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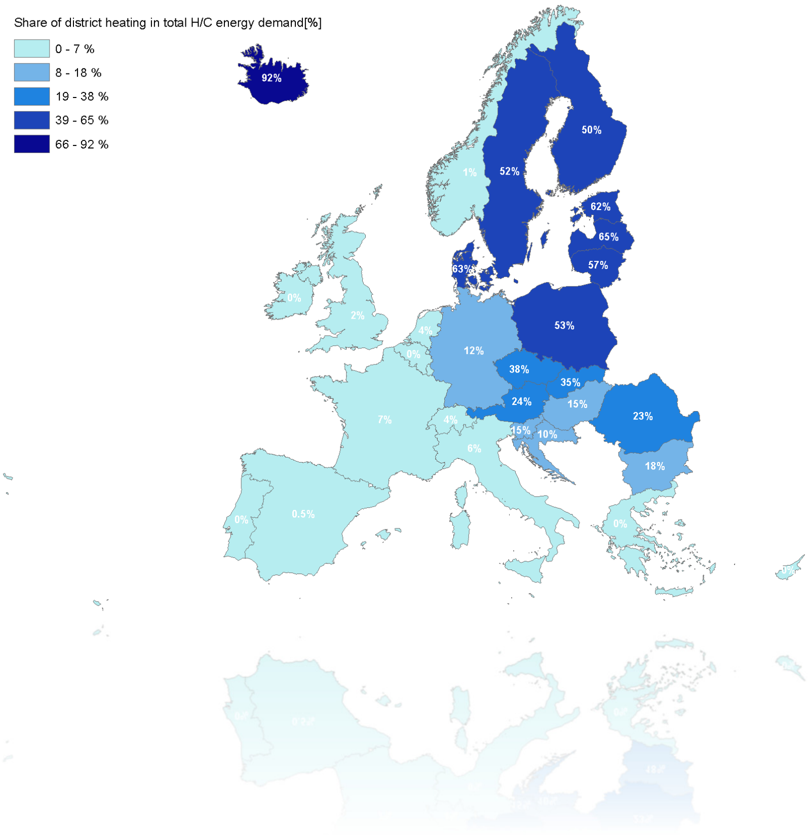
Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)



Work package 1: Final energy consumption for the year 2012

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1 Objective and approach

1.1 Objective

Work package (WP) one assesses the status-quo of energy demand for heating and cooling in the European countries in the year 2012. The main goal of the WP is the calculation of a consistent European end-use energy balance for heating and cooling. In contrast to classical energy balances that show sectors and energy carriers, end-use energy balances also include information on the purposes energy is used for. Examples are space heating or water heating. Consequently, end-use balances provide valuable information to understand the structure of energy demand and provide a basis for demand-oriented energy policies.

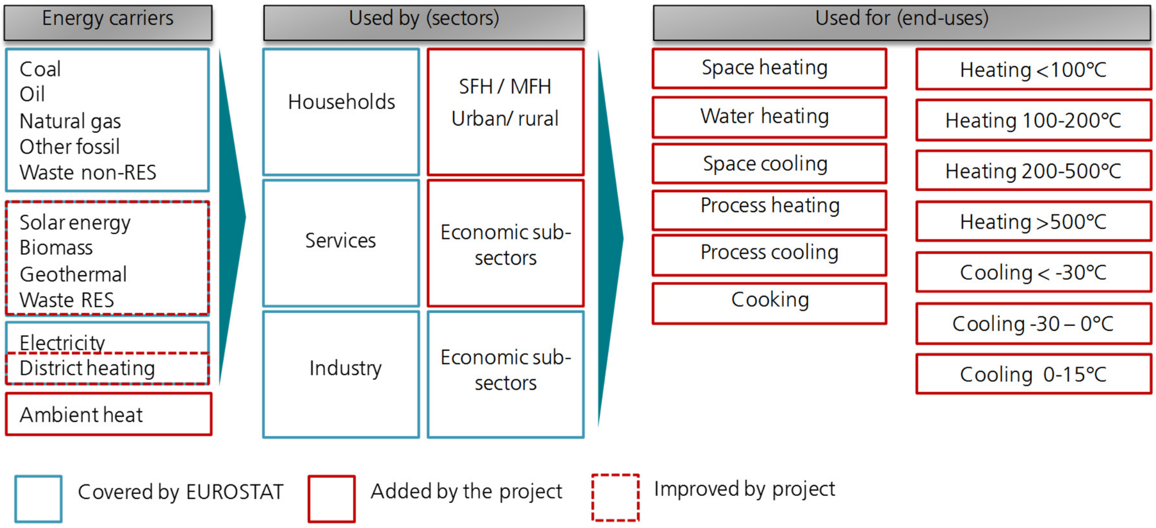
The following objectives are part of WP1.

- Quantification, description and graphical depiction of the final energy demand related to heating and cooling in the sectors households (residential), industry and services/ tertiary, disaggregated in energy carriers and end-use categories.
- Provision of a similar quantification also for useful and primary energy demand by country.
- Assessment of available national and EU energy statistics and other data collections on heating and cooling, and the current data collection practice in Member States. Identify data gaps and derive recommendations on how to improve data collection.

The results of WP1 are considered to be fundamental to other work packages, particularly WP3 (scenario analysis) and WP4 (economic analysis). On the other hand, WP 1 strongly relies on WP2 (technology assessment) to establish consistent conversion efficiencies from final energy demand to useful energy demand.

Data delivery and disaggregation in particular includes the split of energy carriers, end-uses and sectors as set out above in the description of the general scope of the project by country. The end-use categories space heating, water heating, process heating, space cooling and process cooling are distinguished. For process heating and cooling individual temperature levels are distinguished. For the industrial and the tertiary sector energy balances by country are further broken down into sub-sectors, whereas in the residential sector they are broken down by building type and into urban and rural regions. Figure 1 provides a full overview of the dimensions considered.

Figure 1: Structure of end-use balances calculated in comparison to Eurostat final energy balances



1.2 Method

In order to achieve the objectives stated above, we structure our approach into the following methodological steps:

- Assessment of national and EU energy statistics and of other data sources:
- As a first step, we assess national and EU statistical data and other data collections such as energy consumption data bases and energy use balances from individual countries. Moreover, data sources of underlying or indirect character such as building stock and technology stock data as well as sales statistics will be included. Comparing the data requirements arising from the scope of this study we identify main data gaps. Some of these data gaps are even obvious now.

Methodology to derive end-use balances:

- In the second step we will develop the methodology framework to fill these data gaps. Recommendations will be provided how to fill data gaps in national and EU statistics to improve the data beyond this project
- Sector-specific approach to derive end-use energy balance:
- In this step, we set up a detailed approach for each sector with the goal of closing the existing data gaps and providing a consistent end-use energy balance by country. Therefore, a combined approach consisting of a collection of national data sources and EU-wide sector modelling is applied.
- Calculation of final energy for heating and cooling.
- Based on this additional data generated by the previous steps and by WP2 we derive a final energy balance, following a combined bottom-up and top-down approach.
- Calculation of useful and primary energy for heating and cooling:
- Finally, we calculate useful and primary energy demand by taking into account the technological specification and efficiency values from WP2 based on the final energy demand balance.

2 Assessment of national and EU energy statistics

2.1 Eurostat energy balance

Complete energy balances for primary and final energy carriers (table "nrg_110a") for almost all EU (EEA[1]) member states and acceding or candidate states[2] are available in the database of Eurostat over the website or the bulk download facility provided by Eurostat. The comprehensive structure of Eurostat energy balances and the break-down of energy carriers can be found in annex 8.1 and 8.2. Eurostat provides 129 different products for up to 650 categories in its balances, which shows the richness of detail of these data collections. However, little information is available on actual energy balances including useful energy as introduced in (Eurostat, 1978).

Eurostat compiles a report on the quality of data regarding energy statistics based on Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 in intervals of five years (European Commission 2014). This report provides information on several quality indicators defined in the ESS Standard for Quality Reports (ESQR) and the Quality report of European Union energy statistics such as:

- Completeness defined as the ratio of the number of data cells provided to the number of data cells required, meaning that data missing due to derogations/confidentiality or any other reason are included. The ratio is computed for a chosen dataset and a given period.
- Coherence and comparability where coherence refers to the degree to which the statistical processes by which statistics were generated used the same concepts - classifications, definitions, and target populations – and harmonised methods. Comparability is a special case of coherence where the statistical outputs refer to the same data items and the aim of combining them is to make comparisons over time, or across countries, or across other domains.
- Accessibility, which measures the ease with which users can obtain data describing the associated set of conditions and modalities.

Eurostat reports that the criterion of completeness is fulfilled for all its annual energy data collections with very few exceptions (e.g. nrg_105a, nrg_106a) or exceptions simply regarding some sub-aggregates (nrg_107a) (European Commission 2014).

Due to a high level of collaboration with other international organisations and joint questionnaires between Eurostat, IEA and UN, the energy data provided can be considered as fully comparable and coherent in the most important cases. However, for some special cases statistics may not be completely coherent, in the sense that they may be based on different approaches, classifications and methodological standards.

The criterion of accessibility can be considered as being fulfilled at the level of usage for this study as all data is obtainable free of charge as bulk data from the Eurostat website. However these data, available in both kilotons of oil equivalent (ktoe) and terajoule (TJ), have only one, or no decimal place. This may lead to differences due to

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[1] Except Liechtenstein and Iceland (available only until 2014 due to reporting issues)

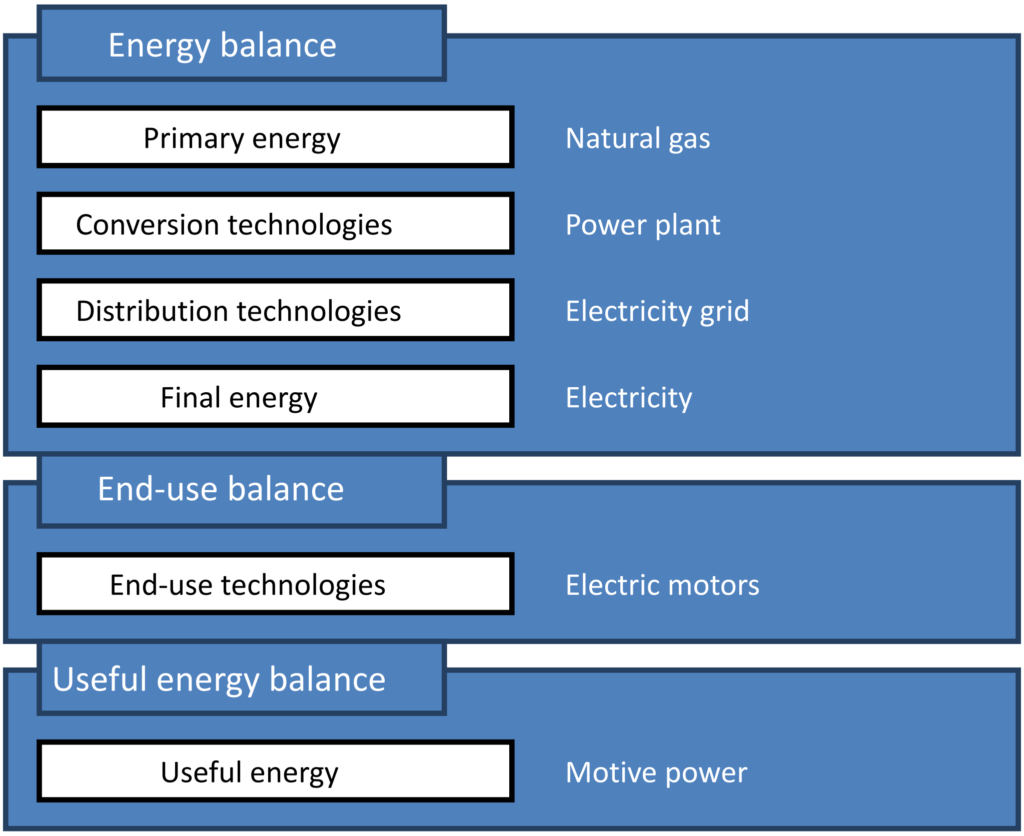
[2] Albania, the former Yugoslav Republic of Macedonia, Montenegro, Serbia and Turkey

rounding when aggregating data, but might be negligible due the relatively small percentage of deviation.

