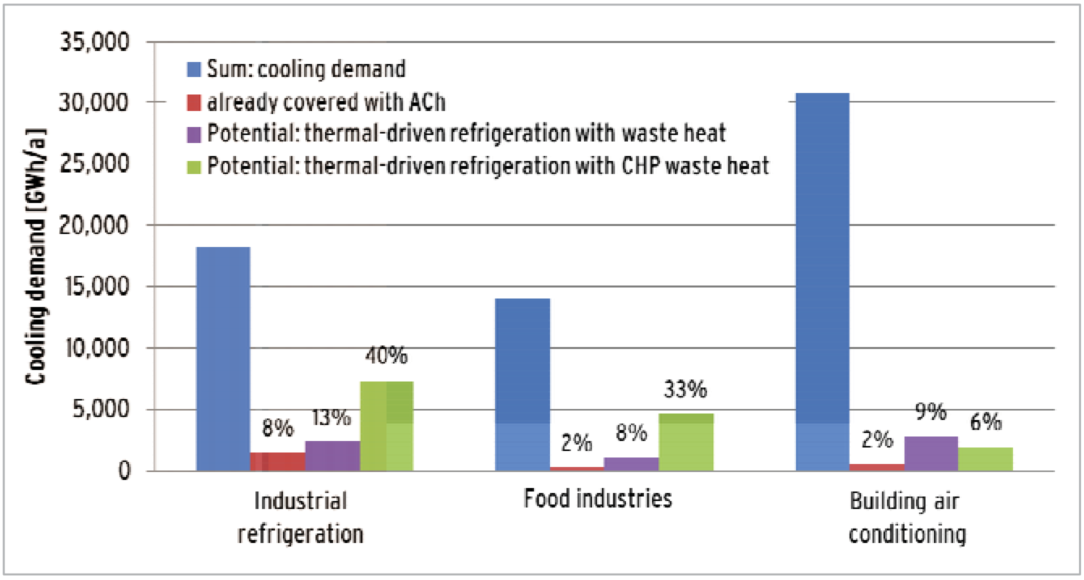
[20] A UK government publication in 1999 suggested that there were 2700 absorption chillers in the UK, the vast majority being small gas-fired air conditioning units, but including over 200 commercial sized units, 20 of which for industrial process cooling applications. The markets for industrial absorption cooling are stronger in Japan, China, Korea, USA and Germany (ETSU 1999).

[21] The coefficient of performance or COP is used to quantify the performance of refrigeration cycles.

heat and for fairness this should be compared with the primary energy ratio of the electrical chiller (taking account of the conversion and transport of the electricity).

A recent major study of the delivery of refrigeration and air conditioning in Germany (ILK 2015) indicated that heat driven cooling (probably almost all absorption type) provides around 8% of the total cooling demand in German industry. This is mostly in chemicals and semi-conductors manufacturing sectors. It is highly likely that these proportions are higher in Germany than they would be in many other Member States due to the more significant proportion of major industry plants. The study went on to look at potential for further heat driven cooling applications, based on exploiting waste heat and also coupling heat-driven cooling units with combined heat and power plant (CHP), referred to as tri-generation. There broad conclusions are summarised in Figure 6-4 which indicates a significant potential to exploit tri-generation in industry (including food) with less scope in the building sector.

Figure 6-4. Results of a study of the German refrigeration and air conditioning sector showing current cooling demand, and the proportion of that cooling demand currently delivered through heat driven cooling (ACh), and the potential for further heat driven tooling using waste heat and heat from CHP plants



Source: ILK (2015)

As shown by the study for Germany (ILK 2015), there is scope to apply absorption cooling for many more applications perhaps accounting for up to one third of the food industry cooling demand and perhaps half of the wider industrial cooling demand for a highly industrialised economy like Germany if all waste heat and potential CHP situations are exploited. The proportions for the EU as a whole are likely to be significantly lower, particularly when economic and investment considerations are taken into account.

However, due to the low efficiency of absorption cooling compared with electric cooling, a switch to non-electric absorption cooling would only achieve energy overall efficiency savings and carbon emissions reductions when the heat driving it is waste heat or CHP heat (ILK 2015). Since the heat needed to drive absorption plant effectively must be at or above 85°C, this is a temperature at which it could be exploited for other heating purposes. An attractive scenario would be using such heat to drive cooling plant in summer and using the waste for heating purposes in winter, when a conventional vapour compression cooling system could provide the cooling fairly efficiently. Gas or heat driven cooling may present an attractive route to relieve electricity grid stress at peak times, as already implemented in Asia.

6.5. Issues impacting the development of refrigeration and air conditioning in the EU

6.5.1. EU Policy on refrigerants: a major change in the coming decade

The refrigerant fluid is a key component of all refrigeration and air-conditioning systems. The EU Ozone Regulation phased out the most widely used refrigerants to that date (CFCs and HCFCs) between 1990 and 2015. From around 1995 HFC refrigerants which have zero ODP were introduced as alternatives to CFCs and HCFCs; by the year 2000, HFCs dominated the market for new systems in the EU. By the late 1990s it was recognised that fluorocarbon refrigerants (including CFCs, HCFCs and HFCs) have very high global warming potential (GWP). The GWP of these refrigerants was between 1,000 and 10,000 times that of CO_2. Controls have been introduced as part of the EU climate policies in 2 stages, to reduce the impact of these powerful global warming gases:

1) EU Regulation 842/2006 created a range of requirements aimed above all at reducing leakage of HFCs from refrigeration and air-conditioning systems. This included mandatory training of technicians handling HFC refrigerants, mandatory leak testing of all systems containing more than 3 kg of HFC refrigerant and mandatory recovery of HFCs from all systems during servicing or at end-of-life. This Regulation was repealed by the following EU Regulation 517/2014.

2) EU Regulation 517/2014[22] added many new controls including an overall phase-down of the quantity of HFC refrigerant that can be sold in the EU and bans on certain refrigerants in specific applications, The phase-down starts in 2015 and leads, by 2030, to a 79% cut in the quantity of HFCs that can be put on the market in the EU.

In this way, EU Regulation 517/2014 will drive a change from using high GWP HFCs to low GWP alternatives.

This implies a radical change to the types of refrigerants used over the next 10 years which will inevitably stimulate investment in plant refurbishment and upgrade. This presents an opportunity to ensure at the same time that the plant is made as efficient as economically justified. The requirements for leak checks and training and certification of technicians will also help to raise energy efficiency. In particular, mandatory leak checks will help improve efficiency since plants with low refrigerant charge often work less efficiently to deliver the same required cooling (and are often less reliable). Energy efficiency forms part of the minimum requirements established at EU level (Commission Implementing Regulation (EU) 2015/2067) for the training and certification of technicians responsible for plant maintenance and better qualified staff will help raise standards in the sector.

There is a significant number of new refrigerants being considered as replacements for high GWP HFCs and the choice is highly dependent on the application. Available climate-friendly

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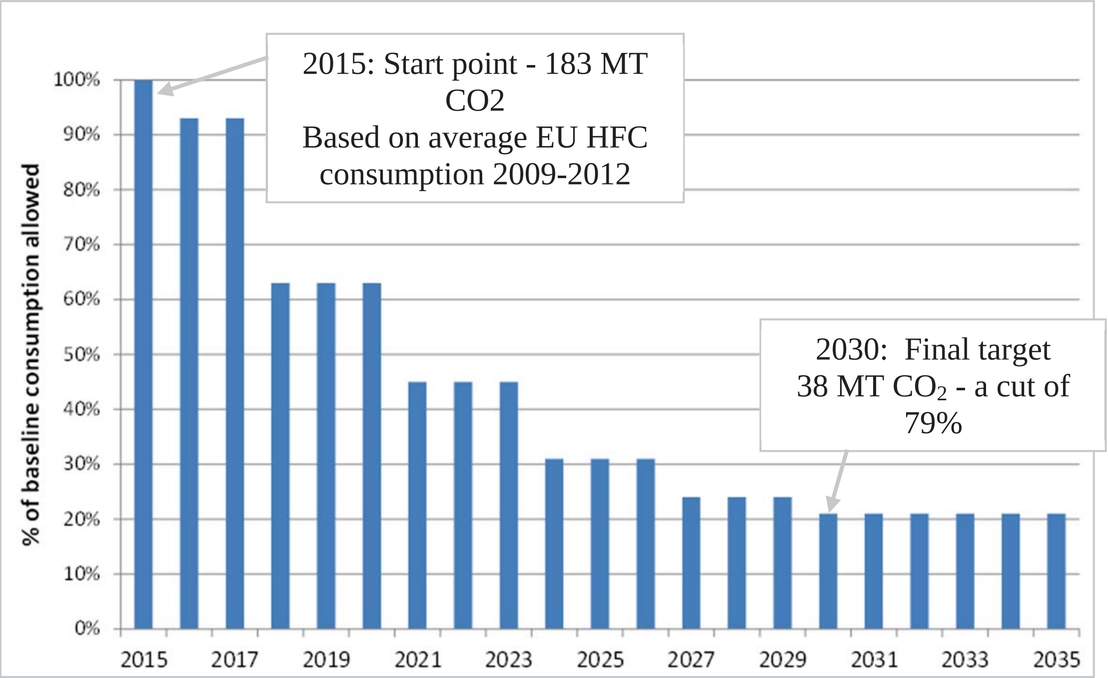
[22] Regulation (EU) No 517/2014 of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. For specific interpretations by end use sector and user, contractor etc., see the EU F-Gas Regulation Guidance Information Sheets available from http://www.gluckmanconsulting.com/f-gas-information-sheets/.

alternatives include CO_2, hydrocarbons, ammonia, unsaturated HFCs (HFOs) as well as low GWP blends, which all have their specific advantages and limitations. Climate-friendly refrigerants offer great energy saving potentials, but require for some applications an update of existing standards to ensure their safe use on a broader scale. Relevant EN standards should better enable the use of flammable refrigerants in equipment than they do today, while ascertaining the safe use of equipment.

In the industrial refrigeration market the use of ammonia is already widespread. Ammonia is one of the very earliest refrigerants, highly efficient and with a GWP of zero. Ammonia is used in around 20% of the medium sized industrial chillers (200kW capacity), 40% of the large chillers (1MW) and virtually all of the flooded systems used in industry (SKM Enviros 2012). But ammonia is highly toxic and subject to strict safety standards and regulation. HFC refrigerants are today still used for the majority of industrial systems between 20 and 200 kW (SKM Enviros 2012). At the lower end of equipment size, in particular in hermetically sealed units such as bottle coolers or vending machines, hydrocarbon refrigerants are becoming increasingly popular, not least due to their high energy efficiency. Hydrocarbons have been used in private fridges and freezers in people`s homes since the mid-1990s. CO_2 is increasingly used in large supermarket systems, either in cascade systems with other refrigerants or in transcritical systems as sole refrigerant. There are close to 5000 of these systems existing in Europe today and their numbers are growing rapidly (Shecco, 2015). HFOs and their blends are the newest type of refrigerants but are starting to be appearing in different kinds of equipment on the marketplace.

Figure 6-5. Illustration of the phase down of the quantity of HFCs that can be placed on the market as required by EU Regulation 517/2014.



Source: SKM Enviros (2012)

It is difficult to predict the way in which different parts of the market will switch refrigerants, but a recent study commissioned by EPEE[23] made forecasts for this that illustrate how pervasive the changes will have to be (SKM Enviros 2012)[24].

6.5.2. Summer peak electricity demand

Spain suffered a period of very high temperatures in July 2015 that created a surge of 8% in electrical demand due to the use of air conditioning. This set a new daily average record demand of 712 GWh. A similar trend is also observed in Italy, where since 2006 the summer daily peaks in electricity demand are higher than winter peaks. Data from Red Eléctrica De España (the Spanish electricity utility) in Figure 6-6 suggests that the peak summer daily average demand in Spain has been consistently catching up with the peak winter demand since 2009, rising from 88.7% in 2009 to 95.6% in 2014[25] (derived from REE 2014). Air conditioning is clearly a factor as in homes in Madrid it may account for up to one third of electricity use during periods of high demand in the summer (UC3M 2011) - and this is likely to be repeated in other large cities. Other factors are clearly contributing to this phenomenon (such as improved efficiency of heating), but the demand for air conditioning is rising and accelerating it. Parity between cooling and heating is further off or less likely for most other EU countries which have a more temperate climate, but the forecast rise in air conditioning use will continue to raise the summer peak for the EU as a whole and for many of its Member States for at least the next 15 years.

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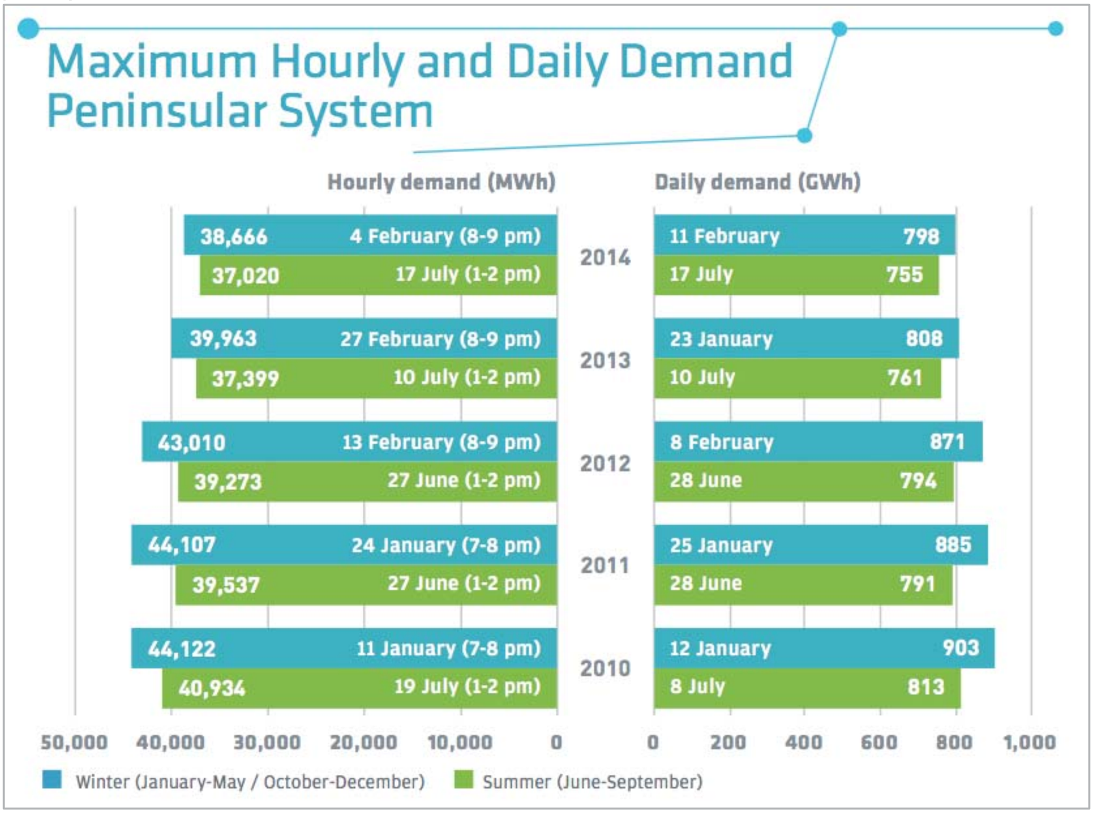
[23] The European Partnership for Energy and the Environment, see http://www.epeeglobal.org.

[24] According to this study, for commercial refrigeration, CO_2 will rapidly grow in popularity and could represent about 60% of new systems in 2020; but lower flammability blends will be introduced slowly (limited by current international safety standards and by lack of practical experience) but could grow to about 30% by 2025. For small and medium split air-conditioning there will be rapid growth in the use of HFC-32 and HFO/HFC blends from 2015 such that these could represent around 70% of the market for new split systems by 2020 and over 90% by 2025. If safety regulations and standards are successfully adapted then a part of this market could switch instead to HCs, displacing some of the market for HFO blends.

[25] The percentage for 2011 was slightly down on 2010 but not as low as 2009; all other years have shown a growth.

Figure 6-6. Annual maximum hourly (left) and daily (right) demand on the Spanish electrical grid, from 2010 to 2014



Source: REE (2014)

Policy responses to this are well rehearsed in the US and in Australia. Australia has taken direct action to manage peak electrical demand in summer by mandating the inclusion of a demand response enabling device (DRED) in all household air-conditioners sold since 2011/2012. Australia has developed and published a standard for a common demand response interface[26] for air conditioners to receive and respond to signals from the energy utility to 'cycle' during peak periods. Consumers can choose whether or not to allow the utility to remotely control their air conditioner, although an incentive is provided through cheaper electricity if they do. In trials, the cycling of air conditioners to reduce peak demand was not noticed by consumers.

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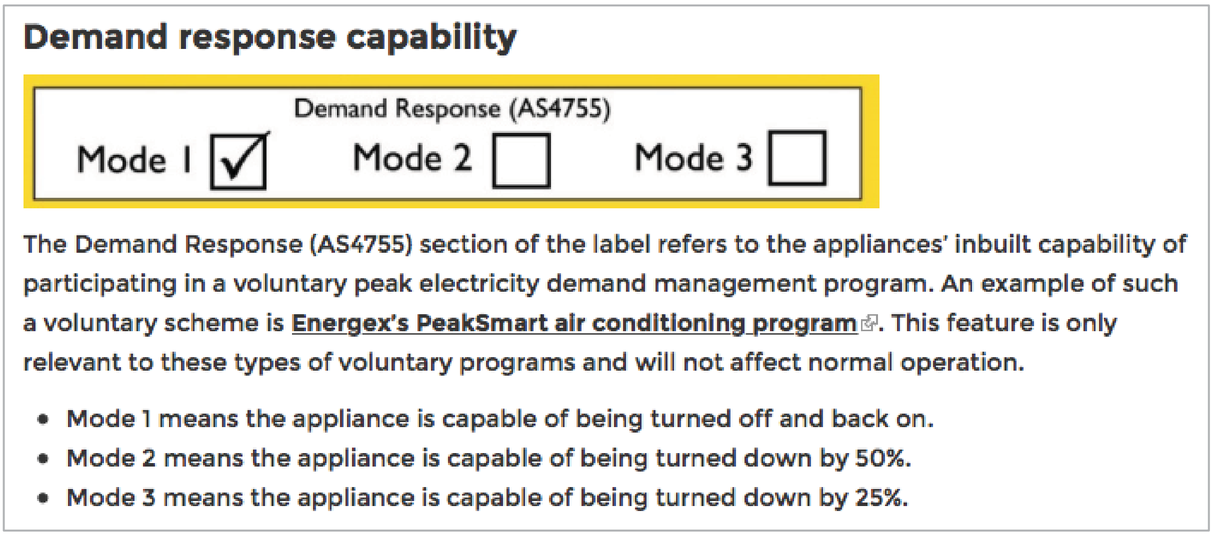
[26] Latest version: AS/NZS 4755.3.1:2014 Demand response capabilities and supporting technologies for electrical products - Interaction of demand response enabling devices and electrical products - Operational instructions and connections for air conditioners, www.standards.org.au.

Figure 6-7. Demand response capability options as noted on the Australian air conditioner energy label[27]*.*



Demand response capability

Demand Response (AS4755)

Mode 1 ☑ Mode 2 ☐ Mode 3 ☐

The Demand Response (AS4755) section of the label refers to the appliances' inbuilt capability of participating in a voluntary peak electricity demand management program. An example of such a voluntary scheme is **Energex's PeakSmart air conditioning program**. This feature is only relevant to these types of voluntary programs and will not affect normal operation.

- Mode 1 means the appliance is capable of being turned off and back on.
- Mode 2 means the appliance is capable of being turned down by 50%.
- Mode 3 means the appliance is capable of being turned down by 25%.

A similar concept has been proposed for using industrial and commercial cold stores for storage of 'wrong time' wind energy (the EU NightWind project[28], Greenpeace 2009), but is equally applicable to reduce peak electrical demand in that sector – demand for power in cold stores also rises with ambient temperature, but not to the same extent as for air conditioners. In the NightWind project, the total capacity of cold stores in the EU 27 was estimated at 4,300 MW (installed electrical maximum capacity and equal to around 10% of the peak demand of Spain presented above). Additional energy supplied to the cold store is transformed into thermal energy (lower product temperatures) like a 'battery' being charged. Assuming that stored goods are not harmed by that lower temperature, the refrigeration plant can then be switched off to reduce demand at least until its storage temperature rises back to the original set point.

6.6. Examples of innovative cooling solutions

This section includes some examples of innovative efficient technologies that are currently under-exploited or just emerging on the market.

