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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}

**Contents**

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.

[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.

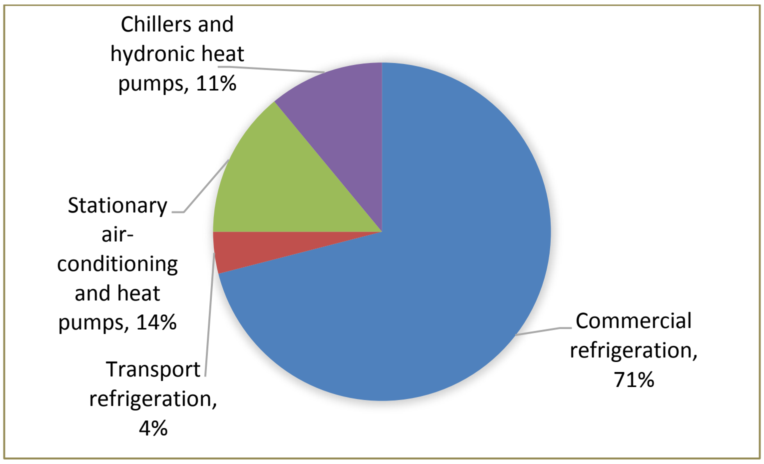
Residential buyers have been able to inform their purchase decisions for room air conditioners of <12kW using the EU Energy label since 2003, although minimum requirements only came into force in 2013.

## 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).

[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*

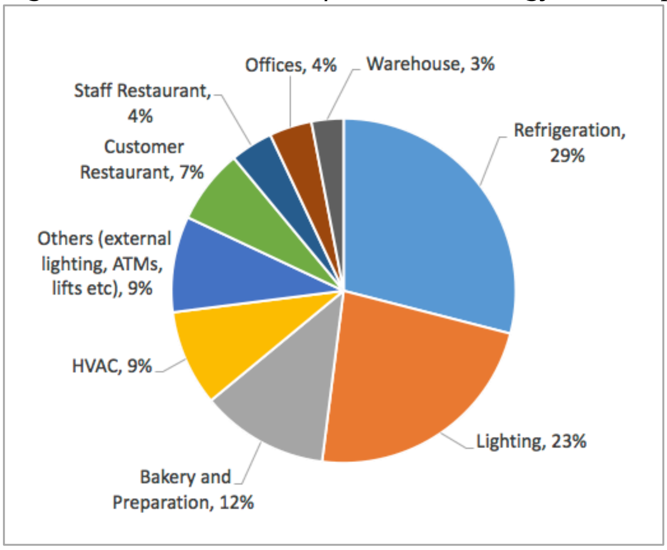
| **NACE Sector** | **Description** | **Types of demands and cooling equipment used** |
|---|---|---|
| G | Wholesale and retail trade | Refrigerated retail display cases for foodstuff<br>Vending machines<br>Walk in cold rooms<br>Cold storage facilities<br>Air conditioning in retail stores |
| I | Accommodation and food service activities | Refrigerated storage cabinets and counters<br>Refrigerated retail display cases and beverage coolers<br>Room and central air conditioning |
| H | Transportation and storage | Refrigerated trucks and vans<br>Reefers / Iso containers<br>Commercial cold storage facilities |
| J | Information and communication | Cooling for data centres |
| Q | Human health and social work activities | Air conditioning<br>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].

[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 (<20$m^3$) for 40% and large (100 to 400$m^3$) 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].

[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).

[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.

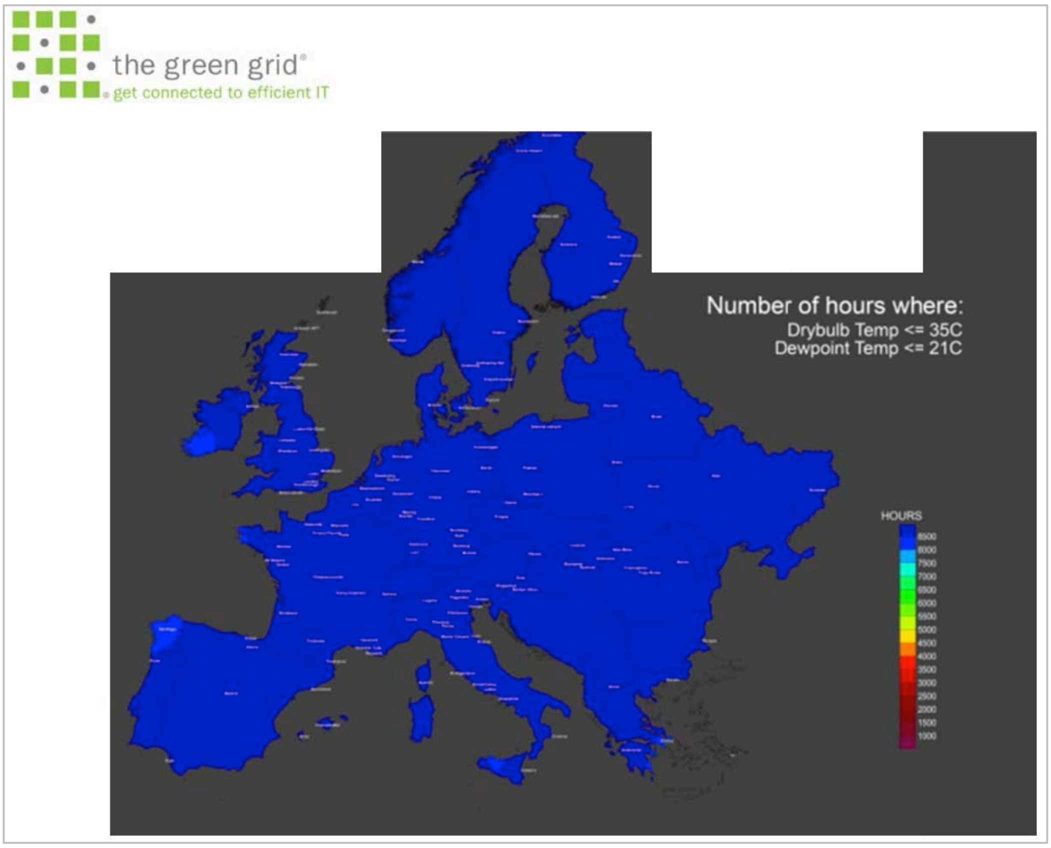
A voluntary EU Code of Conduct for data centre operators has been in effect since 2008. It encompasses the performance of the whole data centre energy system and sets efficiency requirements for both the IT load and the facilities load (which includes refrigeration). There are several Best Practices 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).