2.2 National energy balances

National energy balances (NEB), in a variety of detail, are available for most countries of the European Union. The structure given by the balances compiled by Eurostat provide the “most complete” NEB for comparison. The NEB should at least include primary energy by energy carrier, imports and exports, as well as final energy by energy carrier for each sector.

Figure 2: Hierarchy of balances



Source: Fraunhofer ISI

In order to obtain all information available on national energy balances, end-use balances and useful energy balances, National Statistical Offices and, if applicable, energy agencies were contacted (Table 1)

Table 1: Organisations contacted during the research process

Country	Organisation (NSO and/or Agency)	Website
Austria	Statistik Austria	www.statistik.at
	Austrian Energy Agency (AEA)	en.energyagency.at
Belgium	Direction générale Statistique et Information économique	statbel.fgov.be
	Energie Observatorium	www.economie.fgov.be
Bulgaria	National Statistical Institute (NSI)	www.nsi.bg
Croatia	Croatian Bureau of Statistics (DZS)	www.dzs.hr
	Energy Institute Hrvoje Požar	www.eihp.hr
Cyprus	Statistical Service of Cyprus (MOF)	www.mof.gov.cy
Czech Republic	Czech Statistical Office	www.czso.cz
	Ministry of Industry and Trade (MPO)	www.mpo.cz
Denmark	Danmarks Statistik	www.dst.dk
	Danish Energy Agency - Energistyrelsen (ENS)	www.ens.dk
Estonia	Statistics Estonia (ES)	www.stat.ee
Finland	Statistics Finland	www.stat.fi
France	Service de l'Observatoin et des Statistiques (SOeS)	www.statistiques.developpement-durable.gouv.fr
Germany	Statistisches Bundesamt	www.destatis.de
	Arbeitsgemeinschaft Energiebilanzen (AGEB)	www.ag-energiebilanzen.de
Greece	Hellenic Statistical Authority	www.statistics.gr
	Centre for Renewable Energy Sources and Saving (CRES)	www.cres.gr
Hungary	Hungarian Central Statistical Office (KSH)	www.ksh.hu
Ireland	Central Statistics Office Ireland	www.cso.ie
	Sustainable Energy Authority of ireland (SEAI)	www.seai.ie
Italy	Istituto Nazionale di Statistica	www.istat.it/en
	Ministero dello sviluppo economico	www.sviluppoeconomico.gov.it
Latvia	Central Statistical Berau of Latvia (CSB)	www.csb.gov.lv/en
Lithuania	Statistics Lithuania (LS)	www.stat.gov.lt
	Lietuvos Energetikos Institutas	www.lei.lt
Luxembourg	Institut national de la statistique et des études économiques du Grand-Duché du Luxembourg (STATEC)	www.statistiques.public.lu
Malta	National Statistics Office (NSO)	www.nso.gov.mt
Netherlands	Statistics Netherlands (CBS)	www.cbs.nl
	Energy research Centre of the Netherlands (ECN)	www.ecn.nl
Poland	Central Statistical Office of Poland (GUS)	www.stat.gov.pl
	Polish National Energy Conservation Agency (KAPE)	www.kape.gov.pl
Portugal	Direçao Geral de Energia e Geologia (DGEG)	www.dgeg.pt
Romania	Institutul National de Statistica (INSSE)	www.insse.ro
Slovakia	Ministry of Economy of the Slovak Republic (MHSR)	www.mhsr.sk
Slovenia	Statistical Office of the Republic of Slovenia	www.stat.si
Spain	Instituto para la Diversificacion y Ahorro de Energía (IDEA)	www.idae.es
Sweden	Statistiska centralbyrån (SCB)	www.scb.se
United Kingdom	Office for National Statistics (ONS)	www.ons.gov.uk
	Department of Energy & Climate Change (DECC)	www.gov.uk
Norway	Statistik Sentralbyra (Statistic Norway)	www.ssb.no
Iceland	Statistics Iceland	www.statice.is
	National Energy Authority (NEA)	www.nea.is
Switzerland	Swiss Federal Office of Energy (SFOE)	www.bfe.admin.ch

Source: Fraunhofer ISI

End-use balances (EUB) show final energy consumption for different applications in the industry, household and tertiary sectors. They includes heating, cooling, process heat (or cooking) and electrical appliances such as motors or domestic appliances. They are less commonly available than NEBs as there are more difficulties gathering the data needed by extensive studies and surveys (Table 2).

Following the adoption of the Commission Regulation (EU) No 431/2014, amending Regulation (EC) No 1099/2008 of the European Parliament and of the Council on energy statistics, as regards the implementation of annual statistics on energy consumption in households Member States will be required to report detailed statistics on the energy consumption in households by type of end-use.

Useful energy balances also include information regarding overall energy efficiency of a sector and its particular end-uses. In contrast to end-use balance, energy conversion efficiencies of the appliances specific to the end-use are considered in these balances and the portion of final energy which is actually available after final conversion to the consumer for the respective use is calculated. In final conversion, electricity becomes, for instance, light, motive energy or heat (see Figure 2).

Table 2: Availability of national data

Country	Energy balance[3]	End-use balance[4]				Useful energy balance
		Industry	Households	Tertiary /Services	Transport	
Belgium	X (+R)	-	-	-	-	-
Bulgaria	X (+R)	-	-	-	-	-
CzechRep.	X	-	-	-	-	-
Denmark	X (+R)	-	S A	-	M	-
Germany	X (+R)	S H A P_h	S H A P_h	S H A $P_{h/c}$	M	-
Estonia	X	-	-	-	-	-
Ireland	X (+R)	-	-	-	-	-
Greece	X	-	S H A P	-	-	-
Spain	X (+R)	-	S H A P	-	-	-
France	X (+R)	A P	S H P_h	S H P_h	-	-
Croatia	X	-	-	-	-	-
Italy	X	H	H	-	-	-
Cyprus	-	-	-	-	-	-
Latvia	X					
Lithuania	X (+R)	-	-	-	-	-
Luxembourg	X (+R_w)	-	-	-	-	-
Hungary	X	-	-	-	-	-
Malta	-	-	-	-	-	-
Netherlands	X (+R)	-	S H A P_h *	-	-	-
Austria	X (+R_w)	S H A P_h	S H A P_h	S A P	M	-
Poland	X (+R)	-	-	-	-	-
Portugal	X (+R)	-	S H P_h	-	-	-
Romania	X	-	-	-	-	-
Slovenia	X (+R)	-	S H A $P_{h/c}$	-	-	-
Slovakia	X	-	-	-	-	-
Finland	X (+R_w)	S	S H A P_h	S	-	S
Sweden	X (+R_w)	-	S H	-	-	-
United Kingdom	X (+R)	S A $P_{h/c}$	S H A P_h	S H A $P_{h/c}$	M	-
Iceland	X	-	-	-	-	-
Norway	X (+R)					
Switzerland	X	S H A $P_{h/c}$	S H A $P_{h/c}$	S H A $P_{h/c}$	M	-

Source: Fraunhofer ISI

3 Complete energy balance available (see appendix); +R: Additional balance for renewable energies; Wood consumption accounted explicitly (w)

4 End-use balance by fuel type available for space heating (S), hot water (H), appliances (A) and process heating/cooling ($P_{h/c}$), transport mode (M)

2.3 Additional data sources

The project ODYSSEE[5] aims to monitor energy efficiency trends in Europe and gathers indicators on energy efficiency, CO_2 emissions, detailed data on energy consumption, and activities and related CO_2 emissions (around 1000 data series by country) for all 28 Member States including Norway. The project partners, such as energy agencies or statistical organisations, provide detailed data on energy use and activity data which enable ODYSSEE to produce a database of energy efficiency indicators covering the major final energy sectors (see Table 3).

The database uses a variety of energy use per activity indicators to highlight differences in energy efficiency between countries and trends. These include, for example:

- Energy consumption per dwelling
- Energy consumption per unit of Gross Value Added
- Energy consumption per employee
- Energy consumption per kilometre travelled

To aid comparison, the ODYSSEE data include technical adjustments for key determinants of energy use in the different sectors (for example, adjustments for climate and structure of industry). Currently, energy efficiency data are available from the year 1990 to 2012. The ODYSSEE indicators are accessible under different data tools: the full database, the key indicators facility, and five specific data facilities that focus on specific issues. The access to the full database is restricted, whereas all other data tools are publicly available.

Table 3: Data collected by ODYSSEE

	Energy balance	End-use balance				Useful energy balance
		Industry	Households	Tertiary/Services	Transport	
ODYSSEE	X	-	S H A $P_{h/c}$	S H A $P_{h/c}$	M	-

Soruce: ODYSSEE MURE

5 http://www.odyssee-mure.eu/

2.4 Summary

National energy balances differ widely in their quality regarding depth of detail and length of comparable time series. They range from datasets which contain only a few energy carriers, such as electricity, to complete energy balances including additional balances for renewable energies. The lack of data on a national level can however be largely compensated for by energy statistics provided by Eurostat. However, the low availability of national end-use balances remains an issue. Most countries of the European Union do not provide these for the industry or tertiary sectors and they are hardly available at all for the transport sector. Nevertheless, from 2016 onwards, reporting end-use balances of the household sector will be mandatory under *Regulation (EU) No 431/2014.* The majority of member states already provide substantial information for this sector.

Table 4 shows different methodologies used for the preparation of end-use balances in several countries, such as empirical (surveys, in situ measuring etc.), the preparation through modelling or a mix of both.

Useful energy balances on the other hand are almost completely unavailable for all member states of the European Union (Table 2). However, the availability of such data would be necessary to allow a complete picture of the energy chain. By comparing final energy demand data with useful energy demand data, the related losses of the end uses or appliances are made visible.