The 'liquid air economy' and using waste cold from LNG regasification

It has been suggested that the biggest source of waste cold is that required to turn natural gas into compact Liquefied Natural Gas (LNG) at -162°C for transport by ship, which is discarded when the LNG is re-gasified at the import terminal (Carbon Trust 2015). The Carbon Trust goes on to explain the basic principles behind the concept of 'the liquid air economy':

> *'Air turns to liquid when refrigerated to -196°C, and can be conveniently stored in insulated but unpressurised vessels. Exposure to heat – including ambient – causes rapid re- gasification and a 700-fold expansion in volume, which can be used to drive a turbine or piston engine. Re-gasification also gives off usable and valuable cold,*

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[27] This is explained on the Australian government web site http://www.energyrating.gov.au/products/space-heating-and-cooling/air-conditioners

[28] *EU FP6 project nr. 20045, see http://cordis.europa.eu/project/rcn/79800_en.html.*

> *which gives liquid air a particular advantage wherever there is a need for energy storage and cooling. Storing liquid air requires only an insulated tank, which is cheap. Re-gasification then produces both power and cooling from a single tank of cryogen.'*
> (Source: Carbon Trust 2015)

These principles have been substantially developed along with enabling technologies by a consortium of universities and companies that are now working through the Liquid Air Energy Network[29] in the UK. A key enabling technology is the Dearman Engine, a novel piston engine powered by the vaporisation and expansion of liquid air or nitrogen (LAEN 2013). But most other enabling technologies of the proposed 'liquid air economy' are already well established and widely used throughout the industrial gases industry. Indeed the industrial gas companies have substantial quantities of spare liquid and gaseous nitrogen production capacity[30] that could be used in place of liquid air to support early deployment (LAEN 2013).

Figure 6-8 shows an overview of the elements of a hypothetical 'liquid air economy' which has the following key features and benefits according to the Liquid Air Energy Network:

- Liquid air can be used to store 'wrong time' low or zero carbon electricity by using it to liquefy air, which can then be used to displace higher carbon electricity and petrol or diesel in vehicles when needed. It is suggested that new liquefiers could be integrated with renewables to produce effectively zero carbon liquid air (LAEN 2013).
- Data centers could use liquid air for cooling and for running a cryogenic back-up power generator.
- Logistics companies and supermarket distribution hubs could use diesel/liquid air hybrid refrigerated trucks[31] and zero-emission forklift trucks; a bus depot could use a liquid air tank to support its bus fleet.
- Liquid air is particularly efficient for refrigerated transport because it extracts both cooling (from evaporation) and power (from expansion) from the same tank of cryogen. A transport refrigeration unit is being tested and is due to start fleet trials in 2015[32]
- The process of liquid air energy storage is capable of exploiting low grade waste heat[33] as input to a heat exchanger to boost expansion of the liquid air before it enters the turbine, so increasing the work output.
- Liquid air can exploit waste cold to raise the efficiency of liquefaction; the most significant example of this is at liquefied natural gas (LNG) import terminals for the

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[29] See http://www.liquidair.org.uk (website is planned to move to www.coldandpower.org).

[30] For an idea of scale, in Britain, the surplus nitrogen gas vented every day could be enough to power 310,000 homes or fuel well over 40,000 buses, equivalent to the entire UK bus fleet (LAEN 2013).

[31] A 'heat hybrid' combination of a liquid air engine with a diesel engine can exchange waste heat and cold to raise the efficiency of both engines, and reduce diesel consumption of lorries and buses by about 25% (Carbon Trust 2015).

[32] The liquid air transport refrigeration unit is being developed by a consortium of Dearman, MIRA and Loughborough University with UK government support.

[33] Waste heat at <150°C that is otherwise challenging to use effectively.

> re-gasification process[34]. The LNG is normally warmed by burning gas and the cold given off by evaporation is wasted. However, if air is used to warm the LNG, the resulting cold air can be fed into an air or nitrogen liquefier to raise its efficiency - terminals in Japan and Korea have been shown to use two thirds less electricity than a conventional liquefaction plant, although capital costs are roughly double (LAEN 2013).

The Carbon Trust concludes that:

> *In short, liquid air or nitrogen appears to be a vector capable of joining up waste cold and wrong time energy with cooling loads, and the technologies needed to make use of liquid air are on the verge of commercialisation. This raises the possibility of an entirely new approach to cooling which would recycle these sources of cold and energy to reduce the carbon intensity, emissions and cost of cooling.*
> (Carbon Trust 2015)

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[34] The Carbon Trust report that the annual cold from a UK LNG terminal at the Isle of Grain would be enough to fuel London's entire 7600 strong bus fleet as liquid air 'heat hybrids', achieving six times the efficiency of diesel alone (Carbon Trust 2015).

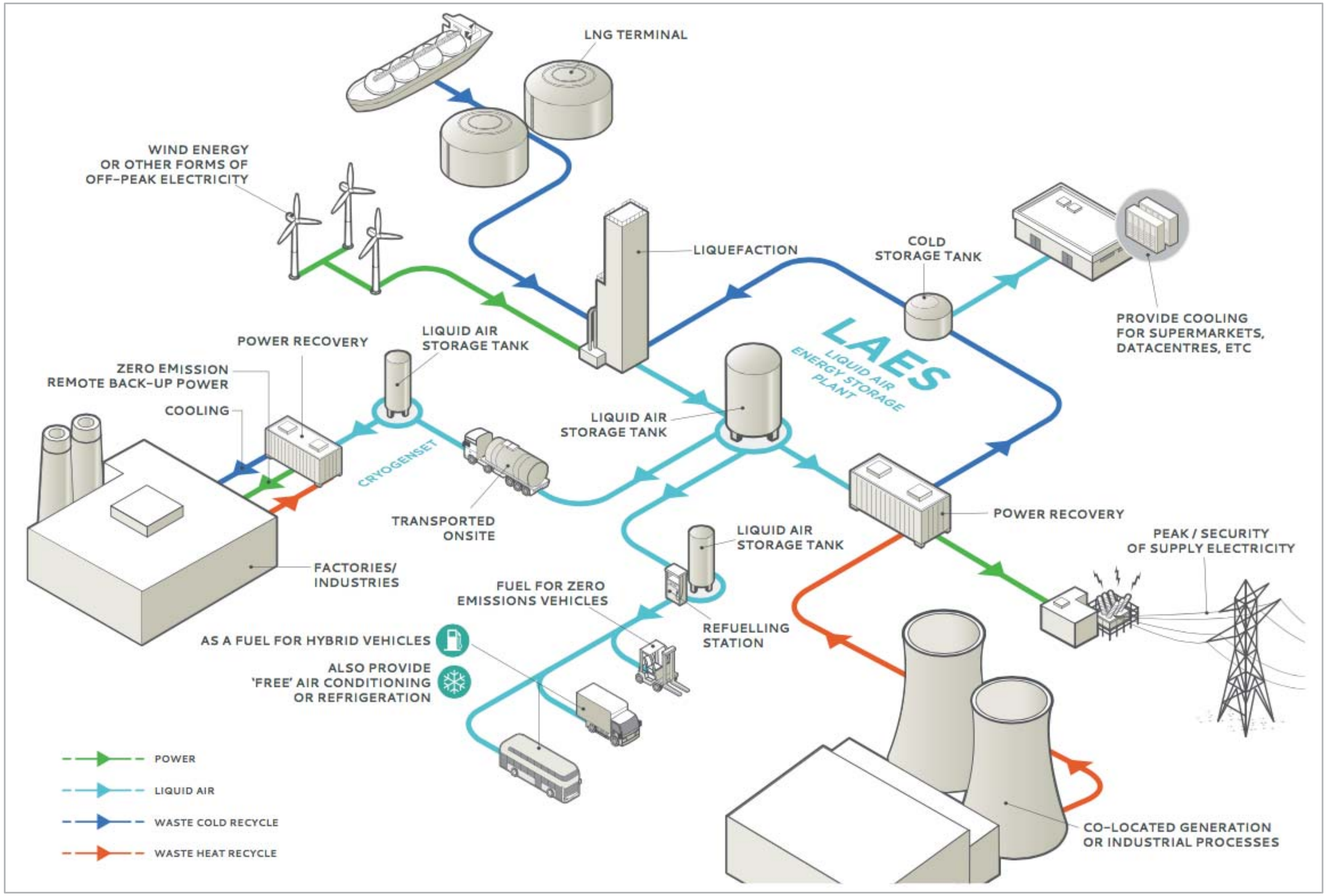


Figure 6-8. Overview of a liquid air economy (LAEN 2013).

The reuse of cold originated from the industrial depressurization process from LNG terminals is also being used in district cooling in Barcelona. LNG arriving by boat at the harbour at a temperature of -165º C is transformed into standard distribution gas through a heating vaporization process. This process uses seawater as a heating fluid (the heat transfers from the seawater to the gas, leaving the seawater at cold temperature). The District Cooling network is being developed to reuse this cold water to cool buildings nearby.

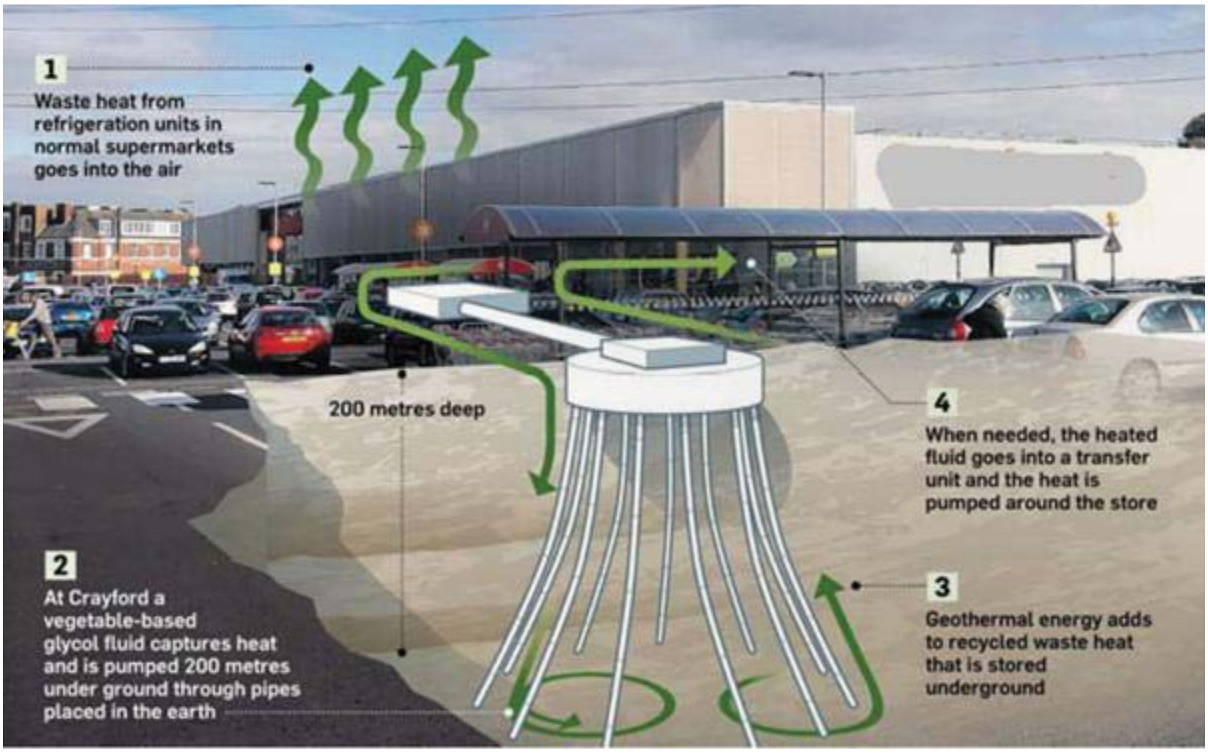
Reversible ground source heat pumps with inter-seasonal storage

Thermal energy storage (TES) systems can be charged with heat or cold and hold this energy over time and work well when combined with heat pumps. The storage can help even out demand and reduce the losses associated with 'wrong time' heating (or cooling).

> *The installation of larger-scale ice and chilled water storage is growing rapidly in some countries as utilities seek to reduce peak loads and customers seek to reduce peak load charges. Integrated ice storage typically allows systems to reduce chiller capacity by 50%, with a similar reduction in the electrical peak demand for chilled water production.*
>
> *Large-scale stores (in the MWh scale) are often placed underground in order to use the ground as insulation. Aquifer thermal energy storage (ATES) exchanges heat through boreholes, with a natural water-saturated and permeable underground layer as a storage medium. Heat pumps with ground coils or a vertical bore hole can be used to disperse heat to ground in summer, but if they are designed to load thermal storage tanks, this can be exploited as a renewable heat source in winter.*
>
> (IEA 2011)

An innovative approach being rolled out in one major retail chain in the UK. The baseline technology was developed from the oil and gas sector and then applied to retail stores. The principle is simple: fridges in stores produce heat as part of the refrigeration process, this heat – which would otherwise be lost as waste - is transported to an underground vault through a series of pipes. The heat is kept underground using subsurface rock, which has good insulating properties and when it is required, the heat is pumped back into the store. This technology uses radial boreholes linked to ground source heat pumps to store waste heat from the CO_2 refrigeration system. The heat is then drawn back via the ground source heat pump when needed to provide heating; the scheme is illustrated schematically in Figure 6-9. The thermal stability of using an underground heat sink that provides cool conditions for condensing even in high summer and other benefits of the system were found to save an additional 30% of energy over and above that of the baseline CO_2 refrigeration system alone (IoR 2012). Twelve such systems were in place at Sainsburys stores in 2013 (Skelton 2013) and the company estimated a cut in energy consumption of 30%.

Figure 6-9. Schematic of a closed loop geothermal heating and cooling system at a UK retail store



Source: IoR (2012)

Free cooling

Making use of cooling from ground, aquifers, lakes and oceans can provide base load cooling, even if topped up with mechanical cooling. In particular, thermal storage systems that store heat from cooling in summer and draw on that heat in winter by use of ground source heat pumps can be economically attractive if ground conditions are right.

Two distinct types of free cooling are available, both can be much more widely exploited:

- Cold can be transferred from ocean, lakes, rivers or aquifers via heat exchangers to the distribution network. Cooling can be topped up or guaranteed through additional cooling from conventional sources. Systems are feasible when the water temperature is appropriate and the plant is close to water sources. This type of renewable cooling scheme exists in Stockholm, Helsinki and also in Toronto (ECOHEATCOOL 2006). For industrial applications such as food cooling after cooking, part of the cooling load can sometimes be met by ambient air cooling with fans.
- Thermosyphon free cooling is used for industrial and central air conditioning systems: as ambient temperatures fall below the return water temperature ‘free cooling’ can be exploited by systems designed to do so through circulation of refrigerant around the chiller without running the compressors. Pumping energy is needed, but not the more significant energy of the compressor. As external temperature rises, the chiller can be switched back into conventional mode. Many types of industrial process chillers and premium air conditioning chillers have this functionality and EU test methods. Unfortunately, because there are several means at building level to perform free cooling (via the air handling unit, a chiller with thermosyphon, chiller with supplementary air/liquid coil, supplementary dry cooler independent from the chiller

> and other options), free cooling was not incorporated within EN14825[35], despite this being of keen interest to rooftop chiller manufacturers (rooftop and air handling units are natural free cooling products) (CLASP 2013). Overall, the best free cooling option needs to be evaluated by the building / system designer using application-specific data.

A detailed case study published by ASHRAE in 2015 for an energy efficiency upgrade at a London data centre with an 1.800 kW IT load showed how free cooling, air flow optimization, adjusting cooling set points within the relevant ASHRAE limits and other measures decreased the annual PUE from 2.29 to 1.49 (35% reduction) and saved € 1,6 million per year (Flucker/Tozer 2015).

Magnetic cooling

Magnetic refrigeration uses the ‘magnetocaloric’ effect by which a temperature change is caused in a suitable material by exposing it to a changing magnetic field. It is the principle applied within an adiabatic demagnetization refrigerator (ADR) and can attain extremely low temperatures as well as the range used in a household refrigerator. It is safe and quiet, with low cost, long life and good efficiency as it only requires one moving part which is the rotating disc on which the magnetocaloric material is mounted (Marketsandmarkets 2015). Magnetic refrigeration had for many years been considered for exploitation in applications such as ultra-low temperature refrigeration and for spacecraft. However, a consortium of Haier, Astronautics and BASF presented a first prototype of a magnetocaloric wine cooler at the International Consumer Electronics Show 2015 in Las Vegas/Nevada. The associated news release claimed that ‘*theoretical studies demonstrate that refrigeration systems based on the magnetocaloric effect can be up to 35% more energy-efficient than vapor compression systems*’ (Haier 2015). One report has claimed that the global magnetic refrigeration market will be worth € 290M by 2022 with exploitation for beverage coolers, stationary air conditioners and heat pumps as well as healthcare (Marketsandmarkets 2015).

Solar cooling

In solar air-conditioning (SAC), solar heat is used to drive a cooling process. This technology has been described in Section 4.3.1.

One innovative application is being developed by a start up company, Solar-Polar[36], which is developing an insulated shipping container-based system for solar driven pre-cooling of food using removable modules for onward refrigerated transport of produce to market. A pilot-scale test of a single module is being carried out at Imperial College, London[37] (IMechE 2014).

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[35] EN 14825 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling Testing and rating at part load conditions and calculation of seasonal performance.

[36] See http://www.solar-polar.co.uk.

[37] “Cross department project to work on cutting-edge hybrid solar technology”, *12 May 2015*, http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/administration/energyfutureslab/newssummary/news_8-5-2015-13-25-24.

7. ENERGY EFFICIENCY AND DECARBONISATION OF HEATING AND COOLING BY 2030 AND 2050

In the context of the preparation of the 2030 Energy and Climate Framework[38] and the Energy Efficiency Review Communication[39], various scenarios have been modeled to assess the impacts of potential targets for 2030 and explore possible pathways to a 2050 EU energy system that fulfils the objectives of keeping climate change below 2° C rise in global temperature. These are based on the modelling of the whole energy system, where electricity and heating and cooling across the main sectors, buildings (households and tertiary sectors), industry and transport are examined together with the possible synergies and trade-off with the electricity and other sectors. Although these scenarios do not focus in detail on heating and cooling, they do establish some potential trends and levels of ambition for the development of heating and cooling until 2030 and 2050.

The scenarios can be divided into a Reference scenario (depicting energy system developments based on current trends and implementation of already-fixed policies) and policy scenarios (depicting alternative policies/outcomes).

7.1. Scenario analysis of heating and cooling by 2030 and 2050 based on PRIMES modelling

No new specific scenarios have been developed for this report. The present analysis focuses on a set of scenarios developed in the context of the Commission's proposals for a 2030 climate and energy framework [COM(2014)15] and the Energy Efficiency Review Communication [COM(2014)520]. The purpose of this analysis is not to test new policy options, but to assess in more depth the implications for the transformation of the heating and cooling sectors in detail, in the light of existing measures and of the policy objectives planned for 2030 and 2050.

In particular, the following scenarios are analysed:

- The 2013 Reference scenario, which includes all relevant policies adopted by Spring 2012 at EU and MS level. Except for the ETS, most of these policies are depicted as being phased out by 2020. This means that the heating and cooling aspects – most of which are not under ETS - have a 'light' policy framework post 2020. This can serve as a benchmark with which to compare more ambitious policy scenarios.

- The EE27 policy scenario. In this scenario, the EU achieves a 40.2% reduction in GHG emissions by 2030, a RES share of 27.8% and an EE share of 27% as well. It is therefore a scenario close to the current 2030 climate and energy framework as agreed by the European Council, but does not embody the review of the energy efficiency target by 2020 'having in mind an EU level of 30%' called for by the European Council. In this scenario the EU comes close to its 2050 goal (reducing GHG emissions by 80-95%), since GHG emissions are reduced by 78.8% by 2050 as compared to 1990.

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[38] A policy framework for climate and energy in the period from 2020 to 2030 [COM(2014) 15]; Impact Assessment on energy and climate policy up to 2030 [SWD(2014) 15]

[39] Energy Efficiency Communication [COM(2014)520], Energy Efficiency Communication Impact Assessment [SWD(2014)255]

- The GHG40RES30EE30 scenario. In this scenario, by 2030 GHG emissions are reduced by 40.6%, the RES share is 30.3% and EE is 30%. 2050 GHG emission are reduced by 81.8% as compared to 1990[40].

These scenarios are projections and not forecasts. They show combinations of actions in all aspects of the EU energy system which lead towards a certain goal. The trends and orders of magnitude of change indicated by these outputs for heating and cooling are therefore more relevant than the exact numerical outputs.