[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,

[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

[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:

[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:

- <u>Small portable units</u>. 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.
- <u>Split ‘air to air’ systems and small packaged room air conditioners</u>. 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

[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

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

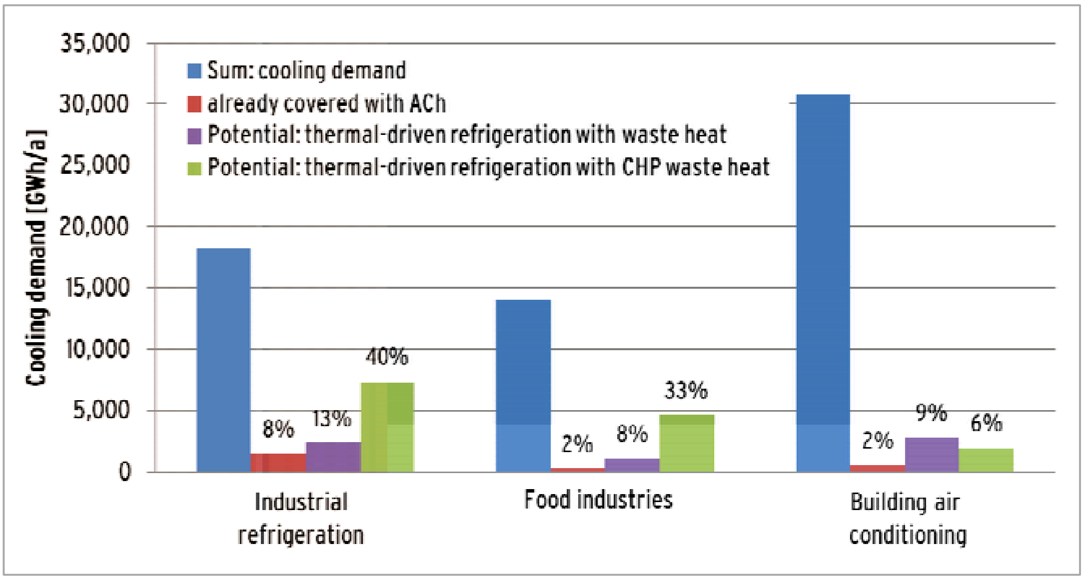
[20] A UK government publication in 1999 suggested that there were 2700 absorption chillers in the UK, the vast majority being small gas-fired air conditioning units, but including over 200 commercial sized units, 20 of which for industrial process cooling applications. The markets for industrial absorption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

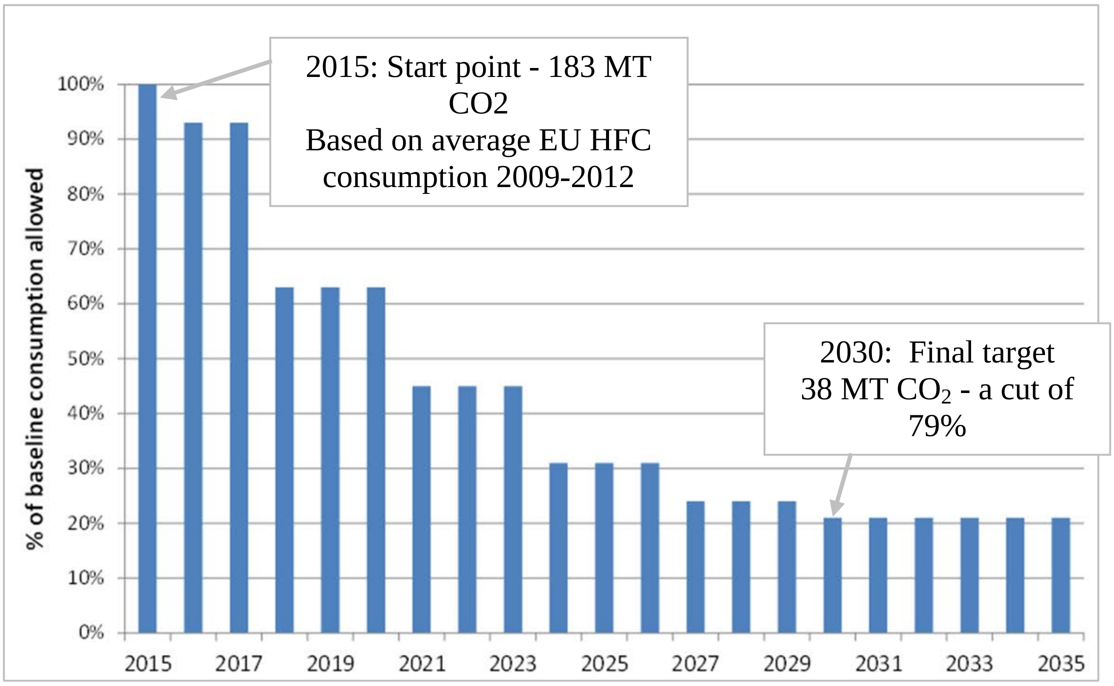
There is a significant number of new refrigerants being considered as replacements for high GWP HFCs and the choice is highly dependent on the application. Available climate-friendly