While Eurostat provides highly disaggregated data on energy of an overall high quality, the so called *data completeness-rate* of the tables “complete energy balances” (nrg_110a) is in the range of 7.4%, considering a total of over three million data points[6]. This overall rate can be considered as relatively low, but frequent data gaps regarding product for example can be found for “Crude oil”[7] and “Natural gas liquids”[8].

Regarding countries, the main data gaps are for Malta and Cyprus. Thus there is still some potential for improving the coverage and quality of the data collections.

6 share of data not available, e.g. marked by “:”, April 2015

7 product code 3105

8 product code 3106

Table 4: Methodologies used for the preparation of end-use balances

Country	Industry	Households	Tertiary /Services
Denmark	-	Mix	-
Germany	Mix	Empirical	Empirical
Greece	-	Empirical	-
France	Empirical	Empirical	Empirical
Austria	Empirical	Mix	Empirical
Portugal	-	Empirical	-
Slovenia	-	Model	-
Finland	Mix	Empirical	Empirical
Sweden	-	Empirical	-
United Kingdom	Model	Model	Model
Switzerland	Model	Model	Model

Source: IEA (2014b); Fraunhofer ISI

3 Methodology to derive end-use energy balances

3.1 Applied approaches to derive useful and final energy balances

From a conceptual point of view, useful energy is defined as the energy required to provide a certain service (e.g. comfortable living areas, use of sanitary hot water, lighting, cooked food, product cooling, etc.). Useful energy appears in different forms, e.g. as heat, cold, air exchange, light, mechanical energy. In other words, as defined by Häfele (1977), "useful energy is the energy available to the consumers after the last conversion made in the consumer energy conversion equipment, hence final energy consumption minus conversion losses" (adopted from Pardo 2012).

In Eurostat (1978), a first attempt was undertaken to define useful energy demand balance sheets, using a similar terminology as described in this paper. Useful energy is thus calculated by multiplying final energy by the "efficiency of the final apparatus used by the final consumer" (Eurostat 1978)[9]. Although the useful energy balance has a certain importance to evaluate all energy losses within the energy chain, only limited information is available on overall useful energy balances within Europe (see also chapter 2).

Due to the fact that no actual data from Eurostat is available regarding useful energy balances, the below described methodology is used to calculate actual useful energy balances on European level.

Useful energy can be defined either directly in relation to the provided energy service, or indirectly in relation to final energy. The latter approach is adopted if, in practice, it is not possible or too complex to calculate useful energy based on the provided energy service, or if the necessary calculation parameters are not feasible.

The terms final energy and conversion efficiency are introduced to describe the concept of useful energy.

- Useful energy is provided by converting either fuel-based energy or the energy available and actively collected on-site, which is called final energy[10]. This conversion can be performed by different systems such as boilers, heat pumps, compression cooling systems or furnaces including the respective distribution, storage and delivery equipment (see Figure 3 for a simplified representation).
- The factor (ratio) between useful energy and final energy is defined as the **conversion and distribution efficiency**. For the sake of simplicity, we use the term '**conversion efficiency**' to cover conversion, distribution, storage and delivery losses.

Losses outside the conversion device or system – e.g. through the building envelope,

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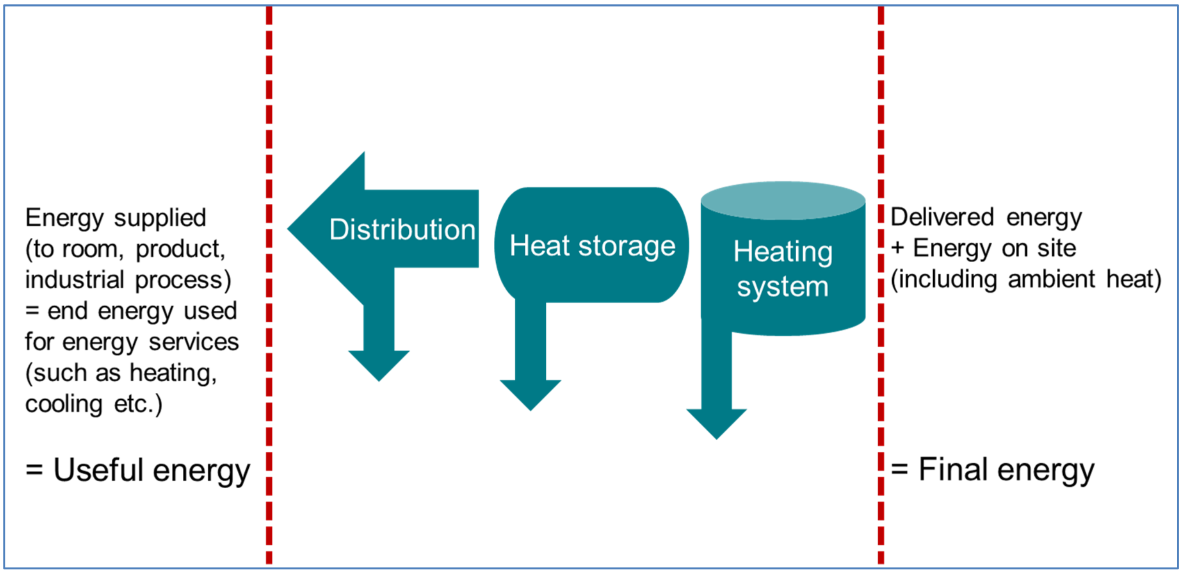
9 The useful energy balance in (Eurostat, 1978) is calculated based on approximately 30 appliances, for a various set of fuels, distinguishing between 3 sectors (industry, transport and households & equivalents). The useful energy balance is available for France and the former Federal Republic of Germany. Main differences between (Eurostat, 1978) and this paper exist regarding the sector aggregations, fuel types and efficiency levels.

10 Final energy as defined by Eurostat is the energy supplied to the final consumer.

or air exchange – and internal heat gains are usually not considered part of conversion efficiency, but as part of 'useful energy need'.

Figure 3: Relation between final energy and useful energy



Source: Fraunhofer ISI, TEP Energy

There are two different definitions of useful energy depending on the approach used:

1. **Definition based on final energy demand and conversion efficiency (FED approach):** in this case, useful energy is defined as the final energy multiplied by the conversion efficiency of the devices generating the useful energy (e.g. final energy consumption of a heating system multiplied by the conversion efficiency of the heating system).
2. **Definition based on energy service** (ESV approach): in this case, useful energy is defined at the level of services, such as the required indoor temperature, and boundary conditions, for instance, thermal heat losses and gains in the case of space heating.

In practice, the following challenges and limitations have to be taken into account when surveying and/or estimating useful energy demand:

1. FED approach: In the past, only commercially traded energy carriers were included in final energy demand statistics, which leads to an underestimation of useful energy demand. Energy collected on-site, such as solar thermal energy, is currently partly included in the official statistics. This gap will be closed by considering all the relevant final energy consumption in our estimation approaches, particularly within our models.
2. ESV approach: This approach requires the definition of a service level such as indoor temperature, ventilation rate, relative humidity etc. The generic service levels defined in norms and standards may not be met in practice. This leads to deviations between the expected useful energy (need) and the actual useful energy demand. For instance, in the case of fuel poverty, inadequate control or different comfort requirements may lead to different service levels with regard to the average indoor temperature. In these cases, calculations of useful energy may lead to different results in the two approaches mentioned above, particularly if only energy consumption is measured and the actual service level is not taken into account.

In practice, the simple concepts introduced in this section need to be differentiated and substantiated by the different constellations of energy services (space heating, process heating, space cooling, etc.) and technologies. Thus, different system boundaries and approaches are defined to substantiate the generic concepts, and described in following sections. Table 5 shows the approach taken in this study to estimate useful energy for different energy services depending on the definition and the data available.

Table 5: Summary of the approach used in this study for the different energy services

	FED Approach	ESV Approach
Space heating		All sectors
Space cooling	Household sector	Tertiary and industry sectors
Water heating	All sectors	
Process cooling	All sectors	
Oven (cooking)	All sectors	
Process heating	Most processes (cross-cutting)	Selected processes (e.g. clinker burning, blast furnace)

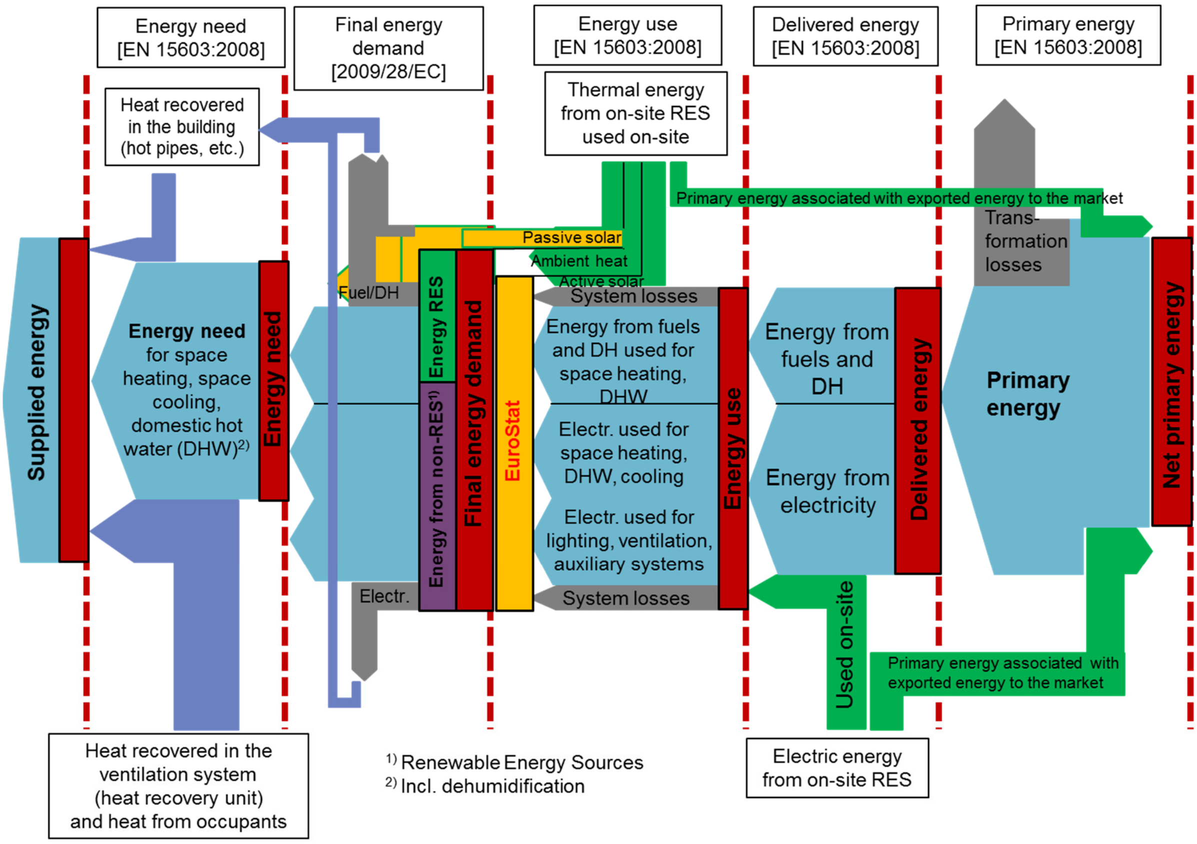
Source: Fraunhofer ISI; TEP Energy

3.2 Adopted energy balance framework

For the case of buildings, the definitions of useful and final energy as well as the conversion efficiencies of heating and cooling energy services are based on established EU norms and standards (DIN EN 15603:2013; ISO 13790:2008). Useful energy refers to "energy need" as depicted in Figure 4 – not to be confused with "energy use" or "supplied energy". In the case of space heating and hot water, this is the final energy including actively collected solar energy and ambient heat but excluding conversion and distribution losses. Passive solar energy collected through windows and the energy recovered and re-used, e.g. from heat recovery systems or internal heat loads, are not included.