How heating and cooling is modelled in PRIMES

Distributed Heat and Steam Modelling in PRIMES

Distributed heat in PRIMES can come either from CHP or district heating boilers. There are several technologies to produce steam, but distribution technologies are rather standard. The CHP technologies are considered mature, therefore no new learning effects are assumed**.** The higher penetration of CHP technologies in the different scenarios is based on policy drivers and ETS carbon prices.

Heating and cooling demand in PRIMES

In PRIMES, for each energy demand sector a representative decision making agent is assumed to operate, who optimizes an economic objective function. For households and passenger transport a utility maximisation function is formulated, whereas for industrial, tertiary and freight transport sector a profit maximisation (or cost minimisation) function is used. Firstly useful energy demand (services from energy such as temperature in a house, lighting, industrial production, etc.) is determined at a level of a sector. Useful energy, as derived, is further allocated to uses and processes (e.g. space heating, water heating, motor drives, industrial processes, etc.). The separation in uses and processes follows a tree structure which is formulated mathematically so as optionally to allow either for complementarity or substitutable relationships among uses/processes. For example to produce a certain product a chain of processes may be followed: in this case they are complementary with each other. But it may be that the product can equally go through electro-processing or thermal processing in which case the processes are substitutable to each other. For some sectors the model distinguishes between sub-sectors in order to get a more accurate representation of the stylised agent. For industrial sectors the model puts emphasis on materials and recycling and so it distinguishes between sub-sectors which involve basic processing (e.g. integrated steelwork, clinker in cement, primary aluminium, etc.) and sub-sectors which use recycled and scrap material.

Regarding the residential sector in particular, the model distinguishes between five categories of dwelling. They are defined according to the main technology used for space heating. They may use secondary heating as well. Each type of dwelling is further subdivided in five typical energy uses. The electric appliances (several categories) for non-heating purposes are considered as a special sub-sector, which is independent of the type of dwelling. There is no distinction between rented and owned dwellings. The dwelling types considered in PRIMES are the following: Central boiler households that may also use gas connected to the central boiler (flats); Households with mainly electric heating equipment (not partially heated); Households with direct gas equipment for heating (direct gas for flats and gas for individual houses); Households connected to district heating network; Partially heated dwellings and agricultural households.[41]

7.2. Projected evolution of heating and cooling demand

In the EU 2013 Reference scenario (REF 13) the absolute consumption trend for heating and cooling is projected to remain rather stable over time, with slight decreases projected for 2020

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[40] SWD(2014) 15. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014SC0015

[41] http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202013-2014.pdf

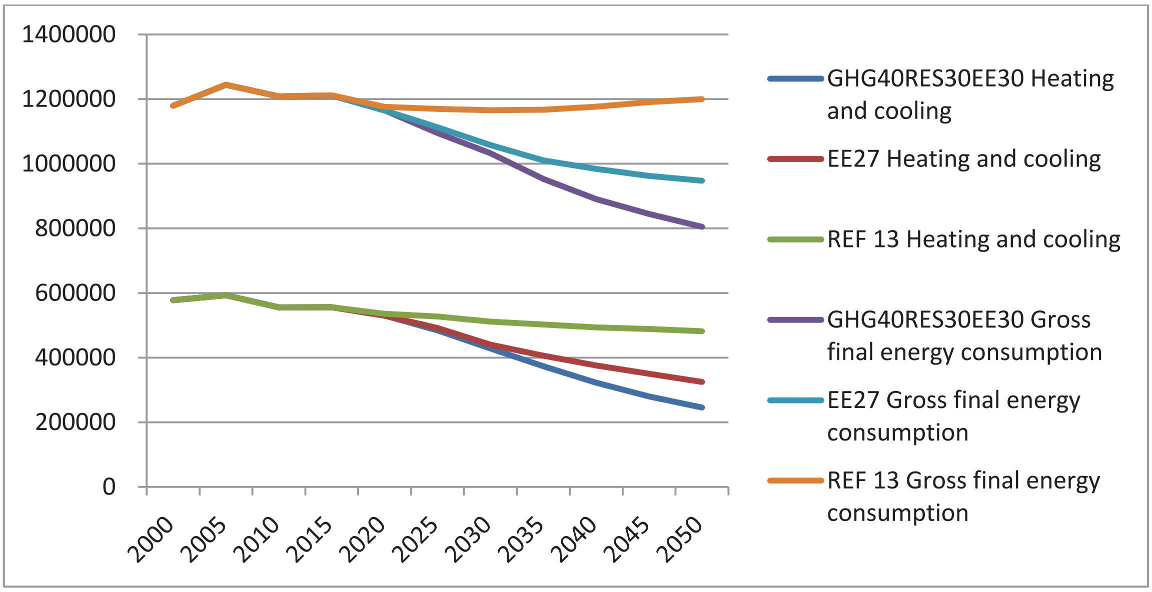
(relative to 2010) and 2030 from 555 Mtoe to 535 Mtoe in 2020 and to 512 Mtoe to 2030 respectively; and a slight decrease afterwards to 2050, with the level still remaining slightly under current consumption. The share of heating and cooling in final consumption also remains rather stable, decreasing from 46% in 2015 to 44% in 2030 and 40% in 2050.

The policy scenarios depict a significant change in (heating and cooling) demand trends. To achieve the 2050 climate objectives, the modelling forecasts illustrate the need for the EU to move away from fossil fuels to low carbon sources and deeply transform its energy system. While the use of oil, natural gas and coal ("solids") will need to decrease significantly, low carbon sources such as renewables are expected to increase, together with a step-up of energy efficiency.

At EU level, the overall energy consumption needs to decrease by 22% (EE27) to 33% (GHG40RES30EE30) from 2010 until 2050. The heating and cooling sector is expected to significantly contribute towards achieving these goals. Heating and cooling demand has to be reduced by 42% (EE27) to 56% (GHG40RES30EE30) by 2050, which is a much higher decrease compared to the other end-use sectors (electricity and transport). Moving from the EE27 towards the more ambitious policy scenario would require delivering almost 15% additional energy savings in heating and cooling demand. Consequently, the share of heating and cooling in total energy consumption decreases as the policy ambition increases.

A possible interpretation of that result relates to the successful implementation of consistent measures to reduce the heating and cooling demand in final sectors such as: deep renovation of existing buildings and construction, significant energy efficiency improvements in industrial processes, consistent demand-side management measures in tertiary buildings contributing to lowering the demand etc. Other reasons linked to the forecasted decrease in the price of certain technologies are also possible and more in-depth analysis is therefore needed.

Figure 7-1: Gross Final energy and heating and cooling consumption across scenarios[42]



Residential heating and cooling demand

In the residential sector in the Reference scenario final energy consumption is projected to be rather stable, decreasing from 312 Mtoe in 2015 to 299, 297 and 304 Mtoe in 2020, 2030 and 2050 respectively. The share of residential in total final energy is stable at around a quarter of total final consumption. The share of renewable energy in residential energy consumption remains low. It is 7% in 2015 and 2020, 9% in 2030 and reaches only 13% in 2050. The level of electrification of heating and cooling is 19% in 2015 according to the Reference scenario and will not grow beyond 20% throughout the period of 2020-2050.

Under the EE27 scenario and the GHG40RES30EE30 scenario respectively, residential energy heating and cooling consumption is depicted as decreasing by 20% to 30% from today until 2050. The heating and cooling sector is expected to significantly contribute towards achieving this, with reductions of 40% to 60% compared to 2005.

As regards cooling, although it represents a small share in final energy consumption and there are several uncertainties regarding its future trends, the forecast show an exponential growth under REF 13 and a more moderate increase under the policy scenarios.

If we look in more detail at the evolution of the different heat uses, it can be noted that heating demand decreases in all scenarios, while cooling demand increases, although at a lower level under the ambitious scenario. Water heating and cooking are projected to decrease due to energy efficiency gains by around 20% to 50% from today to 2050, although this seems particularly challenging.

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[42] Gross Final energy consumption includes final energy consumption of all energy commodities in industry, households, services and agriculture, forestry and fishery except electricity, plus the consumption of heat for own use at electricity and heat plants and heat losses in networks, as defined in Article (2)(f) of Directive 2009/28/EC. Heating and cooling comprises final energy consumption plus network losses and own use of heat and electricity at electricity and heating plants (NB: this does not include consumption of electricity for pumped hydro storage or for transformation in electrical boilers or heat pumps at district heating plants).

Figure 7-2: Final Energy per energy use (Ktoe) Residential Heating (left) and cooling (right) Demand

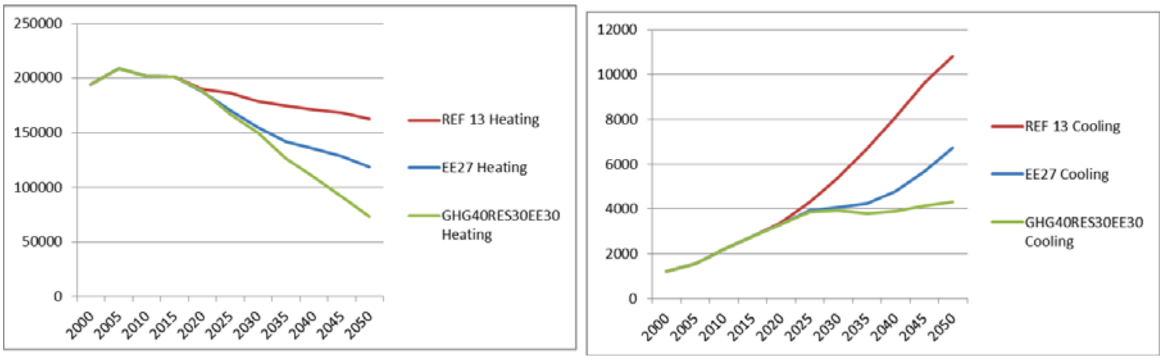
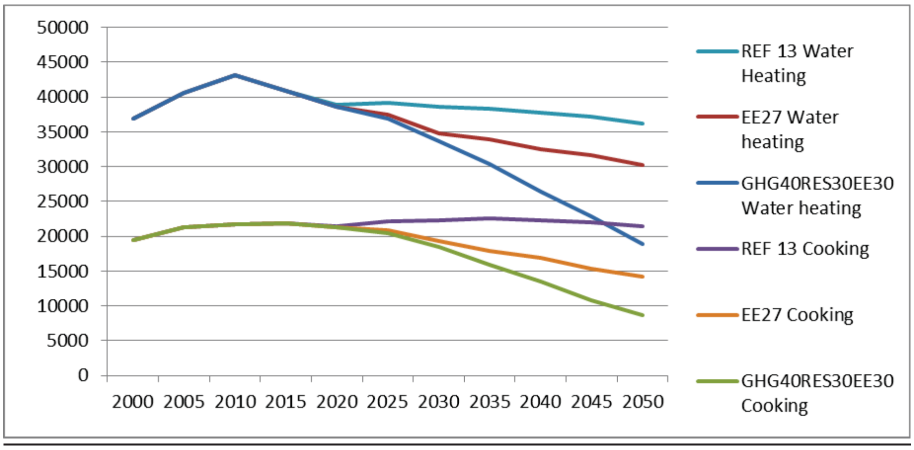


Figure 7-3: Final Energy per energy use (Ktoe) Other Heat Uses: Water Heating and Cooking



As regards the technologies used for residential heating, the projections show an evolution towards more electrical appliances. About a quarter of all heating and cooling demand will be supplied by electricity in 2050. The number of central heating units and direct gas heating units plateau in the 2030s and begin to decrease in the 2040s. Electrical heating appliances significant rises – by as much as five-fold under the GHG40RES30EE30 scenario.

The figures below illustrate in particular the evolution forecasted of the fuel mix in heating and cooling demand in the residential sector.

Figure 7-4: Final Energy per fuel in the residential sector for Heating and Cooling under the Reference scenario (Ktoe)

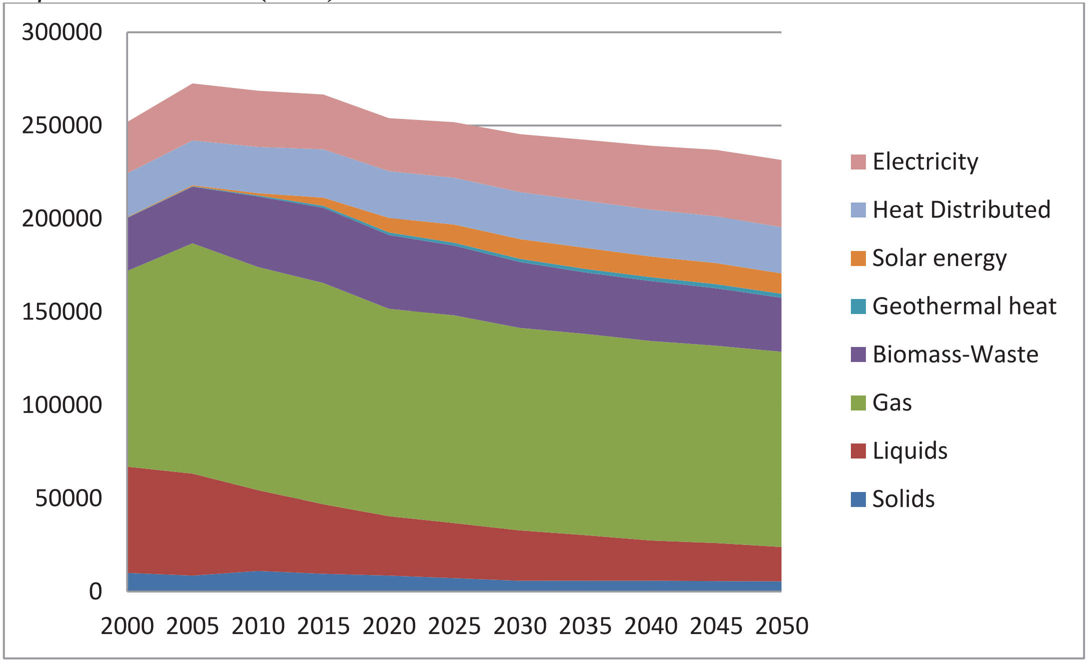


Figure 7-5: Final Energy per fuel in the residential sector for Heating and Cooling under EE27 (Ktoe)

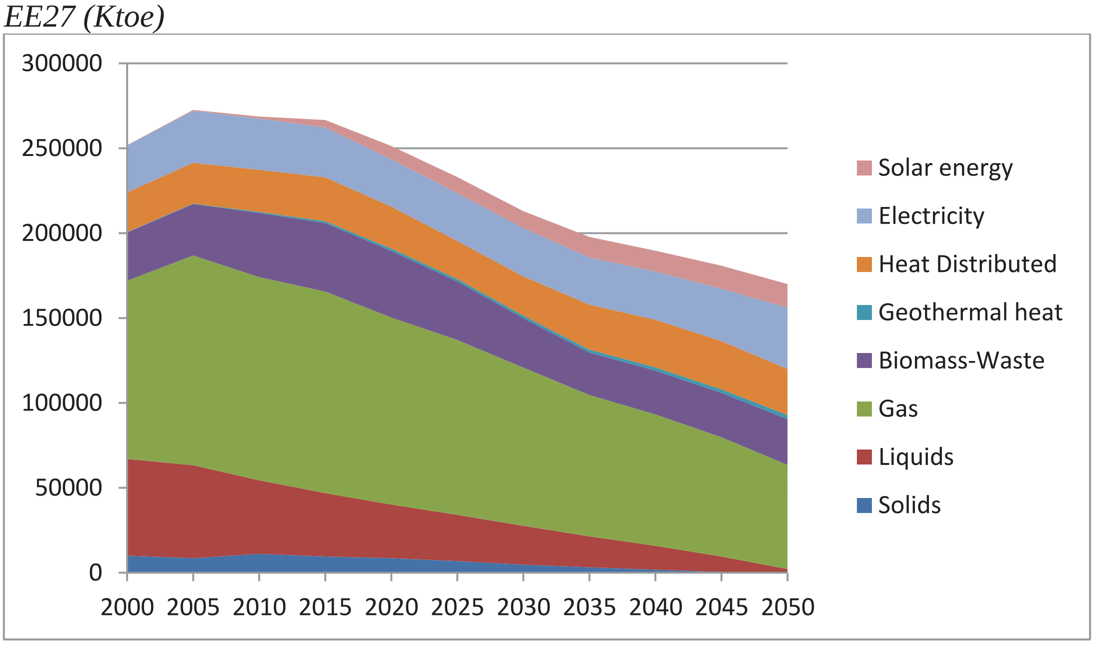
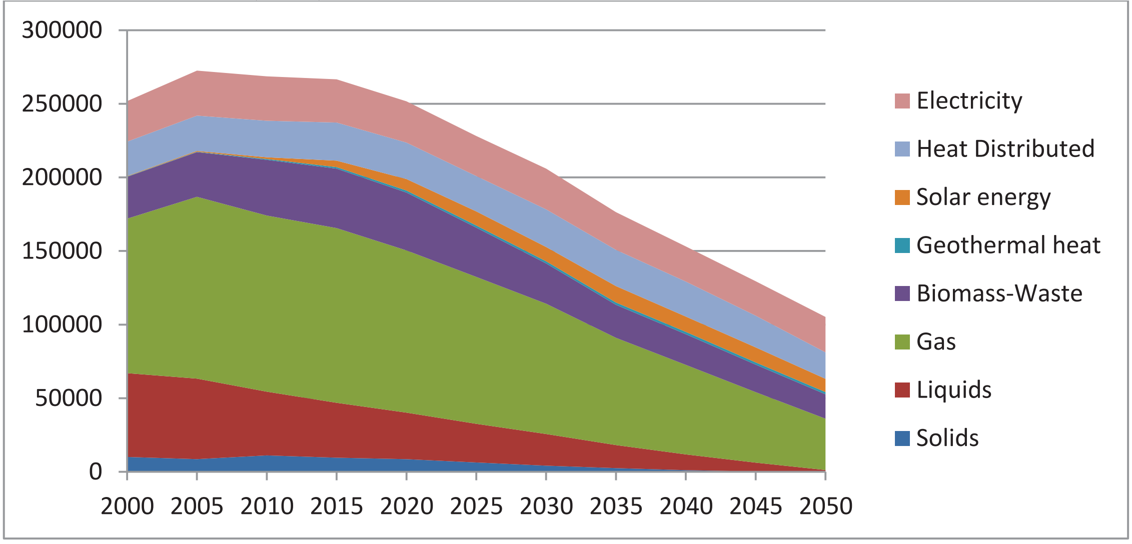


Figure 7-6: Final Energy per fuel in the residential sector for Heating and Cooling under GHG40RES30EE30 (Ktoe)

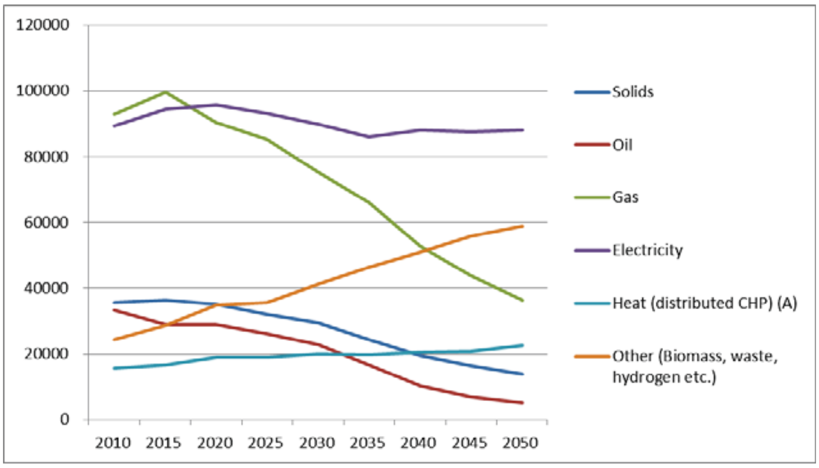


Demand in industry

Energy intensive industry has the second highest heating and cooling demand after the residential sector. It is expected that industry would reduce its overall energy demand by 20% to 30% respectively in the two scenarios called EE27 and GHG40RES30EE30 from today to 2050, as compared to the business-as-usual described in the reference scenario.