[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*

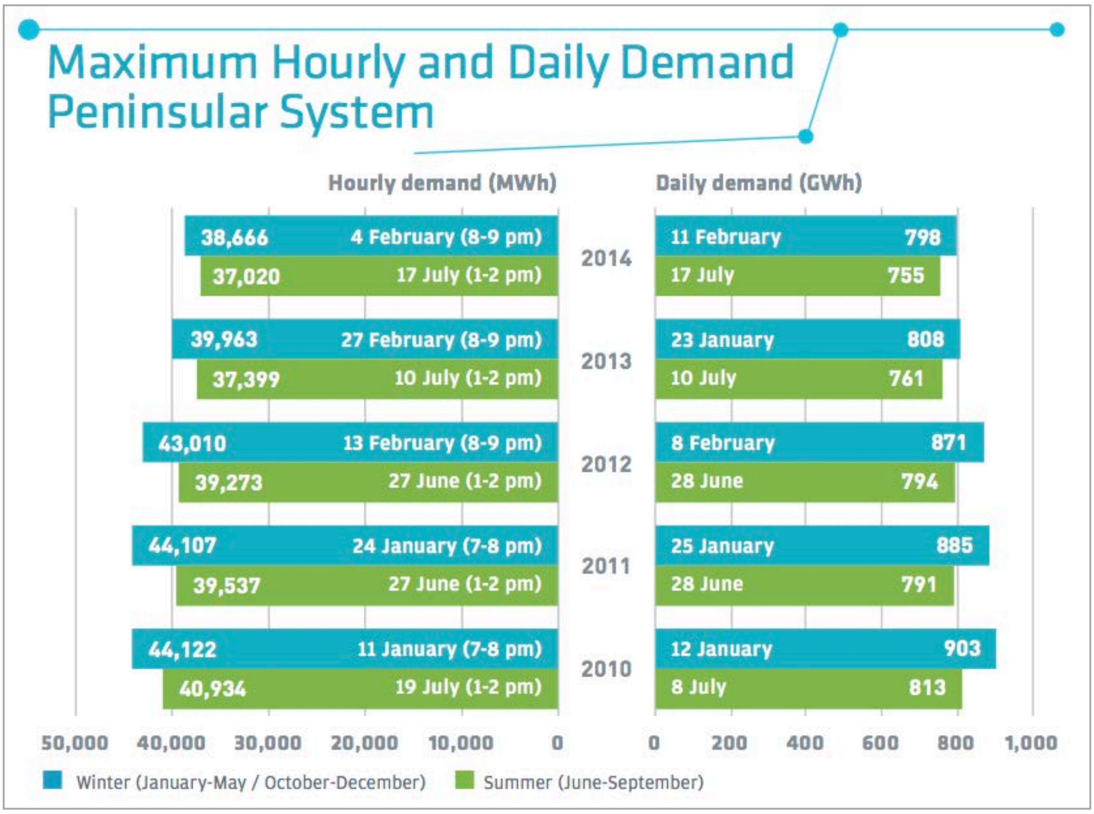
Spain suffered a period of very high temperatures in July 2015 that created a surge of 8% in electrical demand due to the use of air conditioning. This set a new daily average record demand of 712 GWh. A similar trend is also observed in Italy, where since 2006 the summer daily peaks in electricity demand 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.