In the following, the different energy services are described in more detail.

Figure 4 : System boundaries and energy flow definitions in the energy balances of buildings



Source: Adopted from Müller (2015)

3.3 Space heating

3.3.1 Useful energy demand for space heating

Referring to the second energy service approach introduced in section 3.1, the definition of useful energy in the case of space heating is based on the standard "*Energy performance of buildings – Calculation of energy use for space heating and cooling*" (ISO 13790:2008):

> *"3.4.1* ***Energy needs for heating or cooling*** *to be delivered to, or extracted from, a conditioned space to maintain the intended temperature conditions during a given period of time*
> *NOTE 1 The energy need is calculated and cannot easily be measured.*
> *NOTE 2 The calculated energy need can include additional heat transfer resulting from non-uniform temperature distribution and non-ideal temperature control by increasing (decreasing) the effective temperature for heating (cooling)."*

The standard describes various calculation methods (seasonal or monthly/ simple hourly / detailed simulation) and exact definitions. These detailed definitions are not adopted in this report, but the basic concepts are summarised as follows. Useful energy, i.e. the energy needed for heating, is basically the balance of losses and gains (see Figure 5):

Energy needed for heating ($Q_{H,nd}$) includes:

- Net ventilation heat losses (Q_{ve}). Note: Heat from ventilation losses which is re-covered in the ventilation system (heat recovery unit) ($Q_{V,sys,ls,rvd}$) is not included in this definition of useful energy
- Transmission heat losses(Q_{tr})
- Extra losses, because "actual time-averaged (mean) internal temperature can be higher, due to instantaneous overheating" (ΔQ_{tr+ve})

These losses are offset (either yearly, monthly or hourly) by solar and internal heat gains, which means that $Q_{H,nd}$ (energy needed for heating) does **not** include:

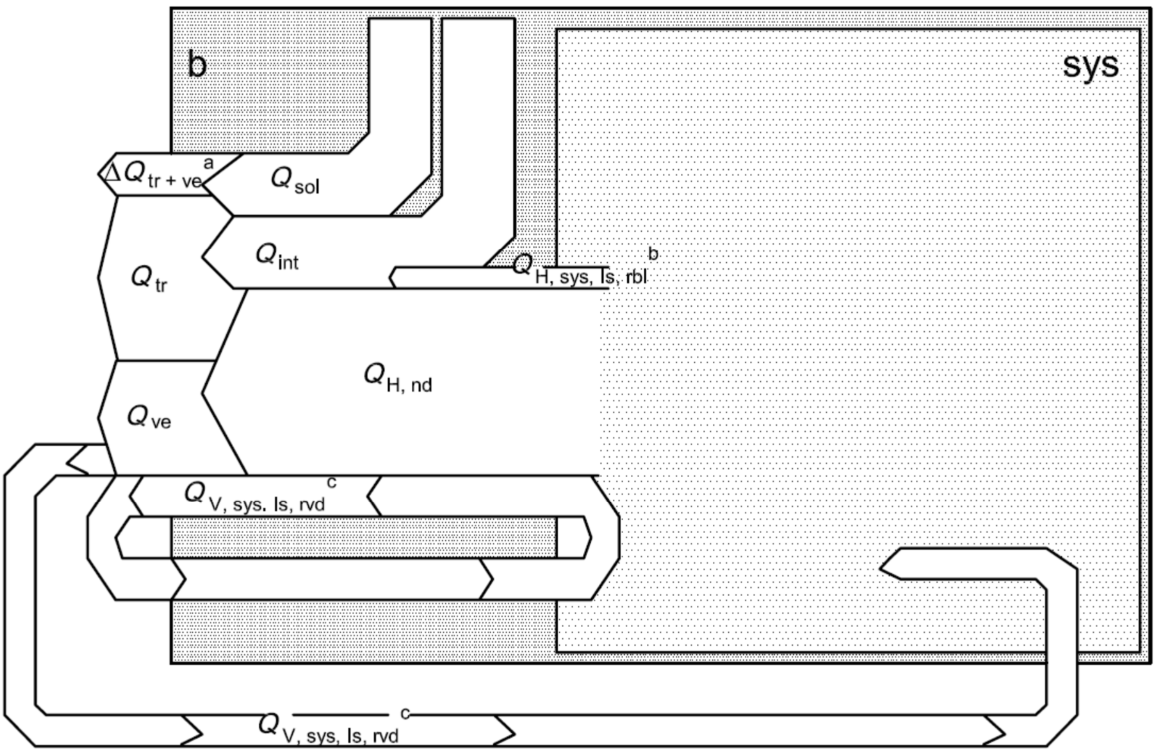
- Heat gains from solar heat (Q_{sol})
- Heat gains from internal heat (Q_{int})

For completeness, three additional types of heat transfer can be accounted for in buildings, but are irrelevant for the energy needed for heating ($Q_{H,nd}$):

- Heat recovered in the ventilation system from ventilation losses (heat re-covery unit) ($Q_{V,sys,ls,rvd}$).
- Heat recovered in the building from heating system losses (e.g. from hot pipes) ($Q_{H,sys,ls,rbl}$).
- Heat recovered in the system from building losses (e.g. heat recovered from building construction to ventilation system) ($Q_{H,sys,ls,rvd}$).

The calculation of space heating is restricted to **sensible** heat (without taking into account the latent heat in humidification (e.g. in ventilation systems)).

Figure 5: Energy balance for space heating in buildings.



Source: adapted from ISO 13790:2008(E)

3.3.2 Final energy demand for space heating

Regarding the definition of final energy demand and referring to Figure 6, we consider $E_{H,gas/oil/del}$, $E_{H,el,del}$ and $E_{H,ren,in}$:

- $E_{H,gas/oil/del}$: the "non-renewable" external energy that enters the heating system (in this case neither solar nor environmental heat. Note: biomass is included in external energy). Recovered energy is not considered in the final energy bal-ance.
- $E_{H,el,del}$: electricity that enters the heating system (e.g. for heat pumps).
- $E_{H,ren,in}$: the renewable energy (solar thermal and environmental heat) used by the heating system (net from losses).

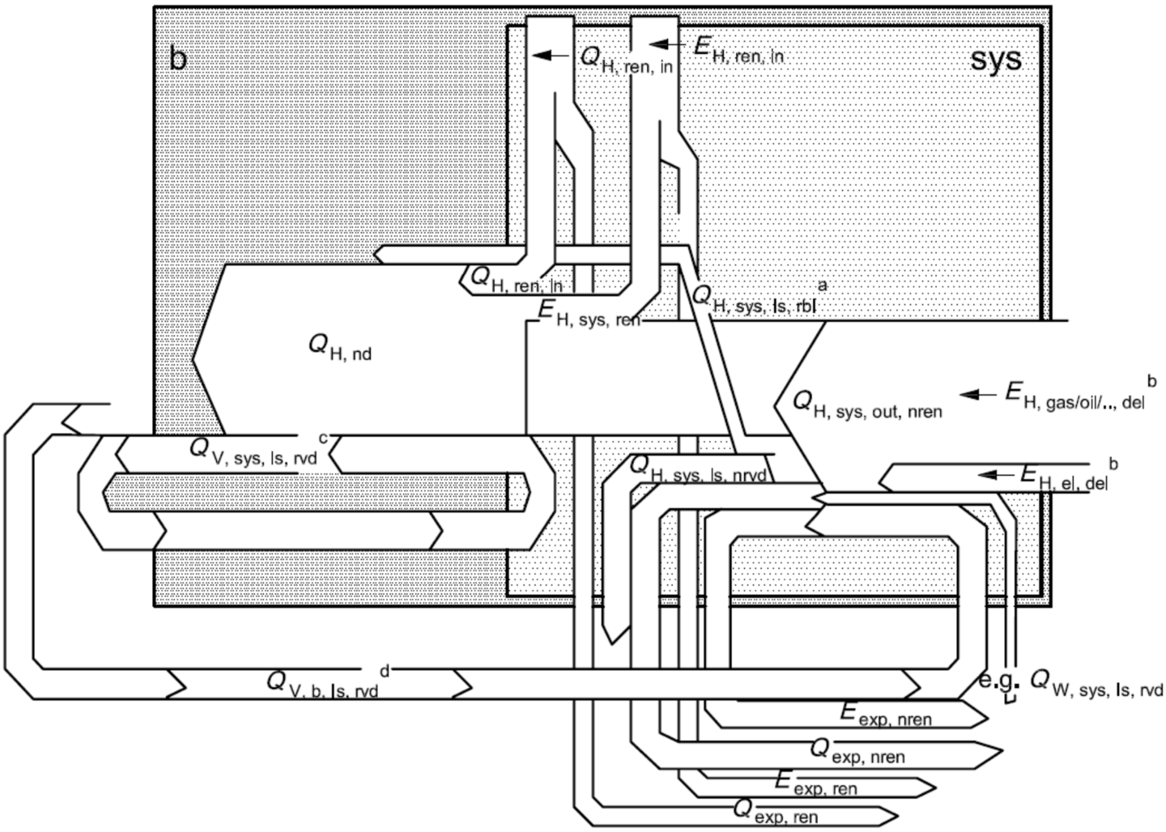
Renewable energy (solar thermal and environmental heat) is included as final energy in ISO 13790:2008(E) and in some national energy statistics (e.g. in Switzerland). It should be emphasised that environmental heat (e.g. the ambient heat extracted by air-to-air or air-to-water heat pumps) is not (yet) surveyed in Eurostat.

Only the solar energy used in a solar thermal heating system is considered when calculating final energy. The solar radiation that heats walls or enters a building through the windows is only considered in the building system (level of useful energy) as reducing the energy needed for heating.

Final energy is calculated using standard calorimetric data (lower heating value). Standard data only take direct heat into account, not the latent heat in gases, so condensing heating systems are able to extract more heat than is given in the definition of a conventional calorimeter.

The heating system is considered within the building boundaries, so that losses outside the building are not considered (e.g. heat losses in the distribution systems of district heating and local heating networks).