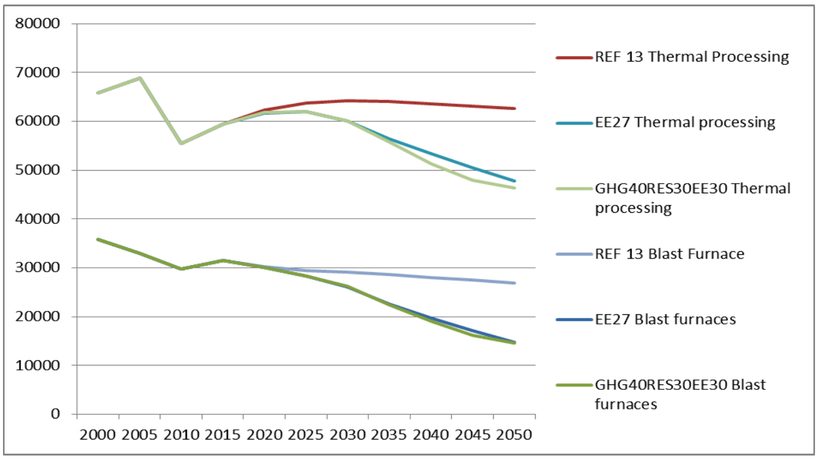
Industry's energy mix is projected to change. Natural gas, which is at present supplying the majority of industry's energy, is projected to be significantly reduced by 2050. By then, electricity will become the first fuel, and biomass, waste and hydrogen combined would become the second most important energy source. Distributed heat (district heat and CHP) is projected to grow slightly, but would still represent a low share. Oil is expected to be nearly phased out as an energy source for industry with an over 80% reduction from today's levels in 2050.

Fig 7-7: Final Industry Energy Demand (in ktoe) by fuel: EE27 Scenario



If different technologies used in energy-intensive industries are considered, it can be noted that, while the reference scenario depicts a stabilisation in energy demand for blast furnaces and thermal processing, the two policy scenarios represented lead to significant decreases in energy demand.

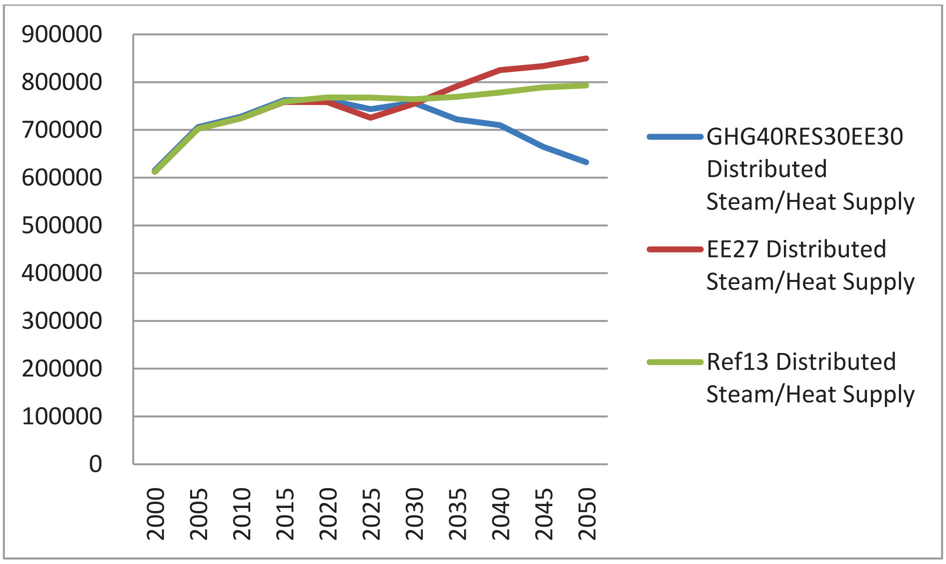
Fig. 7-8: Industry Energy Demand (Ktoe): Blast furnaces and thermal processing



7.3. Projected evolution in distributed steam/heat supply

The difference in developments regarding district heating ("distributed steam/heat supply") is noteworthy. Under the EE27 scenario, its production increases throughout the period. Under the GHG40RES30EE30 scenario, it grows (less rapidly) until 2030 and then falls back. This is also something observable when breaking down between CHP plants and district heating units. Potential explanations for this projected steep decrease of distributed heat generation under the GHG40RES30EE30 scenario relate to the GHG emissions reduction potential of CHP deployment and distributed heat provisions. Initial efficiency gains brought by the use of CHP or district heating may be more than compensated by the limited options to fully decarbonise this sector (e.g due to the reaching of the limits of biomass availability). Besides, the trend towards electrification (i.e. heat pumps) and higher energy efficiency limits the overall demand for distributed heat in the tertiary and residential sectors.

Figure 7-9: Distributed Steam/Heat supply across scenarios



7.4. The use of renewable sources in heating and cooling

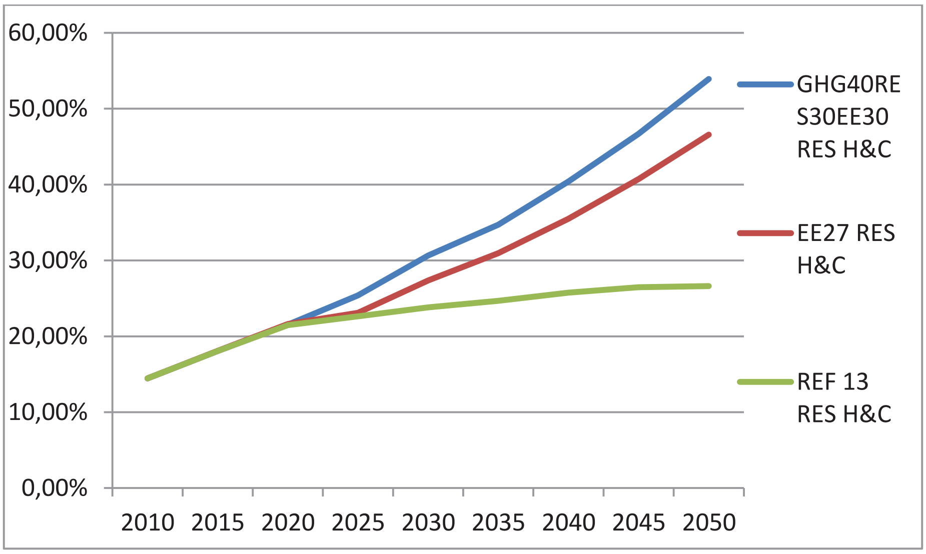
The share of renewable energy in heating and cooling is 14% of total final consumption for heating and cooling in 2010. In the 2013 Reference scenario, this share increases to 21.5% in

2020, 24% in 2030 and 27% in 2050. The absolute volumes of renewable energy used in the sector slightly increases, from 100 Mtoe in 2015 to 115 Mtoe in 2020, 122 Mtoe in 2030 and 128 Mtoe in 2050.

In the EE27 and GHG40RES30EE30 scenarios, the heating sector will see a significant increase in the use of renewables, in particular in the residential sector. The overall share of renewables in heating and cooling will be 27-31% in 2030 and 47-54% in 2050.

In the industrial sector the shift to renewables is expected to take place at a lower and slower rate. The share of renewable in the industry under GHG40RES30EE30 is projected to be 13% in 2030 and 17% in 2050.

Figure 7-10: Heating and cooling RES consumption in the residential sector across scenarios



8. EU-WIDE AND NATIONAL EXAMPLES OF HEAT PLANNING AND MAPPING

8.1. The results of the European heat map strategy

Two successive EU-wide energy system modelling entitled Heat Roadmap Europe 1 (HRE1) and Heat Roadmap Europe 2 (HRE2) prepared by Aalborg University developed possible scenarios for the EU heating and cooling sector. The modelling was underpinned by heat mapping establishing heat demand densities on a 1 km^2 resolution for each country in Europe to identify the share of heat demand that could economically be supplied by district heating. The key finding of HRE1 was that approximately 50% of the heat demand in Europe was in areas with a sufficiently high heat density to justify the development of district heating.

A systems analysis tool developed under the Heat Roadmap 2050 Europe, called EnergyPLAN, was used to model 2010, 2030, and 2050 business-as-usual scenario of Europe based on forecasts from the EU Energy Roadmap report. The results indicated that if district heating is increased from today’s level of 10% to the potential identified in the mapping of 50%, this would reduce energy consumption, reduce carbon dioxide emissions, reduce energy costs, and increase the number of jobs in the EU. The high potential of the development of district heating has however to be interpreted with caution, because several other factors influence the real potential and feasibility of deployment; and cost-effectiveness principles would require comparing this technology with others.

The Heat Roadmap Europe 2 study (HRE2), was expanded to cover the entire heating sector rather than only district heating. The analysis considered heat savings, heat networks in urban areas (i.e. gas and district heating), and individual heating in rural areas (i.e. boilers, heat pumps, etc.). The potential and cost of implementing heat savings in European buildings were also assessed, together with some individual heating considerations. The scenario analysed in HRE2 was not a business-as-usual scenario, but instead it was a low-carbon energy system scenario. The 2050 scenario was again taken from the EU Energy 2050 Roadmap, but this time it was for a scenario where Europe achieved its greenhouse gas emission target of 80% reductions by 2050. The final HRE2 scenario proposed included 35% reductions in heat demand in 2050, 50% of which was achieved through district heating (i.e. in urban areas) and 50% through individual heat pumps (i.e. in rural areas). This HRE2 scenario was able to achieve the same level of decarbonisation as proposed in the European Commission’s scenario, while the total system costs of the HRE2 scenario were estimated to be lower by €100 billion/year. Several factors however impede straightforward comparisons of the different cost forecasts, as the methodological approaches applied vary greatly. In HRE2, the cost-effective potential of district heating is achieved in urban areas, while heat pumps were assumed to be the only technology that could be used to achieve decarbonisation in areas where district heating is not cost-effective or feasible. This assumption about technologies should be taken into account in the interpretation of the scenario results.

The heat mapping was expanded in HRE2 to locate and quantify the waste heat available in Europe that could potentially be used to supply district heating systems in the future. The study indicated that the availability of waste heat is substantial, and could have a strong impact on the cost-effectiveness of district heating in comparison to other technologies. In particular it was estimated that there is currently more waste heat available from thermal power generation, industry, and waste incineration than is required to heat all buildings in

Europe. The mapping in HRE2 also identified the areas of Europe that have suitable resources for renewable heat supply in the form of solar thermal and geothermal heating, which could also be used to supplement waste heat in a district heating system.

Under the third stage of this study, which is currently ongoing under the Horizon 2020 project STRATEGO, the objective is to move from an EU wide analysis to individual Member State assessments[43] covering the entire heating and cooling sector. The five Member States that are analysed in STRATEGO are the Czech Republic (CZ), Croatia (HR), Italy (IT), Romania (RO), and the United Kingdom (UK).

Like the HRE2 study, the heat strategies developed under STRATEGO consider a combination of heat savings, heat networks in urban areas, and individual heating in rural areas. The cost of heat savings is analysed separately for each of the countries considered, as well as the renewable resources available in each Member State. The mapping in this study also includes the cooling demand[44] and have been developed using EnergyPlan.[45] [46]

The quantitative results relating to the energy efficiency potentials of the heating and cooling sectors in the Czech Republic, Croatia, Italy, Romania and United Kingdom are provided in Table 8-1. The Heat Roadmap scenarios are compared to business as usual ("BAU") scenarios from a total energy system perspective as well as for the heating, cooling and electricity sectors on their own.

The results show that when comparing the Heat Roadmap scenarios to the BAU 2050 for the entire energy system, the energy efficiency potentials in terms of primary energy savings are between 15-25%, with the largest reductions in fossil fuel consumption. Due to these savings in fossil fuel consumption, there is a corresponding reduction in carbon dioxide emissions of 20-30% for all the STRATEGO countries. Furthermore, the energy efficiency gains also

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[43] This approach is based on/draws on the requirements currently in place in Article 14 of the Energy Efficiency Directive, which specifies that "By 31 December 2015, Member States shall carry out and notify to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling".

[44] The map developed by the Ecoheatcool project suggests that the cooling demand in Europe can vary by +/-40% across Europe (whereas the same report suggested that the heat demand across Europe only varies by approximately +/-20%). Each of these factors add to the uncertainty in the cooling sector. If people start meeting their cooling requirements, cooling demand could expand by approximately six times in Europe. If cooling demand does expand rapidly in the future, in combination with a decrease in the heating demand, then cooling demand could reach up to 30-70% of heating demand across the five STRATEGO countries. In this context, the cooling sector will have a major influence on the rest of the energy system.

[45] The modelling represents each country under three difference contexts:
- The current situation, which is represented by the year 2010 and called the 'reference' model;
- A future situation for the year 2050, which is based on the European Commission's current projects for that member state. This is referred to as the 'business-as-usual' model;
- Alternative heating and cooling scenarios based on the new knowledge created in STRATEGO WP2 such as the potential for energy savings, district heating and district cooling, and renewable energy. These scenarios are based on the reference and business-as-usual models created here, but they are presented and analysed in the Main Report titled "Enhanced Heating and Cooling Plans to Quantify the Impact of Increased energy Efficiency in EU Member States".

[46] EnergyPLAN simulates the electricity, heating, cooling, industry, and transport sectors of an energy system. It simulates each sector on an hourly basis over a one-year time horizon and it is typically used to analyse national energy systems. EnergyPLAN is typically referred to as a simulation tool since it optimises how a mix of pre-defined technologies operate over its one-year time horizon. The EnergyPLAN user can define a wide range of inputs before the simulation begins, such as technology capacities, efficiencies, and costs, which EnergyPLAN then uses to identify how this energy system will perform under either a technical or economic simulation. A technical simulation strategy is utilised here for all models so the energy system is operated as efficiently as possible during each hour in the EnergyPLAN tool.

affect socio-economic costs, which despite increased investment costs, are reduced slightly (5-10%) compared to the BAU 2050 scenario.

The level of heat savings recommended in this study based on the energy modelling is 30-50% of the total heat demand, depending on the country[47].

Table 8-1: Heat Roadmap impacts on Energy, Environment and Economy compared to the 2050 BAU scenario for the entire energy systems.

Change in Primary Energy Supply			**Change in Carbon Dioxide**		**Change in Energy System Costs (Excluding Vehicles)**	
Unit	***Mtoe/year***	***%***	***Mt***	***%***	***Billion €/year***	***%***
Czech Republic	-9.7	-19%	-5	-19%	-0.63	-7%
Croatia	-1.5	-15%	-33	-30%	-2.44	-7%
Italy	-33	-17%	-100	-21%	-13.48	-8%
Romania	-9.9	-23%	-34	-36%	-3.35	-9%
United Kingdom	-37.9	-19%	-114	-24%	-17.18	-9%

Source: STRATEGO

Table 8-2: Heat Roadmap vs. BAU 2050

Heat Roadmaps	**Heat savings**	**District heating**	**Individual heating technologies**	**RES supply**
Unit	**% of BAU 2050 Heat demand**	**% of total heat demand after savings**	**Primary technology**	**% District heat production**
Czech Republic	50%	40%	Heat pumps	60%
Croatia	40%	40%	Heat pumps	45%
Italy	30%	60%	Heat pumps	40%
Romania	50%	40%	Heat pumps	45%
United Kingdom	40%	70%	Heat pumps	40%

The analysis of the transformation of heating and cooling demand and supply across the different PRIMES scenarios and the ones elaborated under the STRATEGO project reveals that significant transformation would be necessary to decarbonise heating and cooling up to a level consistent to the 2030 and 2050 climate end energy goals.

Such transformations will be driven by efficiency gains and fuel switch, towards less carbon-intense fuel sources and especially through renewables. Changes will be needed in the residential, service and industrial sectors, and will face the structural limits that are specific to the heating and cooling needs in each of these sectors.

The alternative models presented show that different pathways are possible and that national and local conditions, for instance related to the economic structure, climatic conditions, fuel mix and existing technology mix will definitely play a role in defining the optimal pathway. The following Section 5 will explore several dimensions which are relevant to identify the

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[47] This number relates to the total reduction across the entire building stock, so the reduction may be higher in some buildings than others. For example, older buildings are more likely to have higher levels of heat savings. At the individual building level, this number is more comprehensible when defined as the resulting unit heat demand (i.e. heat demand per unit of floor area in kWh/m^2). A 30-50% reduction in the heat demand equates to a unit heat demand in the range of 60-90 kWh/m^2. Beyond this point, it the cost of additional savings is likely to be more expensive than supplying sustainable heat.

options to decarbonise and exploit the efficiency potential of heating use in heating and cooling in the buildings and industry sector, together with their barriers and drivers.

8.2. National examples of integrated heating and cooling mapping and planning

The fuel mix and the structure of the national energy systems, the availability of renewable and waste heat resources, the characteristic of energy infrastructures, individual heating systems and building stocks, the development trends and structure of industry vary widely across the 28 EU Member States. These elements affect which demand reduction and decarbonisation solutions are feasible and economically viable, and which synergies across the heating and cooling, electricity, buildings and industrial sectors can be best exploited. Solutions will differ between Member States, depending also on the share and type of fossil fuels, the presence of nuclear energy and on the potentials for wind, solar, geothermal, hydro or bioenergy.

The portfolio of measures that can be used in demand reduction and decarbonisation pathways is vast. National pathways need to build on a thorough understanding of local conditions, as heat and cooling markets are local; demand is defined by the characteristics of local building stocks and by the structure of local industries. Furthermore, locally available renewable energy and low carbon heating or cooling sources are assets to be used for the supply of efficient decarbonised heat or cooling, as these produce added benefits for security of supply, local jobs and growth.

In contrast to electricity, which can be transported over long distances, heating and cooling must be generated close to where it is required. Therefore, decision making makes sense at the regional and local levels, within the national energy policies. It is also at these territorial levels where the opportunities for the use of low carbon and renewable energy sources arise. Maximising these opportunities requires dialogue with different stakeholders.

Regional and local authorities are well positioned to develop and bring policies together on energy, planning and other areas such as transport and waste. Also, they can act as the initiators and be the drivers of multi-stakeholder dialogues with all the relevant actors. For instance, planning authorities can grant planning permission subject to the fulfilment of concrete energy requirements which are in alignment with long term aspirations. They could also designate publicly owned land to key energy projects and infrastructures. As owners of large building stock, public administrations can use public purchases to provide initial markets for renewable and energy efficiency technologies or services, and can commit their public buildings to connect to a proposed heat network to provide the anchor loads that would reduce the risk for developers of new district heating and cooling networks. Public authorities often own or manage energy supply assets, like district heating and cooling or electricity supply and distribution companies, and have decision making rights how energy infrastructures are developed or regulated.

All the above makes sense if it is part of an integrated approach to energy planning at national, regional or local levels. On the one hand, high level political commitment is key to set clear overarching goals and ensure long term continuity and coherence. On the other hand, the political commitment is necessary to produce an evidence base and to use this as the starting point to set long term objectives and to inform the development of short and medium term plans with identified actions leading to concrete investments.

A few Member States have already developed – or are in the process of developing – heating and cooling strategies based on an integrated approach and modelling, taking an energy system perspective. In some Member States communities already have the practice to elaborate Energy Master Plans, often combined with heating and cooling maps (e.g. heat demand density maps) to help develop concrete heating and cooling strategies at regional and local levels. This practice is to develop and expand further, following the Energy Efficiency Directive (2012/27/EU), which requires (Article 14(1)) Member States to prepare comprehensive heating and cooling assessments and heat maps by the end of 2015, and update those regularly. Maps could include, for instance, heat (demand) density maps that could give an early indication on which areas in a territory might be suitable for the use of district energy networks so as to conclude that the use of individual solutions at building level might be more appropriate in other districts. In both situations, adequate planning is required as only in this manner the efficiencies and the use of renewables can be maximised. Examples of this could include, for instance, those situations in which a city planning authority grants approval for new development on the condition of connecting to an existing heating network. Also, some cities have developed guidelines and (GIS) systems to decide the depth and the situation of the wells that are required to supply ground source heat pumps.

The IEE Stratego project applied holistic energy system analysis to perform comprehensive assessments for heating and cooling for five Member States: the Czech Republic, Croatia, Italy, Romania, and the United Kingdom.

A number of Member States and their research institutions have already been considering long-term energy efficiency and decarbonisation pathways for heating and cooling with specific objectives. These strategies use an integrated approach addressing the transformation of the heating and cooling supply systems together with the decarbonisation and reduction of demand in buildings and industry, and the possible synergies between those sectors. These national strategies have already proven successful in driving a gradual but decisive change in the national energy systems. They are characterised by a thorough understanding of the structure of their current energy supply, the mapping of the national energy resources and infrastructure endowment, the characteristics and composition of the building stock, and the structure and development trends of the industrial sector. Based on that understanding they aim to set clear policy direction and realistic goals underpinned by a broad national consensus about those directions and goals.