[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*

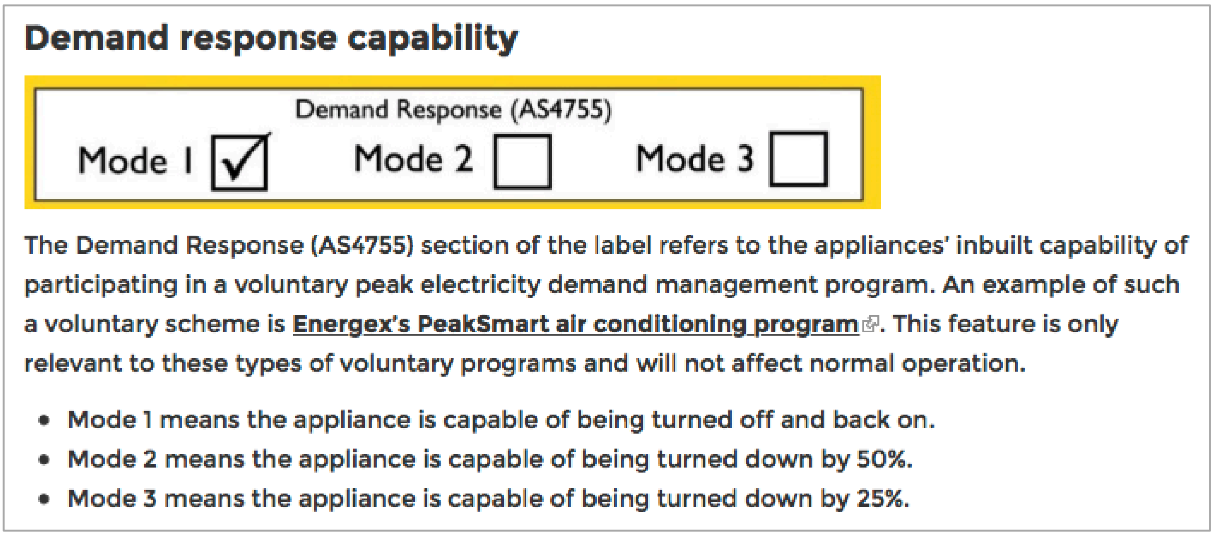



**Source: REE (2014)**

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.

[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].




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,*

[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

[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)

[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).

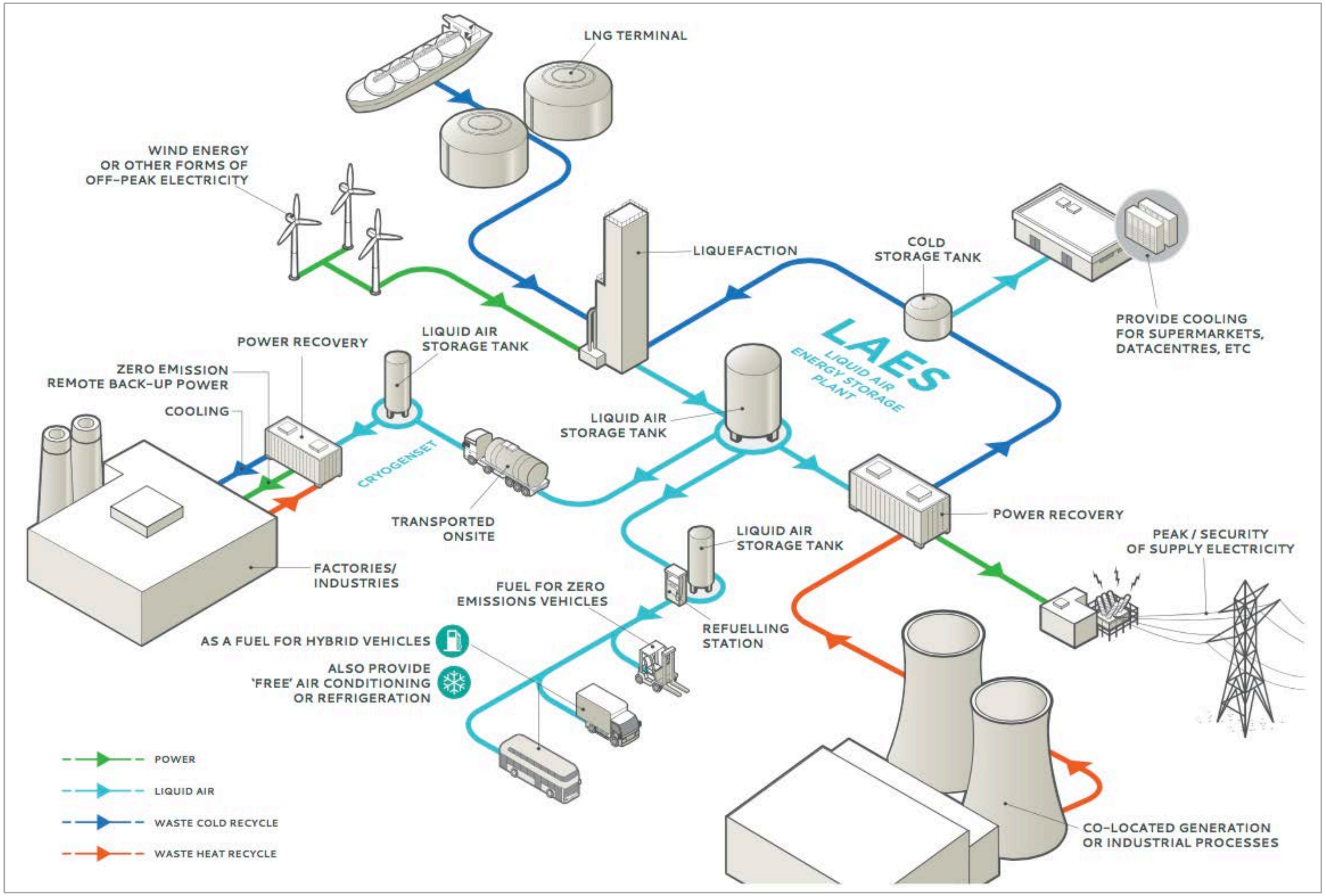



*Figure 6-8. Overview of a liquid air economy (LAEN 2013).*

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.