Figure 6: Energy balance of buildings with focus on system part, heating mode



Source: Adapted from ISO 13790:2008(E)

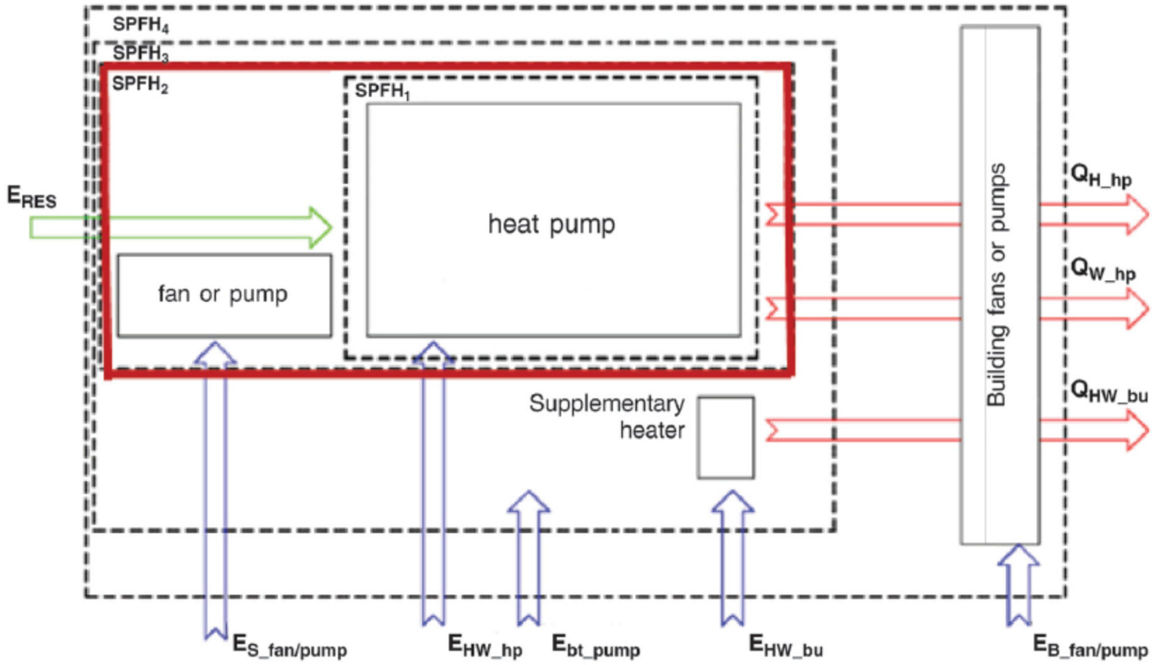
Heat pumps and ambient heat

Environmental heat is officially calculated in heat balances as the difference (see C (2013) 1082: "guidelines for Member States on calculating renewable energy from heat pumps") between the heat which leaves the heat pump and the electricity which enters the system (taking into account the heat produced by motors). See Figure 5 for a description, where:

- $E_{S\_fan/pump}$: Energy used for fan and/or pump that circulates the refrigerant;
- E_{HW_hp}: energy used to run the heat pump itself,
- E_{bp_pump}: the energy used to run the pumps that circulate the medium absorbing the ambient energy (when relevant)
- $E_{B\_fan/pump}$: the energy used for fan and/or pump that circulates the medium supplying the usable heat;
- Q_{H_hp} is the heat supplied by the heat source via the heat pump,
- Q_{W_hp} is the heat generated from mechanical energy used to drive the heat pump;
- E_{RES} is the renewable aerothermal, geothermal or hydrothermal energy (the heat source) captured by the heat pump (here defined as environmental heat). $E_{RES} = Q_{H\_hp} + Q_{W\_hp} – E_{S\_fan/pump} – E_{HW\_hp}$
- E_{HW_bu} and W_{HW_bu} are the energy and heat of the supplementary heater.

For heat pumps, the system boundaries are defined as SPFH2 (in red) in Figure 7. The electricity demand of fans or pumps (and the heat they produce) is included here, but not the supplementary heater and pumps to distribute heat in the building.

Figure 7: System boundaries for measuring the seasonal performance factor



Source: adapted from Official Journal of the European Union, 6.3.2013, L 62/31

3.3.3 Conversion efficiency space heating

Referring to the first of the two definitions of useful energy provided in section 3.1, efficiency is defined as the ratio between useful energy and final heating energy. Calculations are done separately for each heating system.

In the case of heat pumps, the coefficient of performance is defined as the ratio of electricity (or other high energy) input (including electricity for internal pumps, motors) to delivered heat (see CODE2 (2013) 1082: *"guidelines for Member States on calculating renewable energy from heat pumps"*). The additional energy is assumed to be environmental heat (geothermal, water, ambient heat from air etc.).

Note that final energy is usually calculated using standard calorimeter values (lower heating value). This implies that the calculated efficiency increases with technical improvements (particularly with condensation technology), and varies due to different composition of fuels.

3.4 Space Cooling

3.4.1 Useful energy for space cooling

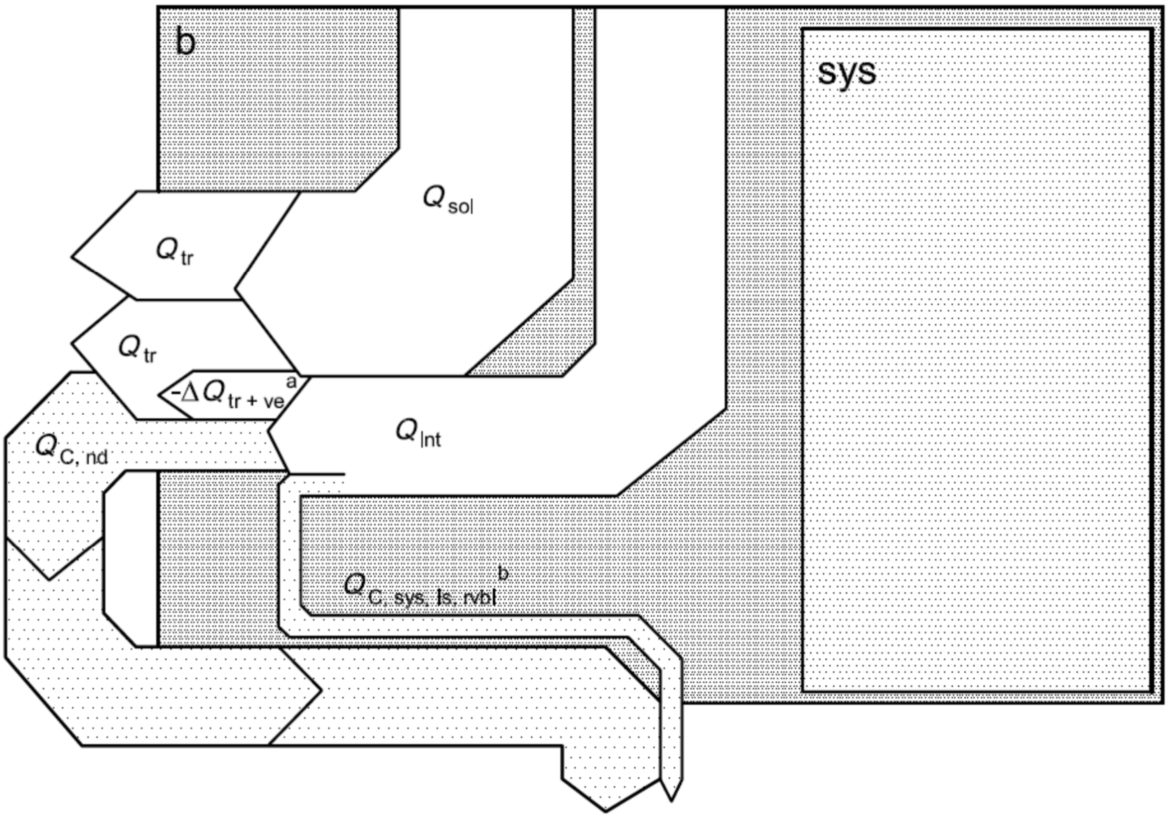
For space cooling, similar methods are used as for space heating. Similar to the heating case, only sensible cooling is taken into account when calculating "space cooling" demand. The energy need and energy consumption for dehumidification are considered in a separate section.

Again, in the case of space cooling, useful energy is defined according to two different approaches (as outlined in section 3.1): the first refers to final energy and the second "*per se*", i.e. in terms of energy balances based on well-defined boundary conditions.

In the second case, useful cooling energy is defined in a similar way to useful heating energy: The thermal cooling energy needed to maintain rooms in a defined comfort zone is taken into account. Solar heat gains, internally generated heat, and the heat from air exchange offset by losses due to transmission, radiation, ventilation and air exchange (e.g. free cooling during nights) are balanced by providing useful cooling energy ($Q_{C, nd}$, see Figure 8).

Similar to the heating case, internal "cooling gains" may also occur: cold that is "lost" from cold appliances, typically in supermarkets with open fridges and freezers. Hence, $Q_{C,sys,ls,rvbl}$ describes the *"cold recovered in the building, coming from the cooling system losses (e.g. from cold pipes)"*, and is not considered part of the cooling demand needed ($Q_{C,nd}$).

Figure 8: Energy balance of building part, cooling mode (blank arrows: usually warm part of energy supply, dotted arrow: cold part)



Source: adapted from ISO 13790:2008(E)

In a moderate climate zone such as the one covering most of Europe, useful energy depends heavily on the defined service levels, which, in turn, depend on conventional comfort concepts and building types. For instance, in the "adaptive comfort" concept, the required or allowed indoor temperature depends on the outdoor temperature because building users adjust their comfort perceptions and expectations to external conditions. Comfort zones are defined in EN 15251:2007: "Indoor environmental input parameters for design and assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting and acoustics". Note that comfort temperatures depend on humidity as well (and vice-versa).