Denmark, for instance, has set an objective of a 100% renewable energy system in 2050 with several energy policy milestones in the years 2020, 2030 and 2035. The strategy, embodied in the national Energy Agreement, aims at a more energy efficient society. It requires that half of the consumption of electricity is covered by wind power in 2020. By 2030 coal from Danish power plants and oil burners should be phased out. By 2035 the electricity and heat supply must be covered by renewable energy. In 2050, all energy supply – electricity, heat, industry and transport – is to be converted to renewable energy. Key elements of the Energy Agreement are wind power and new renewable technologies, the use of renewables in industry, buildings and transport, bioenergy in the energy supply, smart grids and a financing framework. The Agreement is based on a number national analyses covering the role of biomass, biogas, geothermal energy, large heat pumps, heat storage, cogeneration, district heating, the use of waste heat from industry, district cooling, electricity infrastructures, transport technologies, gas infrastructure, energy efficiency of buildings, industry and transport.

Denmark has had heat planning in place at local level since long, as part of efforts to move away from oil and coal in heating and cooling under long-standing energy strategies. Heat planning by municipalities has recently been complemented by national level assessment for heating and cooling and the relevant energy sectors.

In Sweden, municipalities set decarbonisation and energy efficiency strategies and implement those through dedicated energy managers and programs.

In Poland, municipalities are required to plan heat supply to enhance energy efficiency. This planning should include the description of the current state of heat, electricity and gaseous fuel supply systems, foreseen changes in population growth trends, description of industrial activities in the municipality, analysis of building stock (year of build, area, typical energy consumption), and the state and foreseen changes in district heating, electricity and natural gas supply systems. The analysis covers the state of renewable energy supply and consumption, and environmental pollution levels.

The UK heat strategy is also based on an assessment of the entire national energy system. It addresses efficient low carbon heat in industry, the role of heat networks, heating and cooling for buildings, grids and infrastructure. This comprehensive approach is based on the principle that a pathway to low carbon heat will, over time, mean significant change for the UK's industry and building stock, as well as to the energy infrastructure. The strategy posits that the transition to low carbon efficient heating and cooling system will have impacts on the existing gas and electricity networks; sees the emergence of new infrastructure like heat networks and heat storage, and potentially also new infrastructure to support the use of hydrogen and to take carbon dioxide away. It is underpinned by economic modelling on the future scenarios for heat supply, consistent with the UK's emissions reduction goals, suggesting a much more diversified range of heat technologies in the future – with roles for electric heating, and gas and hybrid heat pumps and heat networks (with a range of heat sources) for buildings, and fuel switching and innovation in new technologies for industrial heat, including Carbon Capture and Storage (CCS). The UK Heat Strategy recognises that decisions on the different elements of the UK's energy infrastructure cannot be taken in isolation and there will be a number of economic and technical trade-offs and constraints that will impact on the respective scale and pace of infrastructure development, both for 2050 and for solutions in the interim. The strategy stems from a number of analyses such as on homeowners' willingness to change their heating systems, barriers to deployment of district heating networks, CHP capacity projections, and scenario modelling, e.g. on pathways for domestic heat.

In the framework of its energy transition strategy, Germany has set the target to reach 80% share of renewable energies by 2050, with intermediate targets of 35% to 40% share by 2025 and 55 to 60 % by 2035. As regards energy efficiency, gross energy consumption is to be reduced by 50% by 2050 compared to 2008 levels. Heat demand in buildings should be reduced to 20% on 2050 compared to 2008, while overall greenhouse gas emissions should be cut by 80% by 2050, compared to 2005. Germany is currently analysing least cost options to the decarbonisation and energy efficiency of its buildings. The on-going elaboration of the strategy is building on existing policies that support the introduction of renewable energy, cogeneration and district heating in building refurbishment projects. As part of the national energy efficiency and renewable energy strategies, Germany has set a target of 25 % share of cogeneration in electricity production.

Heat planning has been a common practice at municipal level for over a decade in Lithuania to provide a framework for long term modernization and development directions of each municipality's heat sector and to transfer national energy goals into the lower, municipal level. The plans should harmonize interests of different stakeholders (consumers, district heating companies, suppliers of energy sources municipalities). The heat plans define how consumers should be supplied, what fuel types and energy sources can be used for heat generation in different parts of municipality (territorial zones). The heat plans include analysis of current demand of buildings, the evaluation of the heat sector (i.e. existing heat generation equipment, systems of local heating and district heating, etc.), of the infrastructure of natural gas and electricity supply, of air pollution levels. The plans are based on the forecast of heat demand and infrastructure development and how these would change, taking into account forecasted energy prices (biofuel, natural gas, electricity) and other technical and economic indicators. The plans contain strategic planning for the municipality by territorial zones and setting heat supply rules for each zone. Heat plans usually also contain development plans of municipality's heat sector; possible development and renovation of district heating networks; calculations of feasibility of the use of different renewable energy sources and different technologies, such as heat pumps.

Under the EU Covenant of Mayor Initiative, more than 5800 cities and municipalities prepare sustainable energy plans often in the frame of national strategies and aiming for ambitious energy efficiency and decarbonisation goals, so as to provide a blueprint and program of the changes needed and paths local communities have the follow to implement the energy transition. These plans often consider the heating and cooling system in an integrated way, looking at the evolution of the whole energy supply and demand in a municipality to define the least cost approaches.

As shown in the previous chapters, demand reduction and decarbonisation of heating and cooling at the scale and pace needed to achieve the 2050 goals will not happen under business-as-usual scenarios. There is therefore a need to conceive appropriate strategies and pathways to drive the transformation. The types of technologies that are implemented in the heating and cooling sector have a major impact on the performance of the national energy systems. For example, if electric heating is used to heat buildings, then it will increase the demand for electricity for the entire electric grid. If district heating is utilised, then it is more likely that the electricity demand will be reduced rather than increased. If buildings are refurbished to high energy performance and low energy buildings, their supply systems need to be adjusted. The size of their heat supply system can be reduced and new sources of renewable or low carbon energies and technologies become available, such as heat pumps, solar thermal, waste heat and low temperature district heating systems.

The fuel mix and the structure of the national energy systems, the availability of renewable and waste heat resources, the characteristic of energy infrastructures and building stocks, the development trends and structure of industry vary widely across the 28 EU Member States. These elements have all impact on which demand reduction and decarbonisation solutions are feasible and economically viable, and which synergies across the heating and cooling, the electricity, buildings and industrial sectors can be best exploited. Solutions will differ in countries, depending on the share and type of fossil fuels or nuclear energy, the potentials for wind, solar, geothermal, hydro or bioenergy. Solutions should be analysed and selected from the standpoint of which achieve the goals with the most energy, economy, and environment benefits at the lowest costs. Therefore pathways and their impact need to be analysed at national level, since the synergies across electricity, heating, cooling, and transport can be overlooked if the components of the energy systems, such as electricity or transport are looked in isolation or only local issues are taken into consideration.

The combination of technologies, infrastructure, supply sources and demand reduction solutions will differ from country to country. It will be not the same for Poland or UK, for Spain and Italy, Romania and Sweden or France. Poland supplies heat mostly from coal, has large legacy district heating systems, limited gas networks and moderate potentials for the main renewable sources, wind, solar, geothermal and biomass. The pathways of the UK is defined by the dominant role of natural gas and an extensively developed gas networks, settlement structures defined by high dense cities and excellent endowment in wind and ocean energy. France’s pathways is influenced by a large nuclear sector, well-developed electricity and gas networks and a rich endowment in renewable sources, in particular geothermal, solar and biomass, as well as the presence of large industrial clusters offering cheap waste heat sources. Industrial waste heat supply is a big asset in countries with well-developed energy intensive industries, such as the Netherlands, Romania, Sweden, Luxembourg and Germany. Romania in addition have the potentials to utilise its well-developed legacy district heating systems to distribute waste heat and use efficiently biomass, if these systems are modernised, losses in distribution reduced and efficiency of generation increased, e.g. through cogeneration. Geothermal energy is especially strong in Central Europe, such as Hungary, Slovakia, where legacy and new district heating systems offer good options of their use. The Nordic countries have important wind and hydro potentials, which they can combined well developed efficient district heating systems that can help maximise the share of intermittent wind power via exploiting large heat pumps, CHP and vast thermal storage capacities, etc.

Many national decarbonisation strategies see district heating as an integral part of the transition to a fully renewable or low carbon energy system. Denmark, Sweden and Finland have already been using district heat to move away from coal and oil since the 70s oil shock. Most recently, the UK identified district heat as key elements of decarbonisation of heat in her cities. The portfolios of measures that can be used in demand reduction and decarbonisation pathways are vast. It includes the increased use of cogeneration, the deployment of renewable heat and variable renewable electricity in buildings’ heating and cooling systems, decentralised energy and demand response, the roll-out of energy storage and novel technologies, the use of transport sector for additional demand and storage through battery technologies in electric cars, and smart energy networks. Energy savings through more efficient, refurbished or new buildings and increase industrial energy efficiency are part of most national strategies to reduce and decarbonise heating and cooling.

Regional and local authorities have the opportunity to be in the heart of this stakeholder involvement and to use the tools they have available to shape the energy aspects of their territories. Relevant stakeholders include fuel suppliers, owners of resources including local industry, technology providers, building owners and managers and other end users and consumers as well as already established community groups.

In some Member States communities already have the practice to elaborate some type of Energy Masterplan, often combined with heating and cooling maps (e.g. heat demand density maps) to help develop concrete heating and cooling strategies regional and local levels. This practice is to develop and expand further following the Energy Efficiency Directive that requires Members States to prepare comprehensive heating and cooling assessments and heat maps by the end of 2015, and updated those regularly. Maps could include for instance heat (demand) density maps that could give an early indication on which areas in a concrete territory might be suitable of the use of district energy networks and to conclude that the use of individual solutions at building level might be more appropriate in other districts. In both situations adequate planning is required as only in this manner the efficiencies and the use of renewable can be maximized. Examples of this could include for instance those situations in which a city planning authority grants condition for new development on the basis of connecting to an existing heating network. Also, some cities have developed concrete guidelines and (GIS) systems to decide the depth and the situation of the wells that are required to supply ground source heat pumps.

The IEE Stratego projects applied holistic energy system analysis to perform comprehensive five assessments for heating and cooling for five individual Member State: the Czech

Republic (CZ), Croatia (HR), Italy (IT), Romania (RO), and the United Kingdom (UK). This is in line with the requirements currently in place in Article 14 of the Energy Efficiency Directive, which specifies that "By 31 December 2015, Member States shall carry out and notify to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling". Article 14 also allows going beyond this scope. Accordingly, Stratego does not only focus on cogeneration and district heating, but instead it covers the entire heating and cooling sector. It considered the heating and cooling sectors as part of the entire energy system, rather than as isolated components. The comprehensive heat strategies for the five countries consider a combination of heat savings, heat networks in urban areas, and individual heating in rural areas It developed methodologies and tools to understand the cost of heat savings, the renewable resources available, the feasibility and costs of district heating systems, the potentials for energy generation and storage technologies. It compared the various individual heating solutions for each country and quantified the impact in terms of costs, energy savings and carbon emissions.

ANNEX I
Minutes of the Ad-hoc Consultation Forum on Heating and Cooling

MINUTES
EU Heating and Cooling Strategy Consultation Forum

Brussels, 9 September 2015 (10.00 – 18:00)

Participants: See "Attendance List" in Annexes

1. Welcome and Presentation

The Chair welcomed the participants and indicated that the Energy Union announced an EU Strategy on Heating and Cooling. The adoption of an EU Heating and Cooling Strategy is in the Commission Work Programme for 2015. The timing depends on other actions as this Commission has the approach of adopting measures as part of a package rather than as stand-alone measures.

It is planned that the strategy would take the form of a Communication supported by a Staff Working Document. The Communication will be a state of intent of the Commission on heating and cooling with recommendations. It will then be for the European Parliament and the Council to decide on how to follow it up.

The Chair gave some information on the structure of the Consultation Forum, explaining that the aim was not to go into specific comments on the Issue Papers prepared and distributed in view of the Consultation Forum itself. It was indicated that the contributions could cover any issues and are in particular welcome to address the correctness of the facts, to offer additional facts / elements and the questions in the five Issues Papers sent out to steer the discussions. If time allows, additional comments and cross feedbacks could be made. In order to make the maximum use of the time available, each Member State and association would be given the floor once.

2. DISCUSSION

EIIF indicated that the heating and cooling strategy should mirror the principles of the circular economy: reduce, reuse, recycle. The main barriers to achieve a more efficient heating and cooling sector are the split responsibilities between those benefiting from the measures and those doing the maintenance, and the lack of updated standards.

EHI welcomed the focus on the heating sector. They asked for a multi-technology approach, and added that the conditions that determine the optimal approaches are varied (population, climate, energy demand of buildings, etc.). A generalisation of the solutions can lead to a less positive outcome than a more flexible approach that leaves several options opened. Another reason to keep all options open is the lack of data. We do not know how the electricity grid will decarbonise and how the load will evolve, the amount of biogas or bio-fuel that will be available, the role of building insulation etc.

Consumer should be at the centre of the Strategy and they need to be informed and have the technologies that help moderate and control consumption. The Ecodesign and Energy Labelling are relevant tools for this. Existing infrastructure should be used, in order to reduce cost.

They added that Issues Papers III does not focus sufficiently on putting the consumer at the centre and giving them incentives, e.g. to replace old inefficient boilers.

It is also essential to engage installers with better training and by easing the regulatory burden. Innovation relies largely on industry, therefore it is better not to "pick winners", but instead to establish partnerships with industry.

E.V.V.E. made reference to Issue Paper I on the “Decarbonisation of heating and cooling use in buildings” which mentions behavioural aspects as one of three main drivers of energy consumption. This message should be accompanied by clear recommendations. E.V.V.E. therefore indicated that consumption-based billing of heat and hot water and sub-annual billing information need to be included, as this is key to consumer empowerment.

EUROGAS welcomed the focus on heating and cooling and stressed the need to keep options for decarbonisation open instead of adopting a "narrow" focus. The goal should be that of achieving greenhouse gas reduction and other targets are to contribute to this...

More consideration should be given in the Issue Papers to consumer choice, affordability and demand response. The efficiency of energy transport and of converting energy to heat needs also more attention. The differences among Member States should be considered.

They expressed the concern that a "one size fits all" solutions or a "silo" approach segregating fuels and technologies will not be followed by industry, whereas with an approach grounded on holistic energy polices all industrial sector will come forward.

ORGALIME stressed the importance of technology variety and that the choice of different technologies based on cost-effectiveness principles is given to consumers, who should be the focus of the strategy.

The Commission is to ensure implementation of the Energy Labelling and Eco-design legislation together with the Energy Performance in Buildings Directive (EPBD) as they can respond to most of the challenges. They praised the success of the UK condensing boiler replacement programme as an example of effective regulation. They supported the modernisation of Ecodesign and Energy Labelling.

Energy market design review is to look into aspects such as connected homes and demand side flexibility, cogeneration and the use of residual waste. Under the EPBD Member States should use national building regulation to increase the efficiency of buildings and to use it together with Ecodesign and Labelling, linking it to the top classes under Energy Labelling.

They joined EHI on the need of up-scaling training of installers and asked for increasing refurbishment of the existing stock of building to trigger the replacement of equipment while ensure that cost-optimal levels for hot water and heating are mandatory.

They stressed that more prominence and understanding is needed as regards the role of heat storage as an important source of flexibility, which is needed for demand response and smart grids. Demand response tariffs are vital in order to make the whole system work.

MARCOGAZ welcomed the work on heating and cooling and acknowledged the need for an increased use of renewable energy sources, including biogas and biomethane. At the same time, they stressed the importance of the role of natural gas during the transition period. They observed that replacing the existing boilers with more efficient gas appliances would already produce great reduction in energy use and CO_2 emissions. In the future, hybrid solutions will become important, e.g. heat pumps with gas boilers, as well as biogas systems and hydrogen.

From the consumers' view point, the cost of heating and cooling appliances and systems is a main barrier. End-users should be given more information, including on the efficiency/cost ratio. Installers' engagement is essential. The proposed database of products under the Energy Labelling framework is the right step forward. Gas infrastructure exists in many cities and can be used to move from gas to hydrogen and biogas.

EUROFUEL expressed support for the work done. Hybrid systems are essential for the future transition. Existing hybrid solutions combining fossil boilers as back-up with renewables can be deployed fast. They stressed the importance of consumers' choice and the need to ensure affordability. They indicated that the average age of the current boiler stock is 30 years; changing them for a new boiler would produce energy savings in the range of 30%-40%.

EUHA stressed the potential of electric heating in well insulated buildings, taking into consideration that electricity can be fully decarbonised. They mentioned that decarbonised electricity used for heating is the best option for the 2050 transition. Electric underfloor heating systems can be made smart, react to signals quickly and automatically and are easy to integrate into smart systems to provide flexibility.

C.E.F.A.C.D claimed that some issue papers had a very electrical approach and pointed to issues that this could create for electricity prices, grid capacity and energy poverty. Consumers lately reacted on that by switching to other existing CO_2-neutral energy forms like biomass and solar thermal heat. To improve this consumer-driven energy transition heat storage should be further analysed.

EFIEES welcomed the Heating and Cooling Strategy. Primary energy needs to be the focus. Cost-effective solutions and energy prices are key considerations for consumers and important to reflect in policies on consumers. Barriers for a more efficient heating system still exist, such rules on public debt, VAT and public procurement, as these favour energy efficiency equipment to energy services.

The chain of energy efficiency improvement actions should be looked at together to ensure synergies between building envelop improvement and behaviour addressing also operation and maintenance. Barriers could be overcome by promoting guaranteed savings through a regulatory framework on Energy Performance Contracting and White Certificates (Energy Efficiency Obligation Schemes).

CEDEC welcomed the open approach to district heating, which is key to promote decarbonisation, the integration of renewables and CHP in densely populated areas, and to harness local resources. They agreed with the focus on primary energy and stressed the prominent role of CHP. The State-aid guidelines need to be more open to local solutions.

The differences between rural and urban areas and solutions need to be recognised. Electrification creates risk of stressing the electricity grid, when electric heating is rolled out as already illustrated in France.

CEWEP welcomed the Issues Papers and highlighted the potential of waste-to-energy representing 200 TWh/year by 2050. District heating and cooperation at local levels are key to reaching this potential, which would have positive impacts on security of supply, decarbonisation and air quality.

EPEE asked for a holistic approach in terms of planning, sizing and installation of heating and cooling systems and a technology neutral approach. Existing legislation should be implemented and enforced. They asked to give also attention to cooling. The awareness of consumers is key to trigger investments in efficient solutions, which need to be attractive to the consumer.

GEODE asked to put a focus on decarbonisation and consumer. Lack of differentiation should be avoided because of differences e.g. in heat demand and infrastructures. The strategy should not focus on technologies but on heating sources. Recognition should be given to efficient gas systems as vital to the energy transition, to the seasonal storage in order to meet demand peaks, the renovation of the existing boiler fleet and biomethane, biogas and hydrogen systems.

EURELECTRIC stressed that the focus should be put on decarbonisation and that electricity has a role to play in that. The electricity sector agreed on a carbon neutral electricity system to be achieved by 2050. They mentioned that too much focus is put on on-site renewables in the issue papers and that demand response is not adequately reflected. They added that flexibility of the electric system can be increased with the use of heat pumps and electric vehicles. The positive impacts on air quality of a higher use of electricity for heating and cooling should also be mentioned.

FREE welcomed the Heating and Cooling Strategy and expressed support for cleaner solutions. The difference between rural areas and urban areas should be recognised and rural energy consumers should be considered in more inclusive policies. The lack of information for consumer is a key barrier and the training of installers is essential. They asked for a further consideration of micro-CHP in the issue papers. The specific characteristics of rural buildings should be considered, in particular that these are far less efficient than buildings in urban areas.

AEBIOM supported the focus on decarbonisation and asked for alignment with energy efficiency and renewable energy as no-regret options as recognised in the EU 2050 energy roadmap.

They called for improvement of data, data collection and the parameters on the modelling used for projections on heating and cooling. Barriers to biomass' increased use in buildings and industry are not technical, but political and economic, linked to the lack of awareness of consumers, lack of level playing field for renewable energy sources and the lack of internalisation of the environmental costs of fossil fuels in markets. Strong political signal and support of renewable energy sources is essential.

EURIMA stressed that the "Energy Efficiency First" principle should be the first objective of the Heating and Cooling Communication. Energy consumption should be reduced first to ensure that actions are properly sequenced. They welcomed the focus on cost-efficiency but considered the explanation of the modelling supporting the paper not sufficient, e.g. as regards the question of whether societal benefits, such as job creation, were included. Good implementation of the existing legislation is important.

RESCOOP.eu asked for a type of cost-benefit analysis of the chosen solutions that includes operation and maintenance costs, makes a comparison between individual and collective installations and uses long-term investment perspective to maximise energy savings. Such approach requires close cooperation with political institutions and is effective in finding solutions for financing (e.g. 100% mortgage loans) and empowering consumers in their investment decisions. They asked for local empowerment, including people through cooperatives, and that consideration should be given to the specific needs of rural areas.