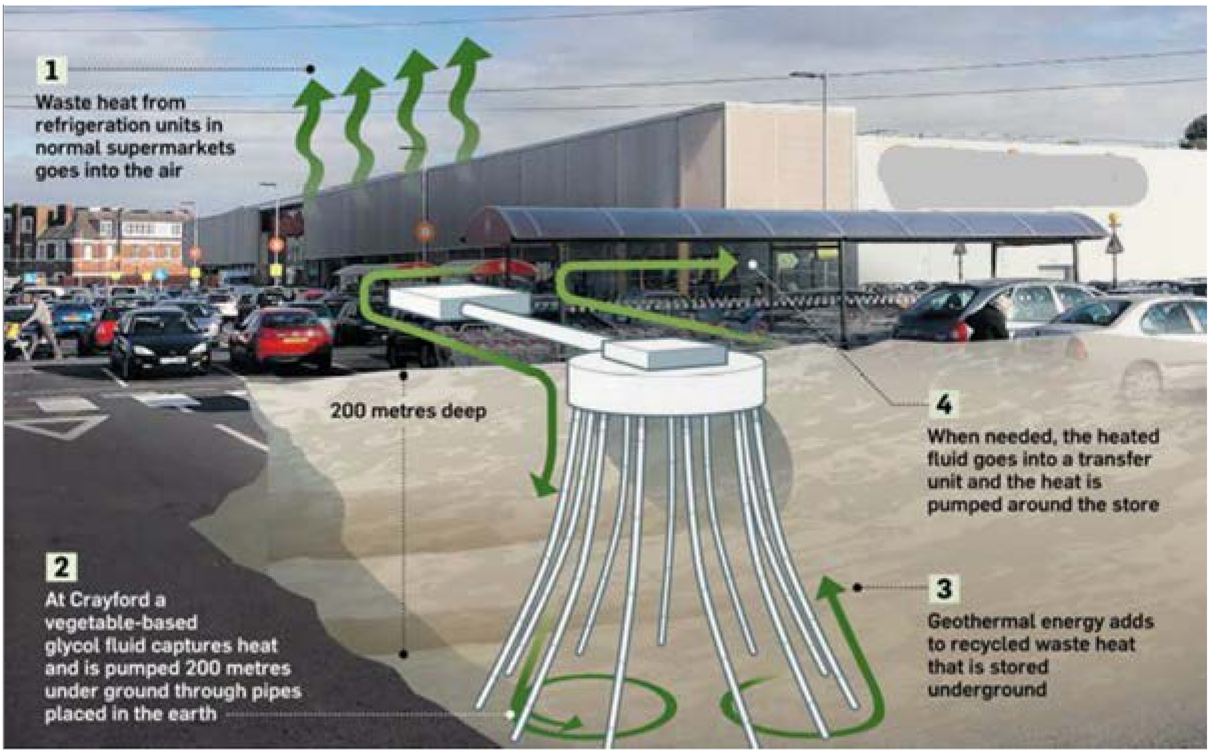
**Reversible ground source heat pumps with inter-seasonal storage**

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.

[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

[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

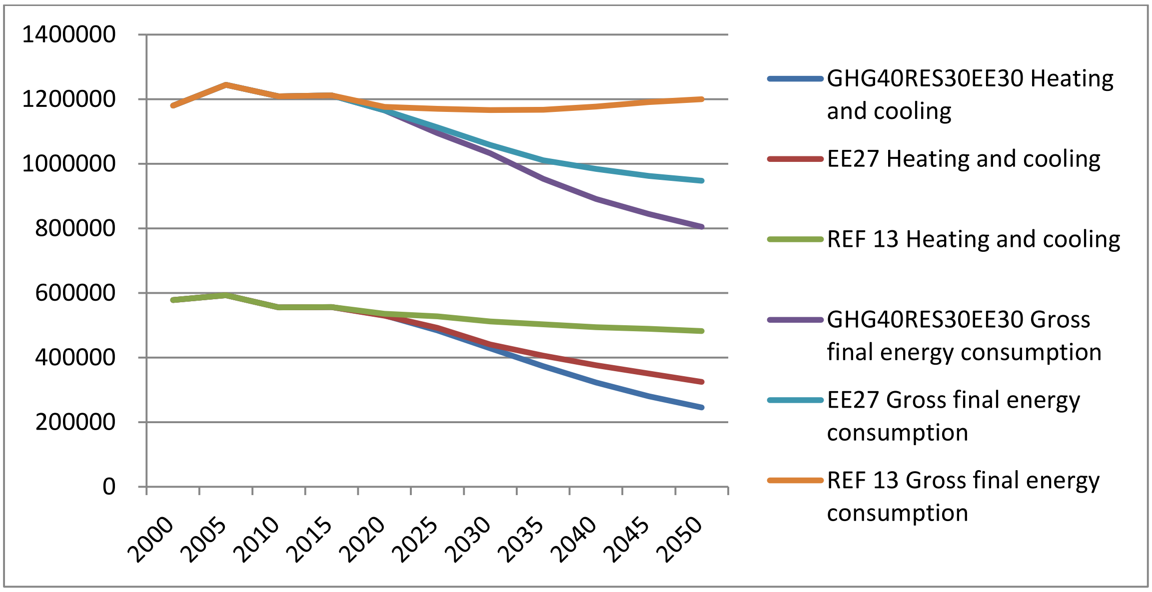
(relative to 2010) and 2030 from 555 Mtoe to 535 Mtoe in 2020 and to 512 Mtoe to 2030 respectively; and a slight decrease afterwards to 2050, with the level still remaining slightly under current consumption. The share of heating and cooling in final consumption also remains rather stable, decreasing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