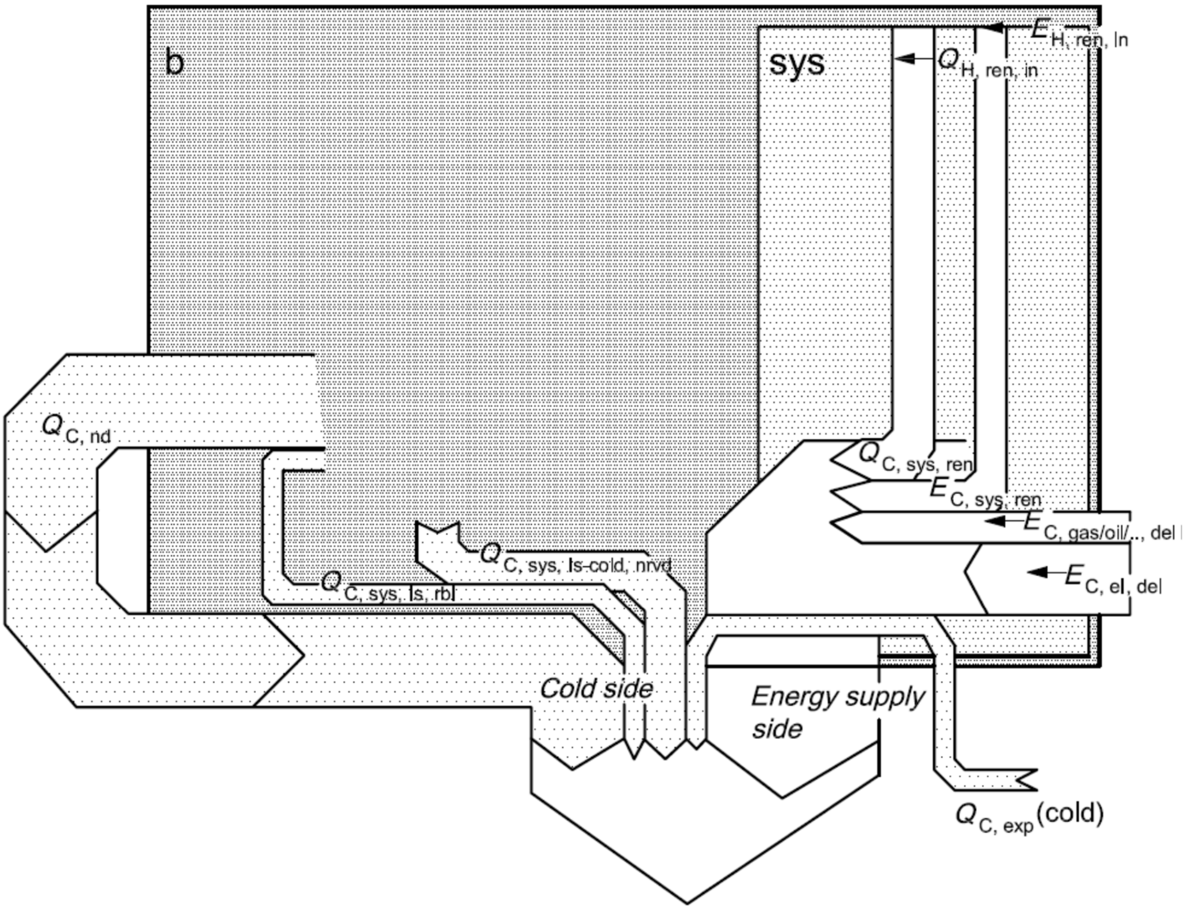
In practice, estimating the useful energy needed for space cooling is particularly difficult regardless of which definition in section 3.1 is applied. In the first case, the efficiencies of appliances and cooling systems is often unknown (and more important their penetration of the building stock) and, in the second case, it might be unclear which part of the useful energy needed is actually provided (serviced), as service levels need to be known alongside the penetration of cooling systems.

3.4.2 Final energy demand for space cooling

With regard to the definition of the final energy demand for space cooling (see Figure 9), the applied method is similar to the one used for space heating: Free cooling (e.g. through windows and ventilation openings) is not considered part of the final energy demand, neither is cooling energy from other appliances (cooling "gains" considered as cooling losses from other appliances). Thus, increasing free cooling would not reduce final energy consumption directly, but indirectly by reducing the amount of useful energy needed.

Environmental thermal or final energy from renewable sources (e.g. from solar thermal) that is used to generate cold or environmental cold (in terms of useful or final energy) and is extracted from the environment (e.g. through heat exchangers from air, ground or water) is considered part of the final energy consumption for space cooling.

Figure 9: Energy balance of buildings system part, cooling mode (blank arrows: usually warm part of energy supply; dotted arrow: cold part, cooling is extracted)



Source: adapted from ISO 13790:2008(E)

3.4.3 Conversion efficiency space cooling

Space cooling efficiency can also be derived from the ratio between useful and final energy, but efficiency is usually calculated within the system boundaries of the cooling device and expressed as an Energy Efficiency Ratio (EER). The EERs are then applied to specific buildings.

It is very important to calculate energy demand at least once a month, because efficiency is heavily affected by conditions such as relative load and temperatures.

EER is usually measured in 4 stages, simulating different outdoor temperatures (20, 25, 20 and 35 °C), and taking different boundary conditions into account according to the technologies used (e.g. water temperature) (*prEN14825*).

To be able to compare devices and specify efficiency labels, a reference seasonal EER is calculated (reference SEER). This is done by considering 35°C as the *full load capacity of the unit* and assuming an average European climate, given by the operating hours at different temperatures and interpolation of the above 4 reference temperature stages. For a specific building, the local climate is then used to determine the real SEER.

An additional correction is done (e.g. distinguishing $SEER_{on}$ from SEER) to consider stand-by and off-modes. This is consistent with the final energy definition: all (non-renewable) energies which enter the appliance should be taken into account.

3.5 Other energy services

3.5.1 Hot Water

In the case of hot water, useful energy is defined as the energy needed to heat water to the desired temperature level. For specific cases (e.g. residential buildings, hotels etc.), standard daily uses are defined (showing different usages of showers, hot water and dish-washing etc.) which describe the start time (storage losses), duration and required temperature.

Note that, in the case of hot water, useful energy demand may refer to the thermal energy "leaving" the heat generation or hot water storage system rather than the energy "arriving" at the user's tap (i.e. the boundary is close to the technical generation and storage system and further away from the user). In this study, the "tap" limit is used. This implies that useful energy for hot water depends not only on the type of user (residents, hotel guests etc.) **but also** on the type of building and the type of technical (distribution and storage) system; distribution and standing losses **are not** considered part of the useful energy.

For the definitions of final energy and efficiency, we refer to the space heating section. The heating units are the same (or similar) to the units used for space heating. Special care should be taken when considering combined space heating and hot water systems: the efficiency of hot water generation is usually lower during the summer season in these systems because the heating system load is (usually) much lower at this time and the system does not operate in an optimal range which implies low efficiency.

Details are specified in EN 15316-3-1:2007, *Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 3-1: Domestic hot water systems, characterisation of needs (tapping requirements)*.

3.5.2 Cooking

Oven energy efficiency = H1 / (H1 + H2 + H3), where:

H1 = heat supplied to food

H2 = heat supplied to interior of oven (internal air, racks, internal panels).

H3 = heat lost to exterior of furnace or oven.

Note: H2 becomes less important with increasing utilisation time (such as in commercial kitchens, where ovens can be on for over eight hours at a time).

"*Measurement of oven efficiency is relatively difficult as this will depend on how the oven is used whereas it is straightforward to measure the energy consumption for a comparison of all ovens on the EU market for EU oven energy labelling scheme.*"

Note: For conventional domestic ovens, the "wet brick test" is used to calculate the reference energy efficiency: a wet ceramic brick is used to simulate roasting a chicken removed from a refrigerator (i.e. this defines a reference H1). There do not seem to be any reference tests defined for commercial ovens.

3.5.3 Process heat

Two key characteristics distinguish the field of process heat from other demand sectors. First, this is a broad and very heterogeneous field covering many different heat uses and conversion technologies. Second, energy conversion mostly takes place in conversion chains rather than in individual conversion technologies. Both characteristics need to be considered to achieve a practical definition of useful energy for process heat.

In the following, several definitions of useful energy are listed and their suitability discussed for the main uses of process heat, steam generation and clinker and blast furnaces, before the selected method is presented in detail.

There are multiple ways to adapt the two main definitions of useful energy to the assessment of process heat. All have certain advantages and disadvantages.

1. Based on final energy:
    a. Average conversion efficiency by energy carrier – technologies are not explicitly considered (as used in Pardo et al. 2013).
    b. Average efficiency of technologies.
    c. Relation of specific (final) energy consumption (SEC) of average technology to SEC of best (not) available technology (BAT/BNAT).
2. Based on the energy service
    a. Based on the theoretical minimum for maintaining a chemical reaction and/or the thermodynamic minimum for the required change in the good heated/cooled.
    b. Based on an energy balance of the conversion unit, including heat losses and heat recuperation.
3. Some useful energy analyses are based on energy analyses (e.g. Cullen and Allwood 2010) taking into account the different qualities of individual energy carriers.

Table 6: Different definitions of useful energy for process heat

Method	Steam generation	Clinker burning	Blast furnace
1a	Easily operational; relation to technology is lost and thus might be less accurate	Not operational, because efficiency is not measured, instead specific energy consumption (SEC) is used e.g. GJ/t clinker/steel	
1b	Easily operational; useful heat to be defined in conversion chain (e.g. after steam generation, or after distribution network)		
1c	Operational, but useful energy then depends on technical progress and neglects that large amounts of energy are still lost despite BAT.		
2a	Only operational for steam boiler not for entire steam system, because the final product is unknown	Operational; assessment is required to be process/product specific. Disadvantage: “theoretical minimum” suggests lowest possible energy demand, but e.g. product shift could further reduce demand.	
2b	Operational, should be similar to 1b, as the output unit is tons of steam	Operational; assessment is required to be process/product specific, results should be similar to 1b	

Due to the above mentioned arguments, methods 1a, 1c and 2a are not suitable to calculate the useful energy demand for industrial processes. Methods 1b and 2b will be used. Both methods should result in a similar level of useful energy. The following calculation method will be used.

Following approach **2b**, the total energy demand of a **furnace** can be calculated as (ERA Technology Limited, Bio Intelligence Service 2012):

$H_f = H_c + H_s + H_g$, where:

- H_f = heat supplied by the fuel input to the furnace
- H_c = heat supplied to material being processed in furnace
- H_s = Heat lost by heating the furnace itself (insulation, structure, etc.). This becomes less important with longer utilization times
- H_g = heat lost in flue gases.

Therefore, the energy efficiency equals $\eta_f = H_c / (H_c + H_s + H_g)$

This approach includes the burner and potential heat recovery within the system boundaries of the furnace.

Accordingly, approach **2b** for **steam generation** is defined as follows (PWC et al. 2014):

$H_b = H_c + H_s + H_g + H_d$, where:

- Hb = heat supplied by the fuel input to the boiler
- H_c = heat received after passing the distribution network (water or steam)
- H_s = Heat lost by heating the boiler itself (insulation, structure, etc.). This becomes less important with longer utilization times
- H_g = heat lost in flue gases
- H_d = heat lost in distribution network

Therefore, the energy efficiency equals $\eta_b = H_c / (H_c + H_s + H_g + H_d)$

This approach includes the burner and potential heat recovery within the system boundaries of the boiler.

The approach **1b** defines useful energy (or conversion efficiency) for **steam generation and furnaces** as follows.

$U_b = H_b * \eta_b$

The efficiency η_b can be estimated or calculated based on approach 2b. It should include losses in the distribution network.

Process cooling

Process cooling is usually defined similar to useful energy in the case of buildings: (thermal) energy needed to compensate (unwanted) heat gains, because of transmission and air leakages. In an ideal case, the only energy needed is the energy to bring the product from its initial temperature down to the desired refrigerator/freezer temperature. In practice, however, this is the energy needed to cool down (or freeze) the product and to keep it cool (or frozen).