ECEEE noted that the data supporting the Issues Papers and the way in which those are used could be better explained. The cost-optimal calculation methodology and Life Cycle Cost Analysis under the EPBD should be used in a robust way, including also employment, health and other effects, with adaptations and applying standards, in order to compare and decide on different solutions, building renovation, district heating, and individual heating. The lowest cost, cost-optimal solution needs to be found. Centralised district heating systems are big investment and have a monopoly type of supply unlike individual heating solutions.

The cost-optimality of solutions is essential for consumers and consumers need to be kept in mind when deciding on investment. Energy Efficiency must be first to define demand and ensure economic and cost-efficiency. Multiple technology approach is needed.

Finland welcomed that heating and cooling is addressed and integrated into the Energy Union and energy policies. Heating and cooling is not a separate issue from the targets on greenhouse gas reduction, energy efficiency and renewable energy.

The quality of data needs to be improved; this is a precondition to improve heating and cooling systems in Europe. Consumers must be in focus, which is the same as saying that heating and cooling markets are needed. It is for the consumers to decide which heating and cooling system to choose.

There are big differences among Member States and the beneficial solutions are also different. Integrated energy system approach looking at heat supply, demand side and the energy sources together is important to optimise the whole energy system. Heating and cooling is part of the energy policy, not separate from it. A framework is needed. The communication should provide a strategy and good description of the current situation and the success factors on how to reach the targets. District heating and cooling should contribute to the objectives but it is not easy to increase the heat demand for those systems.

IFIEC pointed out that industry has done a lot to increase energy efficiency and push the thermodynamic limits which are now close to be reached, as industry has made significant investments in energy efficiency in the past. This will continue when economically justified. There is a lot of waste heat to be valorised in e.g. tertiary buildings, but investment is needed in energy infrastructure. Mandatory heat recovery is not a way to go, but voluntary agreements would be acceptable. The temperature levels of heat demand are important, as for high temperatures it will be very difficult to move away from fossil fuels.

WWF stressed the importance of a long-term 2050 perspective. Focus should be on energy efficiency and renewable energy as no-regret options. Energy efficiency should be looked at first in buildings to have realistic energy demand projection and avoid lock-ins by favouring deep renovations. The second consideration is to provide heat efficiently by promoting renewable energy, heat pumps and CHP. The fuel mix should be looked at. The sequencing should be energy efficiency first, than the transition towards a renewable based heat system in a holistic approach to avoid over-dimensioning and sharper the focus on increasing deep renovation. The sustainability of biomass needs to be addressed. Waste-to-energy use should be in accordance with the waste hierarchy to avoid a wasteful society; the first option is not to generate waste.

The United Kingdom welcomed the EU Heating and Cooling Strategy. Energy efficiency should be first; then the residual demand should be addressed; both energy efficiency and decarbonisation are important. Heat, unlike electricity and gas, is a local issue that depends on local circumstances, such as climate, temperature, buildings, users, etc. A major heating infrastructure, the natural gas grid is already in place; the question is how to use it. Exploiting the potential for heat recovery is important for decarbonisation alongside with renewable energy; the Heating and Cooling strategy should provide forward recommendations on that. The focus should be on decarbonisation; renewable energy is one of the specific means of that. The use the existing gas grid in the future raises a lot of interesting questions. In industry, the challenge is the decarbonisation of high temperature process heat and addressing this requires sector specific solutions, as shown in the UK Industrial Roadmaps. In some industrial sectors, e.g. steel, cement and chemicals, fossil fuels are going to be needed also in the future; therefore the potential of industrial carbon capture and storage and its costs should be analysed. The UK asked if the comments of the Consultation Forum's participants would be shared and whether Member States would be further consulted in a working group.

CEPI expressed satisfaction with the Issues Papers, in particular on industry. They observed that industry reached the limits of what it can do. However, by pushing research and development towards breakthrough technologies and by filling the gap to commercial level deployment of existing innovations higher energy efficiency can be achieved. Industry can offer a lot of flexibility and this should be more recognised. They stressed the role of CHP and the alignment of energy efficiency and system efficiency. They asked for more details on the modelling used and on the impact of biomass imports.

AREA said that the role of contractors is essential, as they link manufacturers and users; they added that the correct dimensioning and maintenance of systems is vital to acquire and maintain efficiencies and that technology neutrality needs to be ensured. Any additional training or competence framework should be complementary to existing ones (e.g. F-gas Regulation 517/2014).

Aalborg University pointed out the urgency of addressing the heating sector in climate and energy policies. They said that different options need to be combined and that for the moment we don't have enough knowledge to identify the best options to be pursued. They said that new heating infrastructure has to go hand in hand with the refurbishment of buildings. They added that different technologies and energy sources will have to play a role. They asked for stronger policies to promote faster refurbishment rates and stronger support mechanisms for local initiatives to share heat supply and consumption. Knowledge is needed at country level and at local level.

EPC said that more information on economic facts is needed. They said that the reinvestment times for buildings is longer than for appliances and that a focus should be put on renewing the old European heating infrastructure. They said that consumers have little awareness about how much money and energy can be saved by adopting technologies which are already cost-competitive. They added that communication is very important and that a consistent level on energy taxation needs to be put in place. For the low and medium temperature ranges of process heat in industry, no technical barriers exist in order to integrate renewables. They pointed out that less than 5% of the biomass used in Europe is imported.

Eu.bac said that people behaviour in buildings is the key issue to achieve efficiency. Consumers should be given the control over their energy use. Energy in buildings should only be used where necessary and when necessary, continuous monitoring of energy use through automation and smart systems is the most rational way to achieve energy saving opportunities in buildings. Energy performance contracts are also an important enabler of energy efficiency in buildings.

EIGA observed that hydrogen is an important vector, its production can be fully decarbonised and it can be also used in CHP plants. They also mentioned that the valorisation of waste heat in industry has several advantages and can be performed on a win-win basis, by avoiding CO_2 emissions, securing energy independence, strengthening industrial producers with additional revenues and allowing savings to heat users. A main obstacle is the long return on investments needed (heat networks, storages and back up plants).

ECTP-EEB / PPP EEB supported the development of a heating and cooling communication. They mentioned that different efficiency and decarbonisation possibilities exist and there is no unique solution. They said that stakeholders should be provided with a set of solutions that can be combined and optimised.

AEGPL asked for the communication to be technology neutral and said that cost-efficiency needs to be a key element of it. LPG data needs to be included and more information in order to better understand the modelling done is needed.

COGEN welcomed the communication and said that consistency checks are to be done. They claimed that the whole energy system needs to be looked at and more linkages across the various issues need to be made. The potential for energy efficiency in a global economy and the "Efficiency first principle" would require prominence in the strategy. The heat demand side needs, management and seasonal variability are to be given more visibility.

They observed that the role of cogeneration technology in the transition to a low-carbon energy system should be better highlighted, as well their contribution to the 2030 milestones, about which more importance should be given.

They noted that Eurostat data reflect the current greening of the CHP fleet. In terms of metrics, primary energy consumption should be used to allow for a full account of the benefits of an integrated approach. They added that the state-aid guidelines should be updated as they are not fit for purpose when it comes to low-carbon heat investments.

CEI-Bois/EPF said that the prominent origin of biomass in many cases is wood and this fact should be acknowledged. If too much biomass is used, the extra demand of wood will be difficult to meet, increasing the gap between demand (also for industrial uses) and supply. In addition, the specific energy content of wood should be considered.

International Union of Tenants mentioned that the papers should focus on how the deployment of renewables and energy efficiency could be made attractive and affordable for consumers, especially in the rental market. They said that a bigger role of public authorities is needed to solve the "split incentive" dilemma. A best practice in this field is the Dutch covenant on energy savings, which provides tenants with a "total housing costs" guarantee (the reduced utility costs together with the revised rent are lower than the sum of utility costs and rent before the energy improvements).

EASE commended the technological neutrality and would like to see this retained. They said that energy storage has been underestimated, especially heat storage, of which a description is lacking. Smart electric thermal storage is not mentioned. Storage could help to balance energy supply and demand. They claimed that smart heating is not really developed and asked for including a reference to the use of locally generated electricity (especially PV). Energy Storage should be seen as a decarbonisation tool, additionally it is helpful for peak shaving. In combination with storage, electricity heating can go long way to achieve the decarbonisation goals. Furthermore, it is necessary to retain coherence between the different EU directives relevant to the energy system: e.g. the ecodesign directive could eliminate heating technologies including storage that are very much needed for the goals described in the Issues Papers.

CEFIC also stressed the need to adopt a technologically neutral approach and said that different industrial sectors have different needs, and therefore a sector-specific approach is needed. They said that the lock-in effects should be avoided and highlighted the need to give more prominence for passive solutions for both heating and cooling in buildings. They also mentioned the importance of reducing demand and recognising multiple benefits. They claimed that for industry energy is a major cost and important improvements have already been done only with economic drivers. However, it should not be forgotten that even solutions with short pay-back are anyway in competition with other investments. They said that a further use of biomass in industry will face logistical problems. They added that in some cases the flexibility of CHP plants enters in contradiction with their efficiency.

EuroACE welcomed the recognition, in the Energy Union Strategy that 70% of existing buildings are inefficient; these offer the biggest potential for reducing energy needs for heating and cooling. They said that the driver of the transformations in heating and cooling in buildings should be the energy efficiency first principle and the NZEB concept. They asked for ambitious long term renovation strategies of existing buildings, the implementation of which will enable to maximise energy saving investments and respect the economic lifecycle of buildings. They noticed that there is no technology gap as plenty of solutions are available and cost-competitive. They added that the level of ambition in terms of reduction of energy demand should not be capped, as this would mean locking-in savings and CO_2 reduction, but also less jobs, growth and health benefits.

EHPA said that a fundamental transition of the energy system is needed to reach the objectives mentioned also by Juncker in the State of the Union address, and added that in order to do that, maybe the simplest solution is not the best one to be used. Europe should instead aim at leap-frogging to the best technologies available that could bring the highest energy efficiency gains. They asked for a Strategy that set the framework to move to the most efficient solutions which in some cases are shown by the Energy Labelling for products. Mentioning the best technologies could be useful and there is no need of a technology-neutral approach. They claimed that a focus on consumers is difficult to implement when the markets are distorted by subsidies to fossil fuels that impede to look at the real costs of each solutions and their externalities. However, consumers need to be provided with the means to make informed choices.

EGEC asked for a high level of ambition and for exploring the synergies between energy efficiency and renewable energies; they added that the EU Heating and Cooling Strategy is to be based on the EU Energy Roadmap 2050 and its 3 no-regrets options (i.e. more renewable energy, more energy efficiency, smarter infrastructure)" and that the modelling and data collection in the heat sector should be improved. Decarbonisation should not be the only objective. The other aspects of the Energy Union need to be addressed. Fair competition is in any case needed. Local authorities have to be taken on board.

CELSIUS noted that the use of primary energy and CO_2 emissions will help creating a level playing field. They added that the energy supply should be decarbonised and the energy system should be integrated. The decarbonisation of cities would have an important effect on energy efficiency. Energy master planning at city level will be essential. They also asked for the creation of support mechanisms that understand the risk profile of district heating.

ECF said that not only the average use of energy is important, peak demands ad seasonal trends also have an impact and add risks and stress to the overall energy system, and this is the reason why storage is very important and there is the need to better understand it. They said that the changes needed are not only incremental. They added that the sequencing of decision is important (EU, national, local) and that at local level decisions cannot be technology neutral.

Business Europe said that the role of industry as a driver on energy efficiency should be acknowledged and added that keeping technology neutrality is crucial.

Climate Alliance mentioned that the local level is very important and that consumers and local authorities must be engaged in all aspects of heating and cooling.

ESTIF stated that heating and cooling should also serve to generate jobs and security of supply. Consumers are important but attention should be also given to European citizens in the sense that other aspects of the advantages energy efficiency could bring need to be exploited: security of supply, creation of jobs, etc. They added that energy imports should be replaced by renewables and that the policies should make sure that regional and local authorities are engaged. In addition, cost optimality should be kept in mind. They added that low temperature heat can be generated with energy sources that are not electricity and gas. To operate a real change in energy policy there is the need to engage citizens / consumers / investors. They pointed out the importance of the training and qualification of installers, which are a key actor to make changes. Finally, they mentioned that heat storage technologies are mature.

CEEP said that the local level has a key role to play and mentioned the importance of the access code to the network. Barriers to public service providers should be covered in the Strategy.

BPIE said that the calculation methodology of the energy efficiency of buildings is not fully harmonised. They added that lock-in effects are to be avoided and that the key role of the interaction between buildings and the energy market should be included. The strategy should stimulate higher renovation rates, tackle energy poverty, demand flexibility and acknowledge the multiple benefits of efficiency in buildings.

Slovakia said that the renovation of buildings has an impact on the heating industry and that the heating demand needs to be stabilised and should decrease by 2030. It should not be forgotten that there is already quite a developed heating and cooling infrastructure in many Member States and that downsizing can be a problem. They added that heating and cooling is an enormously important sector and that, therefore, the Heating and Cooling Strategy should be linked to the rest of energy policies, including the security of supply and financing.

Iceland pointed out the importance of the geothermal energy source for them and offered cooperation and expert advice to fully develop the geothermal resources in Europe. They mentioned that the initial capital cost might be high but the investment is quickly paid back. They said that specialised financing mechanisms need to be put in place. Geothermal large district heating already exist in Paris, investments are on-going in Germany where 40 district heating already exist.

CEN TC371 mentioned that a set of standards is being developed under mandate M480 in order to calculate the performance of a building, taking into account also the building systems.

GAS NATURALLY said that the maximum benefit should be made from the legislation already in place. They also mentioned that heat is a local resource, and as a consequence the national and local levels need to be recognized. Both the objectives for 2030 and for 2050 should be taken into consideration; in addition, the final objective should be clear, being this objective to reduce CO_2 emissions. As regards the timing, there should be a clear vision for both the medium and the long term. This needs to be addressed in the Strategy as such a forward long-term pathway is key to drive investments. They mentioned that specific pathways for Member States with a framework of options should be developed in the Strategy. They added that the transition to be made should take into consideration the infrastructure already in place and have a holistic view encompassing heat production, transport, use and storage.

Sweden expressed confidence that the Commission is analysing the right questions and underlined the need to have an integrated approach, to consider decarbonisation and to apply the energy systems perspective. They also asked for an analysis of the different policy instruments that can be used. They added that more elaboration on heat used for industrial processes would be welcome.

EUROHEAT AND POWER said that the current energy model is very narrow and it is positive to see that the Commission is widening the scope. Different technologies will be needed and consideration should be given to heat pumps, solar, etc. In addition, the milestones of 2030 and 2050 should be taken into account. They also said that policies should not be paralysed due to lack of data.

After the general intervention the **Commission services** proposed Member States and stakeholders to provide additional comments on the issue papers that have been shared with them prior to the meeting.

2.1. Issue paper 1. Decarbonisation of heating and cooling use in buildings

EHPA said that in order to reply the question of what would be the cost optimal solution it would be necessary to integrate all the cost of using fossil fuels in such cost optimal calculations.

Sweden mentioned that making specific regulations addressing specific problems is an option while another option is letting the market decide what would be the best solution in the context of an overall strategy.

Finland mentioned that some of the issues mentioned in the issue paper are already covered by other political agendas.

Alborg University said that having a single building focus is a concern and that in urban and dense areas there's the need to share heat and grids and said that electricity storage buildings will be too expensive and it would be wiser to use heat storage.

ECEEE asked for a cost-optimality tool adaptable to different levels to take decisions and added that standards should be available in order to make the necessary calculations.

United Kingdom said that a zero carbon scenario won’t be possible for heating and cooling in industry. They said that the choice of specific technologies should follow cost-optimality principles.

Germany asked for a common vision to reach 2050 objectives, and pointed out that heat markets are fragmented. They said that the use of district heating depends on local circumstances and mentioned that cost optimality is not defined in the current papers.

Eu.bac asked for making sure that the principles adopted will ensure optimality, because technology neutrality won't do that.

GEODE pointed out that, in their opinion, the most important trade-offs are those between CO_2 prices, energy prices and consumer choice. **CEDEC** asked for targets in order to develop a long term strategy and asked for providing information about different alternatives. They asked for stability in order to promote investment and innovation.

C.E.F.A.C.D said that the cost optimality of investments in grids should be calculated having in mind a long term perspective and having in mind a decreasing heat demand due to refurbishment. Let consumers decide on the technologies, but ensure the technology's final energy efficiency.

CELSIUS said that markets need to be defined taking into account the right parameters.

ESWET said that even if the circular economy will be a reality, and recycling is increased, waste will always be generated.

2.2. Issue paper 2. Heating and cooling use in industry and the tertiary sector

Finland said that different pieces of legislation should be aligned and mentioned that the Medium Combustion Plants (MCP) proposals could put obstacles in shifting from natural gas to biomass.

COGEN said that the main barriers in the power market are the legislative uncertainties.

EFIEES mentioned as barriers the public procurement rules, EUROSTAT rules, VAT rules (that sometimes benefit investments in equipment but not in its servicing), heat pricing and the discrimination done by ETS between different sectors.

2.3. Issue paper 3. Technological innovation and uptake of technologies

No comments were raised on this issue paper.

2.4. Issue paper 4. Linking heating and cooling with electricity

COGEN said that CHP and its reliability should be taken into account.

2.5. Issue paper 5. Integrated planning and mapping for heating & cooling

Aalborg University said that on key issue is the type of modelling and analysis that needs to be conducted.

3. Conclusions

The **Commission services** summarized the main conclusions of the meeting as follows:

- There is a general support for having a heating and cooling strategy.
- How existing barriers can be addressed is a major concern.
- Consumers and markets must be considered a key element.
- Taking energy efficiency first and ensuring energy savings in buildings are highlighted

- Technological neutrality should be ensured.
- Member State, regional and local levels should be analysed.
- The heating and cooling strategy is to be an integral part of energy and climate policy. The final objective is a demand reduction and decarbonisation by 2050.

Attendance List

Commission Services
Belgium
Cyprus
Czech Republic
Estonia
Germany
Denmark
Finland
France
Hungary
Italy
Latvia
Lithuania
Malta
Poland
Portugal
Sweden
Slovenia
Slovakia
The United Kingdom
Iceland
Aalborg University
Fraunhofer Institute
ICF International
AEGPL
AREA
AURUBIS
BEUC
BPIE
BUSINESS EUROPE
CEFACD
CEDEC
CEEP

CEFIC
CEI-Bois
CELSIUS
CEN/CENELEC SFEM
CENTC371
CEEP
CEWEP
CLIMATE ACTION NETWORK
CLIMATE ALLIANCE
COALITION FOR ENERGY SAVINGS
COGEN
CEPI
EVVE
EASE
ECTP-EEB / PPP EEB
EFIEES
EGEC
EHI
EIGA
EIIF
EPEE
ESWET
EU.BAC
EUGINE
EUHA
EUREC
EURELECTRIC
EURIMA
EuroACE
EUROCITIES
EUROFUEL
EUROGAS

EUROHEAT & POWER
EBA
AEBIOM
ECF
ECI
ECEEE
EHPA
EPC
ESTIF
EUROVENT
EVIA
FOOD AND WATER EUROPE
FREE
GASNATURALLY
GEODE
IFIEC
IOGP
IRENA
INTERNATIONAL UNION OF TENANTS
MARCOGAZ
NEW-IG
ORGALIME
PU EUROPE
REHVA
REScoop.eu
SHECCO
SPIRE
UIPI
WWF

ANNEX II
Summaries of national practices in performing energy planning, energy

Germany

In the framework of its energy transition strategy Germany has set the target to reach 80% share of renewable energies by 2050, with intermediate targets of 35% to 40% share by 2025 and 55 to 60 % by 2035. As regards energy efficiency, gross energy consumption is to be reduced by 50% by 2050 compared to 2008 levels. Heat demand in buildings should be reduced to 20% on 2050 compared to 2008, while overall greenhouse gas emissions should be cut by 80% by 2050, compared to 2005. Germany is currently analysing least cost options to the decarbonisation and energy efficiency of its buildings. The on-going elaboration of the strategy is building on existing policies that support the introduction of renewable energy, cogeneration and district heating in building refurbishment projects. As part of the national energy efficiency and renewable energy strategies, Germany has set a target of 25 % share of cogeneration in electricity production.