[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*

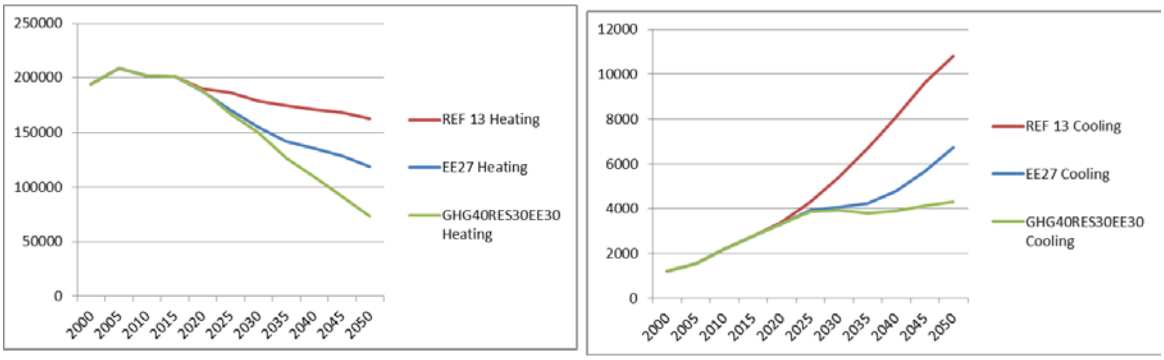
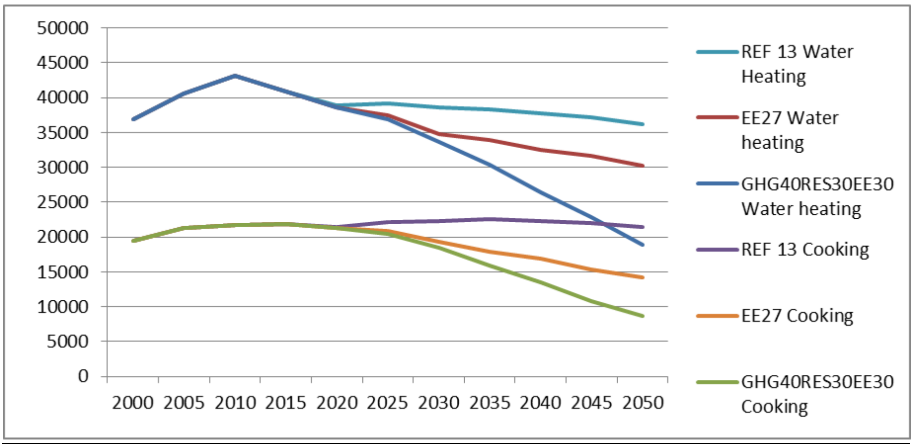



*Figure 7-3: Final Energy per energy use (Ktoe) Other Heat Uses: Water Heating and Cooking*




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)*

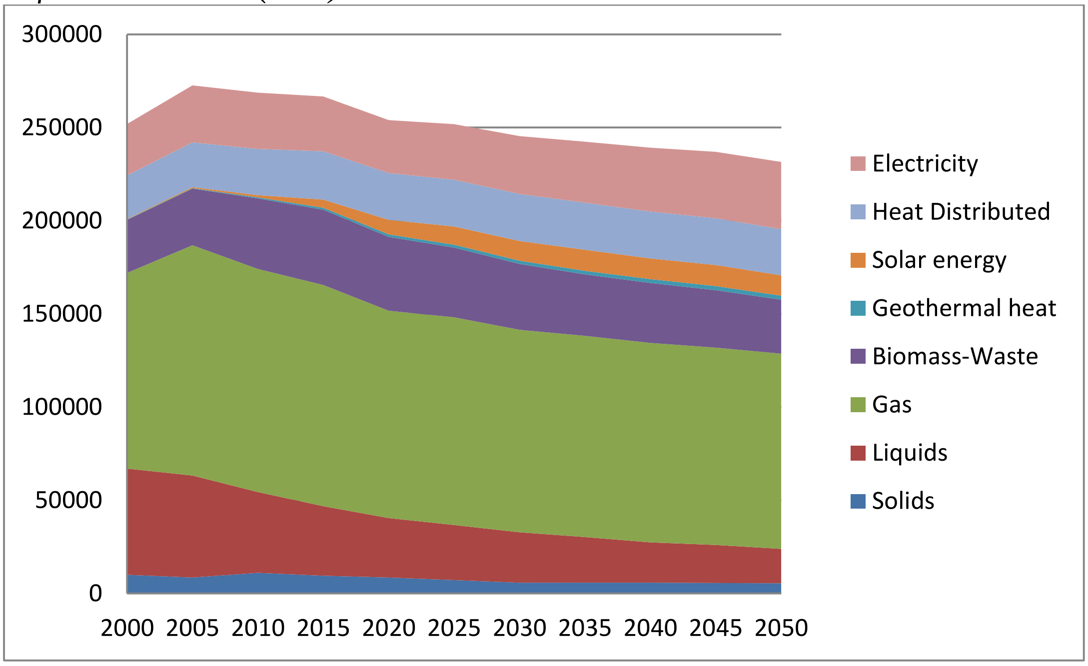



*Figure 7-5: Final Energy per fuel in the residential sector for Heating and Cooling under EE27 (Ktoe)*