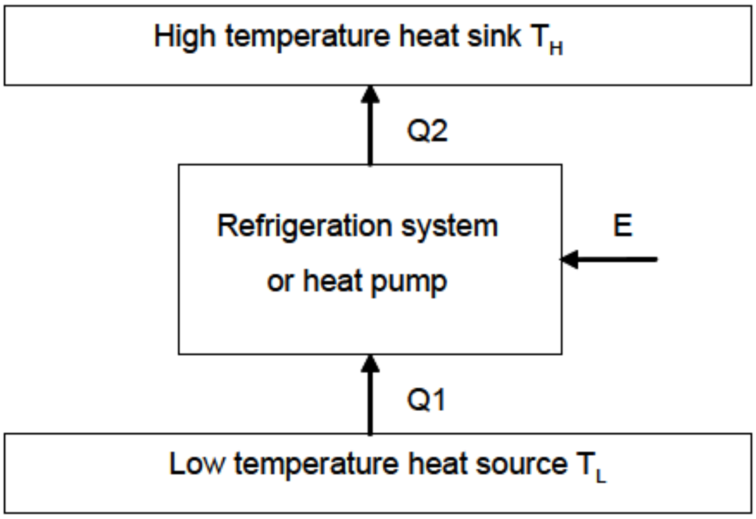
Note that walk-in cold rooms are considered building components (and not as appliance/machinery), so they were included in space cooling (with specific temperature requirements for the cold room's *thermal zone*).

The efficiency of the refrigeration system is expressed by the coefficient of performance (COP), which is the ratio of the refrigeration effect (heat extracted) to the energy input required (see Figure 10):

COP = Q1 / E

It should be noted that, under this definition, the energy-efficiency potentials on the side of useful energy are not visible. This means that factors influencing the useful energy balance are not considered in this equation (e.g. freezers with/without doors in the retail sector, heat losses outside the motors, etc.).

Figure 10: Energy input and heat fluxes in the case of a cooling or freezing device or system (simplified representation)



Note: cooling losses in the unit and in the cooling pipe (e.g. in case of remote refrigerated display cabinets) are included in Q1.

3.6 Definition of energy carriers

In this study, we distinguish 13 individual energy carriers as shown in Table 7. These comprise the main fossil as well as the main renewable energy sources. Some particularities have to be considered. For instance biomass includes all forms of biomass not only solid biomass.

In certain cases it is necessary to deviate from this definition, e.g. for the illustration of primary energy where wind, hydro and nuclear play an important role or for the detailed illustration of individual technologies in WP2, where more detail is of interest (e.g. heat pumps distinguishing air and ground source) or where data availability does not allow the breakdown from Table 7.

Table 7: Overview of energy carriers used in this study

ID	Name_EC	Comment
1	Electricity	
2	Fuel oil	
3	Coal	
4	Natural gas	
5	Other fossil	
6	Waste non-RES	
7	Biomass	including all forms of biomass (liquid, solid and gaseous)

ID	Name_EC	Comment
8	District heating	
9	Solar energy	including solar thermal and PV-heat
10	Ambient heat	including ground and air sources
11	Geothermal	only "deep" geothermal; no HP
12	Waste RES	
13	Other RES	

A detailed definition of the individual energy carriers used with respect to the Eurostat energy balances is provided in Table 8. Each energy carrier used is calculated as an aggregate of one or more energy carriers from Eurostat. The Eurostat energy carriers listed are a selection that on the one side allows a complete aggregation (equals the sum of all products) and on the other side a detailed allocation to the energy carriers used in this study. In annex 8.2 a complete overview of the energy carriers as provided by Eurostat on the various levels of aggregation is provided.

Table 8: Definition of energy carriers used related to the Eurostat energy balances

Product code Eurostat	Name Eurostat	Aggregation used
0000	All products	Total
2112	Patent Fuels	Coal
2115	Anthracite	Coal
2116	Coking Coal	Coal
2117	Other Bituminous Coal	Coal
2118	Sub-bituminous Coal	Coal
2121	Coke Oven Coke	Coal
2122	Gas Coke	Coal
2130	Coal Tar	Fuel oil
2410	Oil shale and oil sands	Fuel oil
2200	Lignite and Derivatives	Coal
3105	Crude oil (without NGL)	Fuel oil
3106	Natural gas liquids (NGL)	Other fossil
3220	LPG	Other fossil
3214	Refinery gas	Other fossil
3215	Ethane	Other fossil
3234	Gasoline (without bio components)	Fuel oil
3235	Aviation gasoline	Fuel oil
3236	Car Spirit	Fuel oil
3237	Premium leaded gasoline	Fuel oil
3238	Premium unleaded gasoline, 95 Ron	Fuel oil
3244	Other kerosene	Fuel oil
3246	Gasoline type jet fuel	Fuel oil
3247	Kerosene type jet fuel (without bio components)	Fuel oil
3250	Naphtha	Fuel oil
3260	Gas/diesel oil (without bio components)	Fuel oil
3270A	Total fuel oil	Fuel oil
3281	White Spirit and SBP	Other fossil

Product code Eurostat	Name Eurostat	Aggregation used
3282	Lubricants	Other fossil
3283	Bitumen	Other fossil
3285	Petroleum coke	Other fossil
3286	Paraffin Waxes	Other fossil
3295	Other Oil Products	Other fossil
4100	Natural Gas	Natural gas
4210	Coke Oven Gas	Other fossil
4220	Blast Furnace Gas	Other fossil
4230	Gas Works Gas	Other fossil
4240	Other recovered gases	Other fossil
5200	Derived Heat	District heating
5532	Solar thermal	Solar energy
5541	Solid biofuels (excluding charcoal)	Biomass
5542	Biogas	Biomass
55431	Municipal waste (renewable)	Waste RES
5544	Charcoal	Biomass
5546	Biogasoline	Biomass
5547	Biodiesels	Biomass
5548	Other liquid biofuels	Biomass
5549	Bio jet kerosene	Biomass
5550	Geothermal Energy	Geothermal
6000	Electrical energy	Electricity
7200	Waste (non-renewable)	Waste non-RES

4 Sector specific data processing

4.1 Industry

4.1.1 Approach

The industrial energy use balance, as it is defined in this study, has five dimensions:

- Country
- Subsector
- Energy carrier
- End-use
- Temperature level

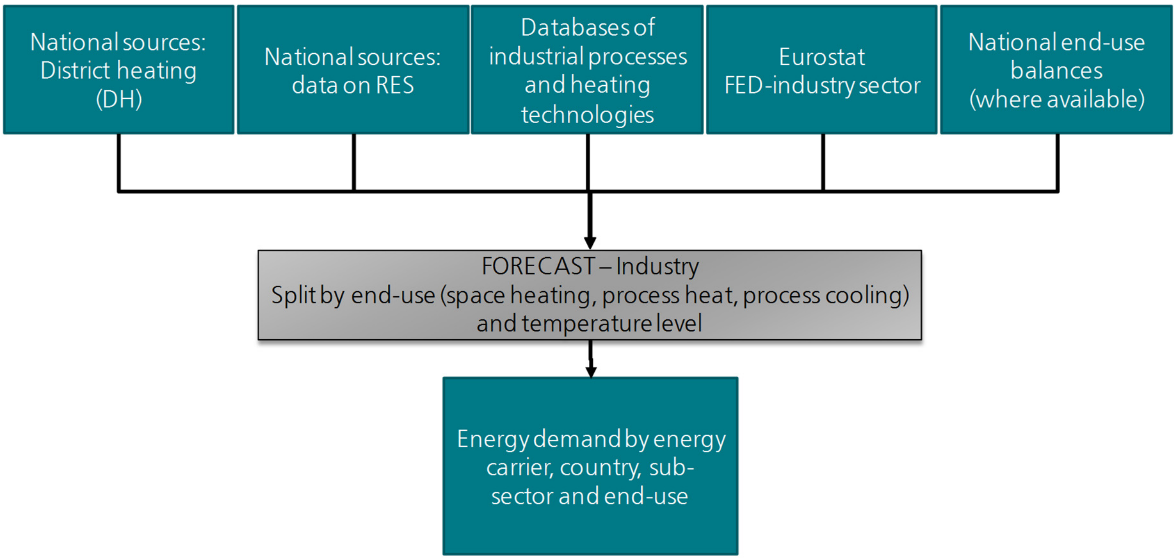
While the first three dimensions are covered by energy balances provided by Eurostat (except for Iceland and Switzerland), the latter either have to be derived from national (end-use) balances (that are not necessarily in line with Eurostat) or by using the bottom-up energy demand model FORECAST-Industry. This chapter presents the methodology used; it describes how we have constructed end-use energy balances based on the final energy balances provided by Eurostat.

For the industrial sector there is only a little information on end-uses from national energy balances, as discussed in section 2. Thus, the use of the FORECAST-Industry model is the central piece in our methodology. We use it to disaggregate the industrial energy demand as stated by Eurostat to provide additional information on end-use and temperature level, supported by information from national statistics.

The main data sources and the general data flow are shown in Figure 11. All data used is processed via the FORECAST-Industry model in order to assure a consistent quantity structure incorporating all input variables. Feeding all data into the model to generate the full picture on H/C in industry can be regarded as an additional quality check, given that all the individual values are required to match each other.

The input data comprises assessments of national data sources on district heating (DC) and RES use, but also industry-specific databases containing activity data (e.g. industrial production and floor area), and technical information for main industrial processes and space H/C. Theoretically, national end-use balances are also considered, however section 2.2 indicates there is little information available. The main input for the model is the Eurostat final energy balance. This is the anchor of the calculations, against which all results are calibrated.

Figure 11: Overview of the data compilation to derive end-use energy balances for the industrial sector



Source: Fraunhofer ISI

In the following, we present more detail of how FORECAST-Industry derives end-use balances from the data listed above. To do this, we use three major categories of data:

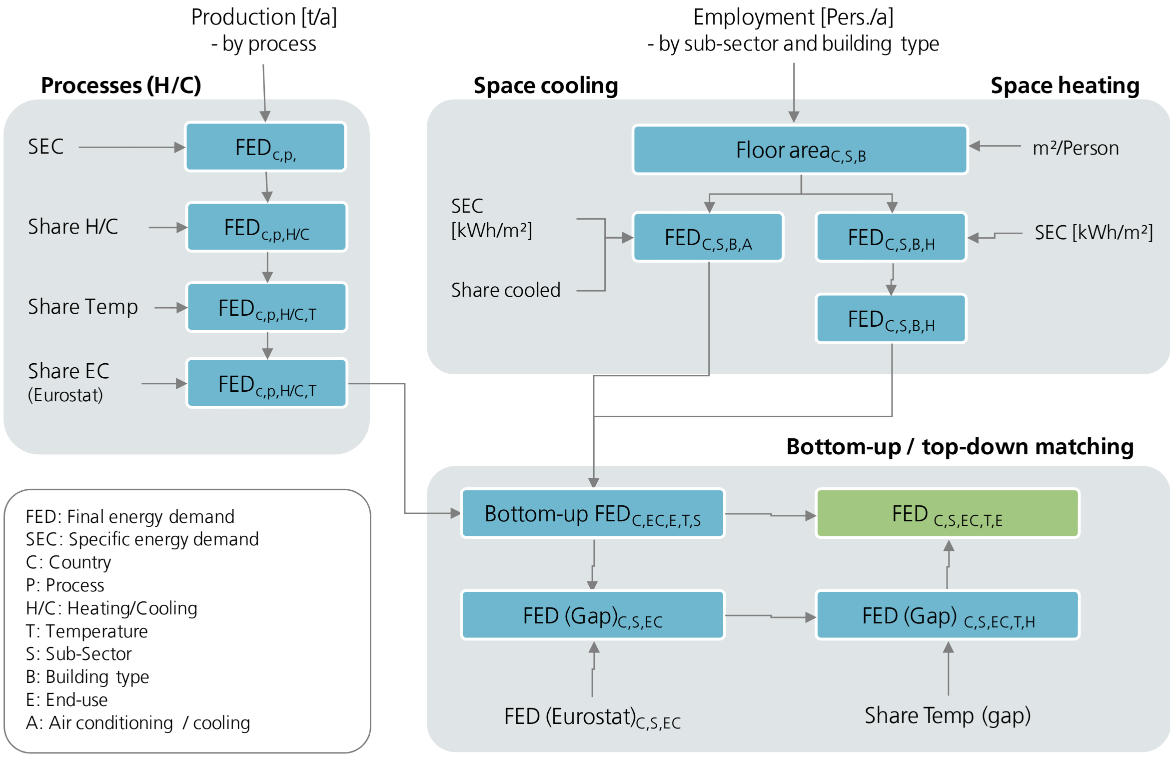
1. Activity data (industrial production by process and floor area)
2. Assumptions about specific energy demand of processes and technologies (SEC)
3. Further knowledge about individual processes (applied energy carriers, temperature level etc.)