Germany prepared a comprehensive assessment to support the decisions taken by the German authorities in regards to heat planning and cogeneration plants. The study is split in 4 sections. A Cost-benefit analysis is conducted first. Its purpose is to compare and to determine the most cost-effective options. The net present value is estimated on both economic and financial terms. There was a split between household, commercial and industrial sector. The cost-benefit analysis is carried out without reference to quantities — unlike the subsequent potential analysis, and only compares the cost of different technological options. In the residential sector CHP was an uneconomical option due to the very high investment costs. Thermal insulation options despite the high capital costs had a better result but gas boilers were clearly the most economic option. For the commercial sector a CHP plant was only superior in economic terms in the hospital subsector. From a financial point of view, in the same sector, the CHP is as attractive as a gas boiler investment. The subsector with the lower NPV was the office buildings. In any case, the heat demand was a very crucial parameter: the larger it is, the more likely it is that the cost benefit analysis favours the cogeneration option instead of a gas boiler.

The results of the cost-benefit analysis are used in the second part of the study which refers to the cogeneration potential, by estimating the amount of investments that can be realized for the whole Germany. For the household and tertiary sectors, the CHP potential was determined based on the detailed analysis of 41 representative model towns. The forecast of the heat demand takes into account both renovations and new constructions. The potential of cogeneration is based on a full cost comparison with a gas boiler for 8 typical applications. The projection of heat production potential by centralized district heating and cogeneration is 128 TWh/a in financial terms and 207 TWh/a in economic terms with the assumption that the connection rate of the consumers to a nearby network is 90%. The heat demand that is going to be covered by district heating is not considered in the potential of individual CHP. This potential is estimated to 21 TWh/a in financial terms and 3 TWh/a in economic terms.

The potential analysis for installing cogeneration in industry is estimated by means of an analysis of the heat demand of individual industries considering CHP temperature range up to 300 ° C and its technical developments in their production. The break down of industrial heat demand per temperature was adopted by an external study[48]. A scenario with the following characteristics was considered:

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[48] Prognos, BHKW Consult, Fraunhofer IFAM, IREES (2014), Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014. Zwischenbericht für den BMWi. Berlin, Raststadt, Bremen, Karlsruhe IREES 2014.

- CHP applications stagnates in the three sectors of industry, (chemicals, quarrying/mining and paper)
- A significantly increase in CHP applications for other manufacturing sectors (Food, capital goods, consumer goods and commodities industries).

The heat generating potential of the first industrial sectors in the baseline scenario will have an 11% (0.6% per year) increase by 2030 (without promoting cogeneration) and decreases in 2050 by about 8%. In contrast, the sectors with increasing CHP generating potential as a whole considers an increase of 5.7% per year by 2030 and after that 3.6% per year by 2050. Overall, through this course in 2050, the heat potential that could be generated by CHP plants, is 20% more than the base case.

For the estimation of waste heat available, no analysis was conducted in this study but assumptions from different sources were adapted[49] (AGEB 2008, FH-ISI, ENOVA Spillvarme 2009). According to those it was assumed that a fixed percentage of waste heat above 140 °C is available compared to their total energy use. Heat of this quality is also considered to be suitable for electricity generation with ORC technologies. Metal manufacturing and processing were assumed to have a big amount of waste heat available (~ 30 – 40%) while other sectors much lower (~3 –8%). According to the above, 87 TWh of waste heat were identified. It is claimed, that there was no available data to assess the economic potential of using this waste heat either for electricity generation (using ORC) or direct utilization of heat was higher.

The 3rd part focuses on the potential for CHP electricity generation, according to the results of potential from the CHP on heat demand. Currently 15% of the heat market is covered by CHP plants. For this study emphasis is given in flexibility: the technical concepts that allow it, or have already been implemented and in which applications the flexibility of CHP is already being used today. The extent to which cogeneration potential can be integrated in the future electricity system along with the role that CHP may take in future power system is also analysed, taking into consideration the security of supply. The long-term positive effects on the CO_2 emissions from the CHP operation are also evaluated.

The CHP especially in areas with high energy density is a favorable option to provide the heat supply and resource-efficient low-CO2 electricity. In the long term, however, the renewable energy share should be increased in the district heat supply in order to exploit the heat-side potential. Power-to-heat concepts can also favour the integration of intermittent high RES shares in the electricity market.

In the final section a mid-term evaluation is conducted for the development of cogeneration and the effects of the Combined Heat and Power Act (KWKG). Based on that, short-term prospects which are crucial for the further development of cogeneration until 2020 are presented.

The proportion of electricity produced in CHP plants in the total electricity production in Germany is also presented along with the development of CHP, networks and storage investment funded. An important aspect of the evaluation is also the development of the CHP plant operation economy. This is differentiated by asset class and type of use and taking into account the revenue from electricity and heat production and possible subsidies to CHP. Based on this analysis, the development of the share and cost of CHP is estimated by 2020.

Finally, recommendations are given for further development of CHP for specific applications as well as other measures that are not directly related with CHP.

Denmark

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[49] AGEB (2012), Energiebilanz der Bundesrepublik Deutschland 2012, Arbeitsgemeinschaft Energiebilanzen. http://www.ag-energiebilanzen.de/DE/daten-und-fakten/bilanzen-1990-2012/bilanzen-1990-2012.html

Denmark has prepared a Comprehensive Assessment on the potential to expand high-efficiency cogeneration and efficient district heating and cooling. The assessment is based on three separate technical studies on district heating, district cooling and scenario analyses.

The scenario analyses were made to illustrate the future Danish energy system within the framework of the Energy Agreement from 2012. These scenarios are designed to meet the energy policy objectives of Denmark to have a fossil free energy system in 2035. The expected role of district heating and combined heat and power is evaluated. The technical possibilities and bottle necks were identified.

The Balmorel model was used together with a heat atlas for analysing the district heating supply. The Balmorel model uses a combined top-down/bottom-up process of the energy system. The model optimises the operation of electricity and district heating systems. It includes both investment and operation costs and socio-economic aspects. The analysis also contains the electric inter-connections with neighbouring countries.

The models calculated the district heating and electricity prices and these were then used to calculate the heat supply rates in all urban areas for district heating and individual heating. The technical potential was assigned to those areas that did not contain district heating today and with sufficient heat demand. The economic district heating potentials were established by comparing the cost of district heating to the costs of individual heating in various optimization processes.

Due to lesser experience with evaluating cooling demand and due to that available data were limited, indirect methods for establishing the cooling demand were developed. The method was primarily based on available data on electricity consumption for cooling from a study of 2008, which were supplemented with information from specific projects. This allowed making an inventory of 82 different industries that were split into comfort-, process- and IT-cooling.

The evaluation of the economic potential for technologies of the Comprehensive assessment started from the technical potential. The unprofitable potential from a society point of view was subtracted from the technical potential. All projects with a capacity lower than 1 MW were disregarded since they were seen as too small for a district cooling project. For cooling the economic gain was compared to individual cooling, which allowed calculating a maximum length of transmission district cooling pipes for a certain project. If the calculated length were longer than the distance between the heat consumers and producers, it was classified as a potential district cooling project.

Mapping of heating and cooling

- The heat atlas contains information about heat demands and the number of heat installations per types and village areas. The atlas contains seven types of heat installations and 4000 villages.
- Heat demand maps have a resolution of 1 km^2. The heat supply points were based on data from the energy production count of the Danish Energy Agency in 2013. Each point was attached to a specific address.
- The district heating network was based on data from the Danish Energy Agency GIS database 2014. It includes both transmission and distribution networks.
- A nation-wide map of local cooling demand that is suitable for district cooling were made based on knowledge of each industry’s expected consumption of electricity for cooling.

Sweden

Sweden prepared the Comprehensive assessment (CA) on the potential use of high-efficiency cogeneration and district heating and cooling. The analysis is partially based on earlier technical and economic studies on district heating and combined heat and power[50,51,52,53,54].

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[50] Öhrlings PricewaterhouseCoopers, 2005, Fjärrvärme och kraftvärme i framtiden (SOU 2005:33).

In the Comprehensive assessment, the potential for new CHP, district heating and cooling were estimated using a Cost-Benefit Analysis (CBA). Net Present value calculations were performed that included socio-economic and environmental costs. The tool used for the CBA was MARKAL-NORDIC. It is a cost optimisation model that finds the most cost efficient composition of technologies to reach energy policy targets. Such studies use input data with regard to projected investment cots, assumptions on energy prices, and the expected evolution of the heat demand. MARKAL-NORDIC comprises the energy system of Sweden, Norway, Finland and Denmark. The heating and cooling demand are divided into more than 80 sectors. The geographical locations of demand and supply were not included in the analysis.

The potential for district heating was based on a report by Fjärrsyn from 2011. The data were collected from national studies and statistics. In addition, these estimations have been enriched by performing interviews and collecting information from district heating companies and by making estimations of energy efficiency effects (e.g. improved insulation of buildings) and increased use of heat pumps. The report concluded that although the number of new connections to the district heating network will increase the total heat supplied by district heating will be reduced.

The potential for district cooling[55],[56] was based on assumptions for three categories of cooling equipment, i.e. compressor cooling machines using electricity, absorption cooling machines using district heating, and free cooling using nearly no primary energy. The expected future shares between these categories were grounded on assumptions related to the present composition of technologies in large district cooling systems in Sweden.

The potential for high-efficiency cogeneration for district heating was estimated based on information from calculations using MARKAL and Martes [57]. The Martes analysis is founded on calculations for 15 real district heating systems. These results were then extrapolated to the national dimension. The potential for industrial cogeneration was evaluated using MARKAL calculations and questionnaires.

The assessment for industrial co-generation was based on five different studies[58,59,]. One study was based on a questionnaire in which the forest industry was asked to describe their production capacities, fuel mixes, and investments plans until 2020. [60] The focus was on the forest industry due to that it supplies 93% of the industrial cogeneration in Sweden today. Three studies were based on MARKAL calculations that were used to project the economic potential for industrial co-generation.[61,62] The conclusion from the five studies was that the potential of industrial co-generation was estimated to be 8.6 TWh in 2020 and 8.8 TWh in 2030.

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[51] Svensk Fjärrvärme, 2009, Fjärrvärmen 2015, branchprognos.

[52] Svensk Fjärrvärme, Svensk Energi, Skogsindustrierna, Svbio, 2011, Sveriges utbyggnad av kraftvärme till 2020.

[53] Profu, 2011, Fjärrvärmen i framtiden.

[54] Fjärrsyn, 2009, Fjärrvärmen i Framtiden – behovet, 2009:21.

[55] Svensk Fjärrvärme, 2009, Fjärrvärmen 2015, branchprognos.

[56] Fjärrsyn, 2013, "Potentialen för kraftvärme, fjärrvärme och fjärrkyla rapport 2013:15", http://www.svenskfjarrvarme.se/Global/FJ%C3%84RRSYN/Rapporter%20och%20resultatblad/Rapporter%20omv%C3%A4rld/2013/2013_15%20Potentialen%20f%C3%B6r%20kraftv%C3%A4rme/Potentialen%20f%C3%B6r%20kraftv%C3%A4rme.pdf

[57] Öhrlings PricewaterhouseCoopers, 2005, Fjärrvärme och kraftvärme i framtiden (SOU 2005:33).

[58] Ibidem.

[59] Profu, 2012, Underlag till Energimyndighetens Långsiktsprognos.

[60] Svensk Fjärrvärme, Svensk Energi, Skogsindustrierna, Svbio, 2011, Sveriges utbyggnad av kraftvärme till 2020.

[61] Profu, 2010, Data/information on national potential for the application of high-efficiency cogeneration following Article 6 and Annex IV of the cogeneration Directive 2004/8/EC, 15-15-15 scenario

[62] Profu, 2010, Analys av biobränsleanvändning inom fjärrvärmesektorn och industriellt mottryck, kopplat till MARKALberäkningar, uppdrag för Energimyndigheten

Five national maps[63] were created to meet the requirements of the EED:

- Maps displaying plot ratio based on data from the real property register of Lantmäteriet were created. The geographical resolution of these maps was 1 km^2. The heat demand density is displayed in four classes, i.e.<0.03 (<15 TJ/km^2), 0.03-0.1 (15-50 TJ/km^2), 0.1-0.3 (50-150 TJ/km^2), and >0.3 (>150 TJ/km^2).
- Industry data were collected from the European Pollutant Release and Transfer Register (E-PRTR v4.2). The industries were displayed in 9 separate sectors.
- Power and heat centrals were displayed in a map based on data from the property register of Lantmäteriet. They were divided into condensing power plants, combined heat and power plants, and heating stations.
- A map on all Bio-CHP and Waste incineration CHP plants with data of companies from their register of Swedbio. The register also contains planned constructions.
- Electricity grid data from the Swedish national grid operator for power lines of 400 and 220 kV including switchgears and substations were mapped. The map also includes AC and DC transmission connections to neighbouring countries. Planned constructions are also included.

Lithuania

Heat planning in Lithuania is a common practice at municipal level for over a decade, although no comprehensive national heat planning has been in place up until now. The heat planning process is regulated by dedicated laws and regulations, among which the most important are The Law on Heat Sector (IX-1565 on 20-05-2003) and The Rules for Preparation of Heat Sector Special Plans (4-13/D1-28 on 16-01-2004). The most important objectives of these laws are the increase of energy efficiency, legitimisation of competitiveness in heat sector, assurance of reliable energy supply, protection of consumer rights, increase in utilisation of renewable and local energy sources and decreased environmental pollution.

According to the requirements of the law, all the municipalities should have heat plans prepared for their territories. Already existing plans should be renewed after changes in the municipality's heat sector or national energy policy occur, but at least every 5 years. There are 60 municipalities in Lithuania, among them 7 are so-called city municipalities, containing the largest cities of Lithuania.

Special plans are meant to contain long term modernization and development directions of each municipality's heat sector. Thus they should emphasise the transfer of national energy targets into the lower, municipal level. Special plans should harmonize interests of different stakeholders supplying the consumers with heat and energy sources. The most important stakeholders are heat consumers, municipalities (as representatives of heat consumers or controllers of district heating infrastructure), district heating companies, and suppliers of energy sources (mostly natural gas and biomass).

The process of heat planning is started, organized, supervised and finalised by the municipality. For preparing the plan an external contractor is selected after a public procurement process. The preparation of a heat plan can be financed by municipality, as well as by local and foreign support funds and programmes and by using other financing sources.

The heat plan consists of the following parts:

a) Solutions of the plan, containing explanatory notes and map of municipality or its part, containing a set of rules for heat supply. One of the most important outcomes of heat plan are the rules how consumers should be supplied with heat and what fuel type and energy source can be used for heat generation in different parts of municipality (territorial zones). These rules are presented in the form of maps. Maps are to be prepared on the basis of georeferenced

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data base, however, in case proper data is lacking, as a base the newest topographical maps with the scale 1:10000 or 1:5000 can be used. There is no requirement for a map to be interactive and municipalities usually make it available to the public on their web sites only as scanned copies of the maps. Electronic copies of explanatory notes are usually also available through municipality's web sites.

b) Documents on planning procedures. These contain different rulings of municipality on heat plan being prepared as well as documents related with public consultations, report on evaluation of heat plan outcomes from environmental and economic points of view and so on.

The preparation of a heat plan is performed in steps:

- Calculation and analysis of current demand of heat for the heating of the buildings and preparation of sanitary hot water. The emphasis in the heat plan is mostly on consumers in high density urban areas where district heating usually already exists. Heat consumption in rural areas or low density urban areas is usually not evaluated at all. Energy demand for space cooling is usually also not evaluated.
- Evaluation of heat sector of municipality (i.e. existing heat generation equipment, systems of local heating and district heating, etc.) and infrastructure of natural gas and electricity supply.
- Evaluation of current air pollution level.
- Forecast of heat demand evolution as well as forecast of infrastructure development and changes in air pollution levels. Other forecasts, necessary for completion of the heat plan are also made, such as forecast of prices of energy sources (biofuel, natural gas, electricity) and other technical and economic indicators.
- Strategic planning of municipality's territory: division of municipality's territory into zones and setting of heat supply rules for each zone.

The main energy supply option for each zone is selected based on a number of criteria. The decision is based on the evaluation of different scenarios, such as supply of heat to all the consumers of the zone through district heating network, supply of heat to all the consumers from individual natural gas or biomass boilers and so on. The preferred method of heat supply chosen is the one which has lowest long term costs.

If district heating network already exists, then it is analysed if its decentralization would mean lower costs of energy to consumers in the long period. If it is the opposite, then district heating is the preferred option. District heating network could be analysed in parts in order to assess how decentralization of that part affects costs of energy supply to that part's consumers as well as what would be the impact on other consumers of district heating system. Another important factor to consider preference of energy supply in particular zone is the effect of decentralization on air pollution level. If decentralization (through replacement of large centralized heat generators with a lot of small local energy generation installations) would significantly increase air pollution, then it cannot be considered as a preferred option.

Heat plans usually also contain additional parts, dealing with development plans of municipality's heat sector. The content of these parts depend on the specific conditions of each municipality and on different energy related laws and national strategies. These may contain, for instance, analysis of possible developments and renovations of district heating networks and their energy generation installations, calculations of feasibility of use of different renewable energy sources and different technologies, such as heat pumps, etc.

Poland

Heat planning in Poland is a common practice at local (municipal) level. According to the Article 18.1 of the Law of Energy of Poland, planning and organizing of heat, electricity and gaseous fuel supply is a responsibility of municipality (gmina) in its territory. The process of preparation of a so-called *Draft framework of heat, electricity and gaseous fuel supply* is organized by the major of municipality. For preparing the draft framework an external contractor is selected after a public procurement process.

The draft framework should be aligned with the regional energy policies of province (wojewodztwo) and state energy policies. The main goal of state energy policy is to create conditions for the sustainable and balanced development of energy sector through ensuring the energy security of the country, increased competiveness and energy efficiency and decreased environmental impact. The provincial government evaluates the alignment of these policies prior to the final approval by the council of the municipality.

Information is derived from different sources, among other plans prepared by energy companies, which under the law they are obliged to provide to the mayor.

The draft framework for municipality's territory is prepared for a period of at least 15 years and it should be renewed at least every 3 years.

The draft framework should include the following information:

- Description of current state of heat, electricity and gaseous fuel supply systems as well as foreseen changes. The current situation analysis includes population growth tendencies, description of industrial activities in the municipality, analysis of building stock (year of build, area, typical energy consumption), etc. The current state and foreseen changes in district heating, electricity and natural gas supply systems are also analysed. Additionally information is presented about the state of renewable energy supply and consumption. Evaluation of current environmental pollution level is also performed.
- Description of solutions for rationalisation of heat, electricity and natural gas consumption. After evaluation of likely developments in the energy sector of a municipality, it is described what measures could be taken to overcome foreseen hurdles, such as renovation of buildings, use of waste heat, increase in renewable energy penetration, etc.
- Description of possibilities to utilize local and surplus resources of energy and fuels, including electricity and heat produced in renewable energy and cogeneration installations as well as how to utilize waste heat from industrial installations. Technical and economical potentials of main renewable energy sources, such as biomass, are usually calculated. However, thorough analysis of potentials of many renewable and waste energy sources is often lacking.
- Description of the measures which could be taken in a municipality to implement energy efficiency improvement measures in the buildings, especially public institutions. Potential of energy savings is usually presented. Draft framework might include work programme for implementation of the measures to achieve this potential.
- Since energy supply systems of particular municipality usually are parts of national or regional systems, the draft framework also discusses measures for collaboration with neighbouring municipalities, needed to maintain and rationalize shared energy supply systems.

In the case when energy supply companies do not align their plans to the decisions set in Draft framework, major of municipality prepares a second stage document, so-called *Draft plan of heat, electricity and gaseous fuel supply* for the territory of municipality or its part. Draft plan should adhere to the decisions set in Draft framework, approved by municipality's council.

Draft plan contains the following information:

- proposals for modernising and development of heat, electricity and gaseous fuel supply systems supported by their economic evaluations;
- proposals for utilisation of renewable energy sources and high efficiency cogeneration;
- proposals for implementation of energy efficiency improvement measures in the buildings;
- schedule for implementation of proposals;
- expected costs of implementation of proposals and the sources of their financing.

Implement the decisions of the Draft plan could be discussed during negotiations with energy supply companies. In case the negotiations do not lead to decisions being implemented, municipality's council may decree to which parts of Draft plan energy related activities, carried out on the territory of municipality should adhere.

There are no specific requirements for both Draft framework and Draft plant to contain comprehensive heat maps. Graphical information in heat maps usually only contains information about heat, electricity and gaseous fuel supply infrastructure, such as the extension of district heating network or the location of main electricity transformers.

UK

Energy planning

UK has an extensive experience in energy planning. Planning on energy efficiency is one its dimensions. UK Government published the Energy Efficiency Strategy in November 2012. The Strategy identifies the energy efficiency potential based on the Energy Efficiency Marginal Abatement Cost Curve. Measures are valued taking into consideration the social perspective and valuing environmental benefits. The Strategy identified the barriers for its implementation and the key benefits of energy efficiency.