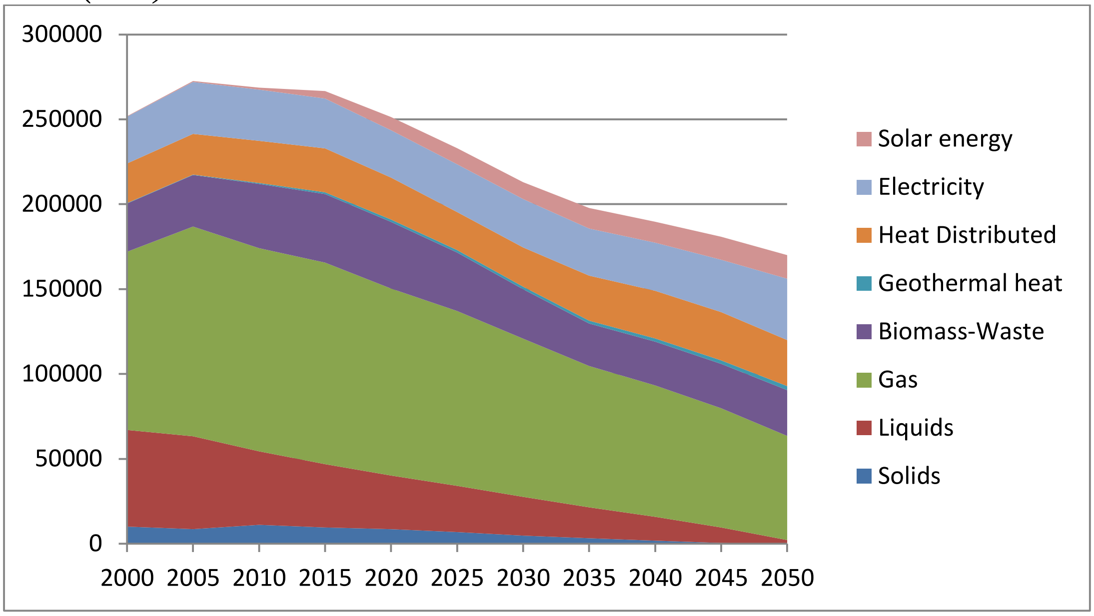
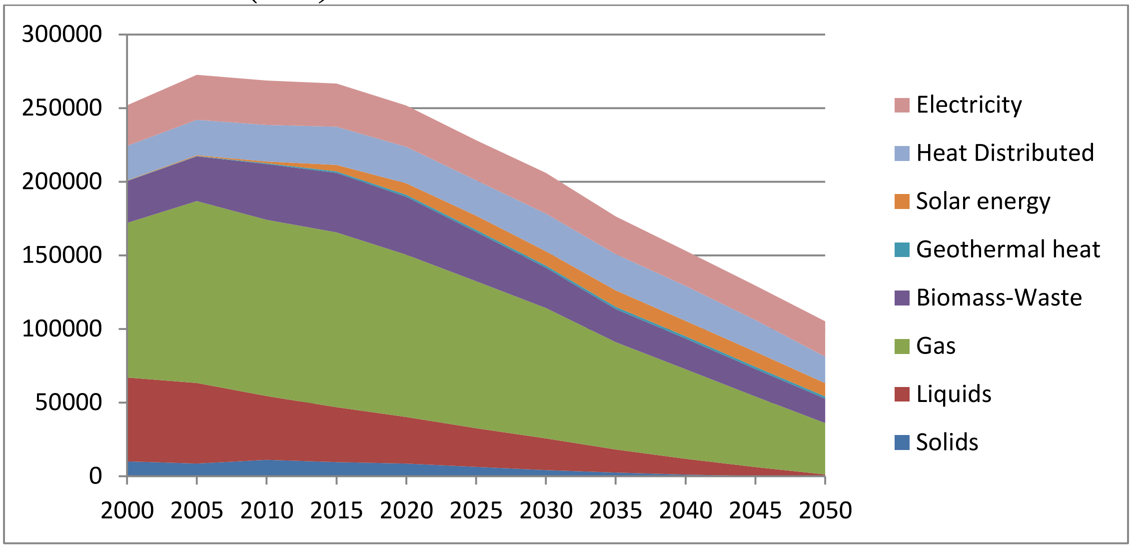


*Figure 7-6: Final Energy per fuel in the residential sector for Heating and Cooling under GHG40RES30EE30 (Ktoe)*

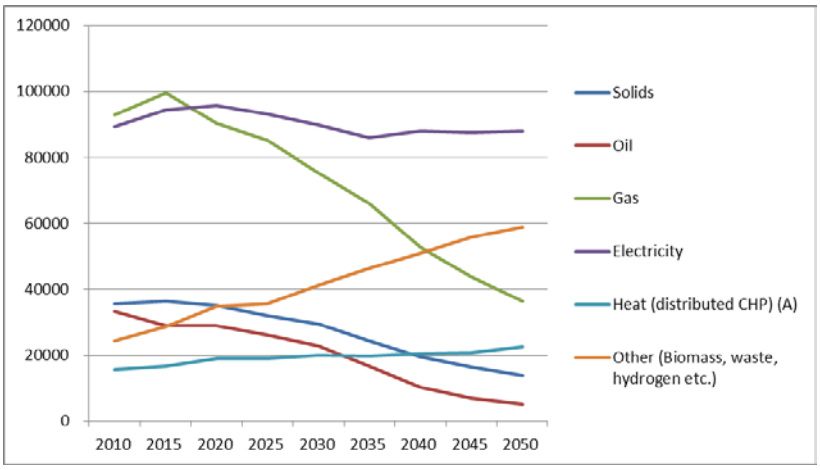



***Demand in industry***

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.

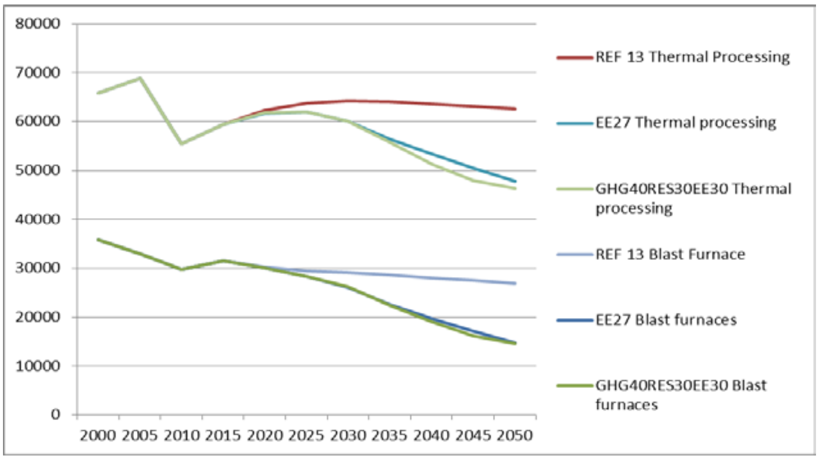
Industry's energy mix is projected to change. Natural gas, which is at present supplying the majority of industry’s energy, is projected to be significantly reduced by 2050. By then, electricity will become the first fuel, and biomass, waste and hydrogen combined would become the second most important 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.

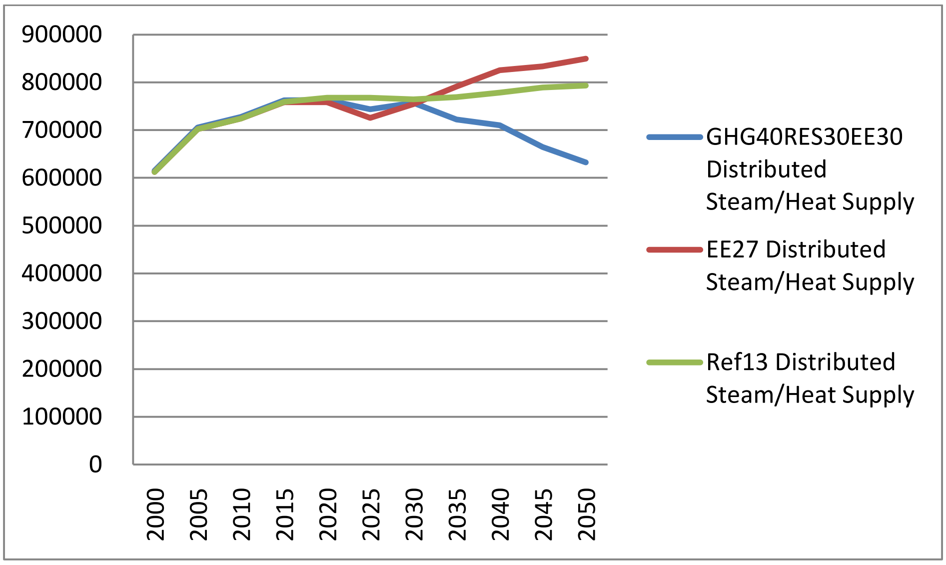
*Fig. 7-8: Industry Energy Demand (Ktoe): Blast furnaces and thermal processing*




## 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

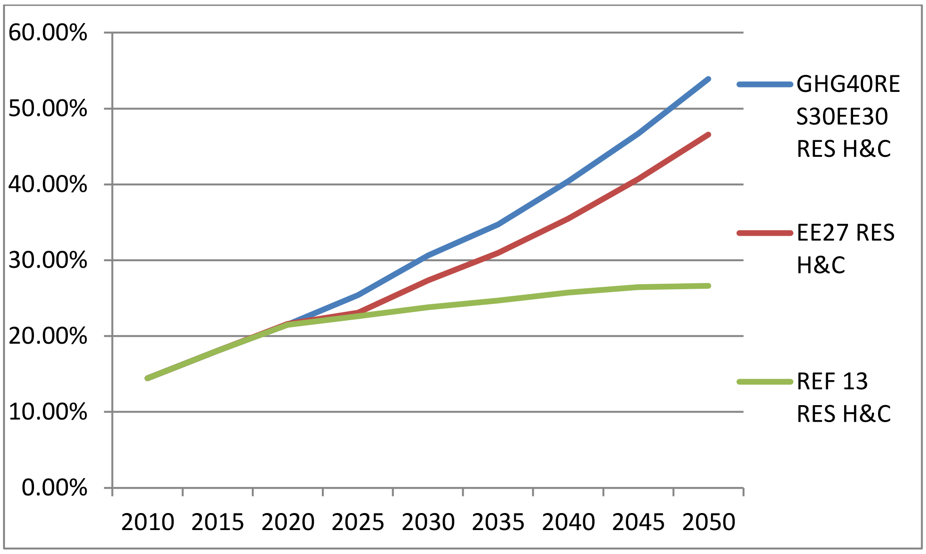
The share of renewable energy in heating and cooling is 14% of total final consumption for heating and cooling in 2010. In the 2013 Reference scenario, this share increases to 21.5% in

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

[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**

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| **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** |

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|---|
| **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** |

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|---|
| **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:

[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***

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

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.

[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<br>ACAES | 2 to 300 | | | | 40%<br>70% | 30<br>30 | Interim<br>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
# List of references


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