In April 2014, the UK Government published the UK Energy Efficiency Action Plan that sets out how the implementation of the Energy Efficiency Directive will help to realising this potential. The Action Plan identified nineteen policy measures to contribute towards the target of 18% reduction in final energy consumption by 2020, relative to 207. Some of the most contributing policies include: Energy Efficiency Obligations, the Carbon Emissions Reduction Target (CERT) and Energy Company Obligation (ECO).

More specifically, in the field of heat planning, the UK Government published in 2012 'The Future of Heating: A strategic framework for low carbon heat in the UK'. It describes how the heat system will need to evolve and identifies the key changes required for ensuring there is affordable, secure and low carbon heating up to 2050.

In March 2013, 'The Future of Heating: Meeting the Challenge' identified specific actions to deliver low carbon heating across, focusing on four different aspects:

- Industrial heat: Installing Combined Heat and Power (CHP) schemes in large heat consuming industries is identified as one of the main options to reduce emissions from in industry.
- Networked heat (district heating): Developing heat networks can have a significant contribution. Networks can be supplied by industrial waste heat as well as new sources, such as geothermal and heat pumps. The Government is supporting local authorities by establishing a Heat Networks Development Unit and providing funding to local authorities to assist with early-stage project development costs.
- Heat in buildings: Apart of introducing energy efficiency measures to reduce space heating and cooling demand (as the Green Deal and smart metering), the Government considers the necessity of finding less carbon intensive ways to heat. The Strategic Framework suggested a combination of an increase in heat networks in urban areas and promoting the renewable heat in rural off-gas grid areas in the short to medium-term, whilst planning ahead for the changes to gas heating in the decades to come. The Government extended the Renewable Heat Premium Payment scheme and will explore the potential role of tighter standards on building emissions and heating systems.
- Grids and infrastructure. Decarbonising the heat sector will, over time, have an impact on energy infrastructure derived from the use of networks for new fuels (biomethane and the potential of hydrogen), the construction of new heat networks and heat storage

infrastructures, and the expansion of the electricity grid derived from the a greater electrification of heat. The decisions on the different elements of infrastructure have to be taken by considering the whole system to balance the trade-offs and constraints.

Heat maps

UK has also a large experience with heat mapping. In 2012 the Department of Energy and Climate Change (DECC) published the National Heat Map of England, created by the Centre for Sustainable Energy. The map shows the heating demand of the entire country, including information relative of all the sectors: households, services (public and private) and industry. The information is provided at an address-level. It also identifies potential heat sources, as CHP and thermal power stations but also energy-from-waste plants, heat recovered from industrial sites, and biomass boilers. The Map provides information related to the water source heat potential, including: the potential for using heat pumps to extract thermal energy from coastal waters, estuaries, canals and rivers; and the total heat available from the rivers and canals intersecting a settlement.

The Map has been designed with the aim of supporting the planning and deployment of district heating networks. It is a tool that allows identifying priority locations where heat distribution is most likely to be convenient based on heat demand density demand but not for designing heat networks directly. The usefulness of the tool is proven as four of the twenty four cities awarded to receive funds by DECC to support the development of heat network projects had requested heat map data from CSE. The cities are Leeds, Manchester, Newcastle and Sheffield.

There are other public accessible maps and tools in UK, as:

- CHP Development Map, commissioned by DECC with UK coverage. It is complementary to the National Heat Map, providing CHP developers, e.g., a higher break down on layers or information about existing district heating networks.
- Leeds Energy Planning Tool, developed by the University of Leeds, which provides a district heating planning tool for England and Wales. The tool allows identifying potential appropriate locations for viable district heating. The tool offers the possibility of taking into account social factors (such as alleviating fuel poverty) in the decision.
- The CHP Site Assessment Tool, provided by DECC to allow developers to get an indicative viability assessment and compare different options for installing CHP on specific locations.
- The Fuel Poverty Map of England, published by DECC, which shows the percentage of households in fuel poverty.

Energy system modelling tools

DECC based their policies in the outcomes of different Energy System Models, such as:

- RESOM (Redpoint Energy System Optimisation Model) that was used to support the 'Future of Heating: Meeting the challenge'. RESOM was used to explore potential pathways to 2050 for decarbonising heat within the context of the whole energy system. The key solutions are those that minimise the total energy system costs to 2050. Using such a comprehensive approach allows finding the key technologies and energy vectors within all the sectors, avoiding partial solutions, to meet the UK climate change targets.
- 2050 Pathway Calculator that was used to explore energy pathways in the long term to meet the 80% emissions reduction target. The 2050 Pathways Calculator allows exploring combination of solutions to meet the emissions target while matching energy supply and demand. The analysis considers the different options and trade-offs to find a solution in the long term.

Netherlands

Heat maps

The creation of Dutch heat maps made part of a larger project aimed at creating an atlas related to sustainable energy projects in the Netherlands. These maps were meant to facilitate the transition to a sustainable energy system. They were developed in collaboration between the Dutch government and several other stakeholders, e.g. the CBS (Central Statistical Office), RIVM, TNO, Tennet, Havenbedrijf Rotterdam, and Provincie Zuid Holland. The heat map is regularly updated with reliable data. Individual data are upscaled or generalised in order to protect the privacy of stakeholders.

The heat demand is broken down in sectors, e.g. residential, industrial zones, agricultural, greenhouses. District heating networks are also available. The location of buildings, e.g. greenhouses, swimming pools, hospitals, offices, schools can be identified on the map.

This heat map also contains information about the amount of heat that is consumed per household down to the level of neighbourhoods. Annual heat demand, greenhouses emissions, and demand from industries by temperature ranges (<120˚C, 120-200˚C, and >200˚C) can be seen to the level of municipality.

Renewable potential is also available, for example, geothermal at 65-120˚C from aquifers between 1500-400 m depth, geothermal energy at 175C at 5500 m depth or 225˚C at 7500 m is available. Different bioenergy sources are displayed, e.g. liquid manure, biowaste from agriculture. Data concerning waste heat at less than 120˚C (TJ/year), and between 120-200˚C are also available. These are provided at the exact geographical location.

ANNEX III
Sector specific Energy Saving Opportunities

List of sector specific improvement opportunities (ICF 2015)

End Use	Sector Specific Energy Efficiency Opportunity Description
Iron and Steel	State-of-the-Art Power Plant
	Coke Dry Quenching (CDQ)
	BOF Waste Heat and Gas Recovery
	Continuous Casting
	Scrap Pre-Heating
	Sinter Plant Waste Heat Recovery
	Optimised Sinter Pellet Ratio (Iron Ore)
	Top Gas Recovery Turbine (TRT)
	Stove Waste Gas Heat Recovery
	State-of-the-Art Power Plant
Non-Ferrous Metal	Optimized Heating Operating Practices
	Waste Heat Recovery for Pre-heating (Combustion Air and Charge Material)
	Waste Heat Boiler for Power Generation
	Low Temperature Waste Heat Recovery
	Oxygen Enrichment of Combustion Air
	Recovery and Combustion of Carbon Monoxide
	Separate Drying of Concentrates
	Selection of Optimal Furnace Design
	Improvements to Alumina production from Bauxite
	Prevention and Minimization of Salt Slag
	Use Clean Scrap
	Increased Recycling
	Inert Anode Technology (Emerging)
Chemical and Petrochemical	Distillation columns operational optimization
	Distillation column improved controls
	Improved EE of existing distillation column with retrofit
	Improved distillation column design
	Optimised heating in distillation column and pre-heating feed
	Improved reactor design
	Improved Catalysts

End Use	Sector Specific Energy Efficiency Opportunity Description
	Optimised heating in furnace (cracking) and pre-heating feed
	CHP for Electricity Generation
	Process optimisation and improved process design
	Waste heat recovery
	Advanced Process Operation
	Membranes and other Pharmaceutical Process Developments
	Novel Separation Processes (Emerging)
	Improved Naphtha Cracking Technologies (Emerging)
	More Efficient Low Grade Waste Heat Recovery Technologies (Emerging)
	Inter-plant Process Integration
Non-Metallic Mineral	Replacement of furnace/kiln/dryer with Optimized Design
	Retrofit of furnace/kiln/dryer to Improve Design (Wet to Semi-dry process)
	Increasing Number of Preheater Stages in Rotary Kilns
	Recovery of excess heat from kilns cooling zone for Increased Preheating (Other than Rotary Kilns)
	Conversion to Reciprocating Grate Cooler for Clinker Making in Rotary Kilns
	Using high efficiency equipment for grinding and other electrical uses
	Fuel substitution for more efficient thermal energy consumption
	Low Temperature Heat Recovery for Power Generation
	Use of increasing levels of cullet for Glassmaking
	Improved Materials (Substitutes) and Product Design for more Efficient Manufacturing
	Advanced Oxyfuel Combustion Technologies (Emerging)
	Smart Design and Clustering of Manufacturing Facilities
Food, Beverage and Tobacco	Increased Combined Heat and Power (CHP)
	Adsorption Chillers and Trigeneration to Meet Cooling Requirements
	Fuel switching, substitution, and combustion of waste gases
	Optimized Facility Operating Procedures
	Optimization of Operating Practices for Cooking and Baking
	Optimization of Operating Practices for Distillation, drying and evaporation
	Optimization of Operating Practices for Refrigeration
	Improved Mechanical Equipment Efficiency
	Improved Cleaning, Washing, and Sterilizing Equipment Efficiency
	Contact Dryer for Improved Drying Efficiency

End Use	Sector Specific Energy Efficiency Opportunity Description
Pulp, Paper and Print	TMP Refiner Heat Recovery
	Efficient TMP refiner and pre-treatment
	Efficient Screening of Recovered Fibres
	Paper Process Heat Recovery and Integration
	Paper Drying Section Shoe Press
	Efficient Paper Process Refiners
	Energy efficient vacuum systems for dewatering.
	Thermo Compressors
	Combined Heat and Power
	Heat recovery for the biomass and sludge drying process
	Heat recovery from radial blowers used in vacuum systems
	High Efficiency Grinding (GW) for Mechanical Pulp
	Enzymatic Pre-treatment for TMP Refiner
	Black Liquor Gasification
Machinery	High Efficiency Process Equipment (Electrical)
	Implement Lean Manufacturing System
	Optimized Process Re-Design
	Optimized Techniques for Efficient Equipment Operation
	High Efficiency Process Equipment (Thermal)
Petroleum Refineries	Distillation columns operational optimization
	Improved EE of existing distillation column with retrofit
	Advanced Distillation Column Designs
	Heat Integration and Waste Heat Recovery
	CHP for Electricity Generation
	Integrated Gasification Combined Cycle (IGCC)
	Power recovery using backpressure turbogenerator
	Advanced (Predictive) Process and Maintenance Control Systems
	Inter-plant Process Integration
	Cogeneration using gas turbine exhaust gas as combustion air for heating furnace
	Progressive crude distillation
	Fouling mitigation in the crude distillation preheat train and fired heater
	Catalytic Reforming: replace horizontal feed/effluent heat exchangers with vertical plate and frame exchanger
	More Efficient Low Grade Waste Heat Recovery Technologies (Emerging)

End Use	Sector Specific Energy Efficiency Opportunity Description
	Improved Water Treatment System Operation and Design
	Improved Catalysts (Emerging)
	Novel Hydrogen Production Technologies (Emerging)
	Novel Desulphurization Technologies (Emerging)
Transformation input in producers	Higher Efficiency new CHP Systems
	Hot Water Thermal Storage
	Supplementary firing of a CHP system's gas turbine exhaust
	Optimized gas turbine inlet air filtration
	Thermal load tracking for reciprocating engines.
	Improved fuel/air ratio control
	Full engine rebuild
	Ignition system upgrade
	Thermal system audit
	Retrofit of Existing coal CHP to fire or co-fire Biomass
	Steam Turbine Retrofit for Efficiency

ANNEX IV
Selected district heating development country snapshots[64]

AT:

District heat is expanding due to favourable legislation. CHP supplies 2/3 of DH. DH delivery increased 6% between 2006 and 2011.

DH delivery is 36% in the residential sector; 50% in public and service sector. Pipelines length is 4400 km length and expanded 3% annually in 2006-2011.

30% of final energy is used for space heating and hot water out of 19% was provided by DH.

Annual 60 million EUR state aid for DH/C investment since the 2008 WKLG law.

Investment aid for new CHP plants capacity up to 10% of the total investment cost.

Environmental law gives also support for e.g. biomass CHP up to 30% of environmental costs.

Building regulation at federal State levels, which is different province by province. Subsidies are given to the heating systems with a focus on renewables. The provinces provide subsidies also for district heating.

BG:

Fuel for DH did not change much in the past ten years; it is 70% natural gas.

In the last decade, there was a significant reduction in the thermal energy used in household of -19% in 2006 and -15.6 in 2011.

Between 2006 and 2011, the share of thermal energy used by household and the no-residential sector was stable.

As regards the legislative framework, there is a Regulation on pricing heat and regulation on pricing electricity. Multinational companies own some of the city DH systems.

HR:

The fuel used for DH is natural gas 79%, oil and petroleum products 19% and renewable energy 2%. The share of gas has been steadily growing. The use of renewable is relatively recent and dates from 2011.

The residential sector is the biggest consumer group. Sales for industrial and the services sector are relatively the same.

DH is an energy policy priority for Croatia.

There has been no expansion of DH in the last fifteen years in Croatia and there is a need for refurbishment in order to increase customer confidence, energy efficiency and profitability.

Croatia’s Energy Regulatory Authority approves the tariffs for DH.

The city administration own DH systems. There are DH systems in large continental cities with a local market share of 15-30%. Natural gas is a strong competitor. In renewable wood is the biggest source.

SE:

DH heat floor space decreased from 674 million m^2 in 2007 to 424 million m^2 in 2011. DH is the dominant mode of heating in multifamily houses and the service sector. 12% of the family houses are connected to DH. Heat pumps are the main way to heat family homes. More than half of the Swedish population live in family homes.

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[64] Source: Euroheat & Power, District Heating and cooling, Country by Country 2011 Survey [to be updated]

SK: Falling heat sales by DH is still persisting, since natural gas heat is for many a cheaper alternative. This is due to EE measures, but also an exit from DH towards gas heating. The DH sector is shrinking. DH systems are negatively affected by regulatory policy and mismatches between building law and environmental policies. Municipalities do not prevent disconnection from DH systems. Law gas prices – regulated – are provided to households in comparison with wholesale gas prices used by DH and CHP.
New CHP capacity is being built mainly in industry. A new trend is the increase in renewable based CHP, also for DH.

RO:
DH is shrinking by approximately 10% in the last decade. The heated floor space decreased from 69500 million m^2 in 2007 to 55590 in 2011, i.e. by 20%. DH capacity shrank by 74% since 2007 and the pipeline length also declined. Total installed capacity and sales decreased considerably. This is caused by reduced purchasing power, fuel price increase, and unrealisable support from local administration, which is not able to maintain local subsidy schemes for heat. DH systems are in many cases in need of repair and refurbishment. They are characterised by high network losses and lack of investments to modernise and replace old equipment. The DH systems are mainly operated by municipalities, but a recent trend is of private investors' entry (some 7% of the DH market.
The national government is supporting DH through a national plan that started in 2006 and will end in 2015. The plan provides support for building insulation and the modernisation of the DH network. These efforts are not however sufficient in view of the investment need in the DH system of Romania.
The trend is that the use of coal is decreasing and being replaced mainly by gas and renewables, such as geothermal.
DH heat supply is public service and the price is regulated and subsidised, but operators are not able to make sufficient profit to invest in refurbishment and new equipment to replace the old systems. There is a migration away from DH in favour of individual gas boilers.

PL:
Total installed capacity has been decreasing since 2007 from 62750 MWth to 58300 MWth in 011, but pipelines length increased. Heat production in heat sources connected to DH in 2006 amounted to 421.1 PJ and decrease.

ANNEX V
Technology on Energy Storage

I°) Introduction

Energy storage will become an important element of the electricity infrastructure of the future. The storage opportunity is multifaceted involving different stakeholders with various interests. The role of electricity storage is to provide stable and high-quality electricity supplies into the system especially as the share of variable generation increases which will create challenges for matching supply and demand.

When talking about energy storage, two dimensions should be taken into account:

(1) Storage technology and storage characteristics;

There are several types of storage technology and their characteristics are different in terms of installed power capacities, energy storage capacities and storage times, and energy efficiency.

(2) Storage applications.

An application is a specific way or ways that energy storage is used to satisfy a specific need. In other words, how and for what energy storage is used.

The document aims to be factual and technology neutral.

II°) Storage technology overview

1°) Chemical

- Hydrogen (H_2)

Hydrogen can be physically stored in a gaseous state (compressed) or in a liquid state. Both technologies are established and used in the car industry for hydrogen vehicles.

Chemical storage of hydrogen, where hydrides are stores is an emerging technology. Currently the only hydrides used are limited to lithium, boron and aluminium based compounds. Hydrides chosen for storage applications provide low reactivity (high safety) and high hydrogen storage densities. The use of hydrides of magnesium is now being developed.

2°) Electrochemical

- Batteries

They consist of two or more electrochemical cells which through a chemical reaction create a flow of electrons. An increasing number of chemistries are used for this process but the more familiar ones include lead-acid, nickel-cadmium (NiCad), lithium-ion (Li-ion), sodium/sulphur (Na/S), zinc/bromine (Zn/Br), nickel-metal hydride (Ni-MH) and others.

- Flow batteries

The flow batteries use electrolyte that is stored in a separate container outside of the battery cell container. The advantage is that the storage system's discharge duration can be increased by adding more electrolytes. Vanadium redox and Zn/Br are the two more familiar types.

3°) Electrical

- Capacitors/Super-capacitors

Capacitors store electric energy as an electrostatic charge. They are well-suited to being discharged rapidly and to deliver a significant amount of energy over a short period of time.

- Superconducting Magnetic Energy Storage (SMES)

SMES systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. SMES systems are highly efficient (greater than 95%).

4°) Mechanical

- Compressed Air Energy Storage (CAES)

CAES involves compressing air (using inexpensive energy) that can be used to generate electricity (when the energy is more expensive). The compressed air is heated and released into a combustion turbine generator system. For larger CAES plants, underground geologic formations (salt, aquifers or gas fields) are used. For smaller CAES plants, tanks or high-pressure natural gas pipelines are suitable.

Adiabatic CAES (ACAES) uses no fuel to convert stored compressed air into peak-electricity power. Cooling of the compressors and the heating of the stored air for power production are achieved with thermal energy storage. Therefore the round-trip efficiency is must higher.

- Flywheel Energy Storage

The principle is to have a cylinder with a shaft that can spin rapidly within a robust enclosure. The shaft is connected to a motor/generator. To limit fictions, a magnet levitates the cylinder. To charge the storage, electric energy is converted via the motor into kinetic energy (rotation speed). The stored energy is converted back to electric energy via the generator, slowing down the speed of the flywheel.

- Hydroelectric

Most hydroelectric power (conventional) comes from the potential energy of dammed water driving a water turbine and generator. The power extracted from the water depends on the volume and on the difference in height ("the head") between the source and the water's outflow. The amount of potential energy in water is proportional to the head.

Key elements of hydroelectric power (pumped-storage) system include turbine/generator equipment, a waterway, an upper and a lower reservoir. This method produces electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine.

5°) Thermal

- Ice storage

There are various ways to store thermal energy but the most common way is to make ice when energy prices are low and to use it to reduce cooling needs (especially compressor-based cooling) when energy is expensive or the load of the grid is close to the black out.

- Liquid Air Energy Storage (LAES)

LAES system employs proven cryogenic processes that use liquid air as the energy storage medium. Storing energy in the form of liquid air increases the energy density up to five times as compared with similar Compressed Air Energy Storage (CAES) technologies and can achieve high energy storage efficiencies.

Characteristics

When characterizing the rating of a storage system, the two key criteria to address are *Power* and *Energy*.

Power indicates the rate at which the system can supply energy and the *Energy* relates to the amount of energy that can be delivered to loads.

		Power (MW)	Response time	Discharge duration	Capital costs (€/kw/a)	Efficiency	Life time (year)	Type of storage
Chemica	Hydrogen	1000				40%		Long term
Electrochemi	Batteries	500				60% to 75%	6 to 20 (depending on type)	
	Flow batteries					75% to 85%		
Electrical	Capacitor					95%		
	SMES					95%		
Mechanical	CAES ACAES	2 to 300				40% 70%	30 30	Interim Long term
	Flywheel					80% to 90%		
	Hydroelectric					75% to 80%		
Ther	Ice storage							
	LAES					75% to 85%		

<u>Other characteristics</u>: Footprint and space requirements, operating costs (charging, maintenance, replacement …), reliability, etc.

ANNEX VI
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