The process flow of the model is shown in Figure 12. The model consists of two main bottom-up calculation schemes:

1. The energy demand of individual energy-intensive processes (e.g. clinker production)
2. The energy demand for space heating and cooling

Both of these are based on a demand driver (production and employment) and use a set of technical input variables. The bottom-up calculation, by definition, does not cover the complete energy demand, because a number of smaller processes are not significant enough to be separately modelled. Consequently, the results of the bottom-up calculations are compared with the statistical demand and the gap filled with additional assumptions to arrive at the calibrated final energy demand, broken down by end-use. The three elements of the calculation process are described below.

Figure 12: Schematic representation of end-use balance model calculation for the industry sector (FORECAST-Industry)



Source: Fraunhofer ISI

Bottom-up calculation 1: Energy demand for H/C in individual processes

The goal of this bottom-up calculation is to calculate energy demand for process heating and cooling in energy-intensive industries differentiated by temperature. The calculation is conducted for individual energy-intensive processes.

The selection and definition of a “process” depends on various factors including the amount of energy consumed (relevance), the data availability, and the level of homogeneity (whether the process can be described by average values). Consequently, the definition and system boundaries of individual processes do slightly differ. While a process sometimes describes an individual “process step” (e.g. burning of clinker), it also often describes an entire production line to the final product (e.g. paper).

Table 9: Overview of processes/products covered in FORECAST-Industry for bottom-up calculation by sub-sector

Non-metallic minerals	**Chemicals**		**Non-ferrous metals**
Container glass	Adipic acid		Aluminium, primary
Flat glass	Ammonia		Aluminium, secondary
Fibre glass	Calcium carbide		Aluminium extruding
Other glass	Carbon black		Aluminium foundries
Houseware, sanitary ware	Chlorine, diaphragma		Aluminium rolling
Technical, other ceramics	Chlorine, membrane		Copper, primary
Tiles, plates, refractories	Chlorine, mercury		Copper, secondary
Clinker Calcination-Dry	Ethylene		Copper further treatment
Clinker Calcination-Semidry	Methanol		Zinc, primary
Clinker Calcination-Wet	Nitric acid		Zinc, secondary
Preparation of limestone	Oxygen		
Gypsum	Polycarbonates		
Cement grinding	Polyethylene		
Lime milling	Polypropylene		
Bricks	Polysulfones		
Lime burning	Soda ash		
	TDI		
	Titanium dioxide		
Iron and steel	**Food drink and tobacco**	**Pulp and paper**	**Others**
Sinter	Sugar	Paper	Plastics: Extrusion
Blast furnace	Dairy	Chemical pulp	Plastics: Injection moulding
Electric arc furnace	Brewing	Mechanical pulp	Plastics: Blow moulding
Rolled steel	Meat processing	Recovered fibres	
Coke oven	Bread & bakery		
Smelting reduction	Starch		
Direct reduction			

Source: Fraunhofer ISI

The following methodology is used for each of the processes considered.

The energy demand of a process (ED) is calculated as the specific energy consumption (SEC) of one process multiplied by the total annual production (IP) of the same process. Distinction by heating/cooling and temperature level is made through the multiplication by the share of heating/cooling in the SEC (ShareH/C) as well as the share of each temperature level in the SEC (ShareTEMP):

$$ED_{p,t,c,ec} = IP_{t,p,c} * SEC_{t,p,c} * ShareEC_{t,p,ec,c} * ShareH / C_{p} * ShareTEMP_{p,ec} \quad (1)$$

Where t = year, p = process, ec = energy carrier, c = country

Consequently, for each process, the following data is required:

- Annual production [t/a]
- Specific energy fuel/electricity consumption ($SEC_{f/e}$) [GJ/t]
- Share of energy carriers (derived from Eurostat energy balance by sub-sector)
- Share of heating/cooling in SEC
- Share of temperature level in heating/cooling (see Table 10 for the definition of temperature levels)

These shares, as well as the SEC by process, do not vary between the individual countries. However, the industrial structure does vary, and this is fed into the model via the production in tonnes. Thus, we gain individual end-use and temperature differentiated energy balances for the processes in scope.

Table 10: Definition of temperature levels for process cooling and process heating

End-use	Temperature level	Comment
Process cooling	< - 30°C	Mostly air separation in chemical industry
	- 30-0 °C	Mostly refrigeration in food industry
	0-15 °C	Mostly cooling in food industry
Process heating	<100°C	Low temperature heat (hot water) used in food industry and others
	100-200 °C	Steam, of which much is in paper, food and chemical industry
	200-500 °C	Steam used mostly in chemical industry
	>500 °C	Industrial furnaces in steel, cement, glass and other industries

Bottom-up calculation 2: space heating and cooling

The main driver of the space heating and cooling demand is the floor area of industrial buildings, including production and office buildings. Energy demand is included as specific energy consumption (SEC) per m² floor area.

We also use the SEC per m² cooled area for the cooling demand. The cooled area is calculated by assuming a country-specific share of the total floor area.

Matching bottom-up calculation to total final energy demand

The total of the bottom-up calculation of process H/C demand and space H/C demand on a sub-sector level does not exactly match with the Eurostat energy balances. For most sub-sectors and countries a *gap* is expected. This *gap* varies substantially between sub-sectors and countries depending on the coverage of the processes considered in the bottom-up calculation and the industrial structure of the country. Sectors such as iron and steel, pulp and paper or non-metallic minerals are typically well covered (small gap). Other sectors, such as the chemical industry, the food and tobacco industry or the other industries are less completely covered due to a high number of minor processes (larger gap).

In order to close the *gap* between the bottom-up calculation and energy balances, a top-down estimate is used. We assume that fuels (final energy minus electricity) are completely used for heating in industry (cooling and mechanical energy make up only marginal proportions < 1%). Accordingly, the gap in fuels can fully be allocated to process heat. Then it is only the allocation to temperature levels which has to be added to the process heat demand from the *gap*. This is done by exogenously assuming temperature shares for each sub-sector (see Table 15).

4.1.2 Data used

In the following the data used is described for each of the calculation steps described above.

Bottom-up calculation 1: Energy demand for H/C in individual processes

Annual industrial production by process and country in terms of, for example, tons of clinker produced, is a central activity input used to calculate the total use of process heating and cooling. As there is no single database that provides such figures for all European countries, various data sources were used. An overview of the main sources is provided in Table 11 including an estimate of the data completeness and quality.

Table 11: Overview of sources used for production data for all countries and major processes

Sub-sector / process	Data source	Completeness/quality of data
Iron and steel	World Steel Association	Very complete
Cement	Cembureau, Odyssee	Cement very complete, but clinker less robust
Glass	Glassglobal	Complete, but calculated based on capacity and utilisation by country
Pulp and paper	German Pulp and Paper Association (VDP), FAO Stat	Paper very complete, pulp products less complete
Aluminium and copper	US Geological survey	Complete for primary and secondary aluminium, less so for further treatment
Chemicals: Ammonia	UNFCCC	Complete, but some uncertainty
Chemicals: Ethylene	UNFCCC	Complete, but some uncertainty
Chemicals: Oxygen	Eurostat	Complete, but some uncertainty and data for some small countries missing
Chemicals: Methanol	UNFCCC	Many gaps
Chemicals: Polyethylene	UN Commodity Production Database	Some uncertainty
Food, drink and tobacco	Mainly UN Commodity Production Database, UN Data, German brewery association	Several gaps

Different by-products at different purities are obtained, including argon, neon and helium. Different demands for argon indicate changes in SEC but information on shares of argon and oxygen at member state level are not easily obtained. Oxygen and nitrogen are gases that are also used in industries such as steel or glass production.

In Europe the production of oxygen decreased by 23% from 2008 to 2012 i.e. from 42 to 32 million tons. Production in France, Germany and Italy has particularly fallen (EUROSTAT, PRODCOM, UN Database).

Specific energy fuel/electricity consumption by process was collected from literature sources for each of the processes. As for the energy-intensive processes relatively similar technologies are used across countries, only a little variation is expected in international comparison. This justifies the simplification of using similar SEC values for all countries under consideration (data uncertainty is in most cases higher than the expected differences across countries). The SEC used is provided in Table 12.

Table 12: SEC and share of fuels/electricity used for heating/cooling by process

Subsector	Process	Specific energy consumption [GJ/t]		Share for heating (1=100%)		Share for cooling (1=100%)	
		Fuels	Electricity	Fuels	Electricity	Fuels	Electricity
Iron and steel	Sinter	2.2	0.1	1.00	-	-	-
	Blast furnace	11.6	0.6	1.00	-	-	-
	Electric arc furnace	1.0	2.3	1.00	0.95	-	-
	Rolled steel	2.4	0.6	1.00	0.10	-	-
	Coke oven	3.2	0.1	1.00	-	-	-
	Smelting reduction	15.0	0.4	1.00	-	-	-
	Direct reduction	15.0	0.4	1.00	-	-	-
Non-ferrous metals	Aluminum, primary	5.2	53.6	1.00	0.05	-	-
	Aluminum, secondary	9.0	1.7	1.00	0.30	-	-
	Aluminum extruding	4.2	4.8	1.00	0.30	-	-
	Aluminum foundries	7.2	5.6	1.00	0.30	-	-
	Aluminium rolling	3.3	2.2	1.00	0.30	-	-
	Copper, primary	8.0	2.8	1.00	0.20	-	-
	Copper, secondary	4.0	2.3	1.00	0.10	-	-
	Copper further treatment	2.0	3.8	1.00	0.15	-	-
	Zinc, primary	1.0	15.9	1.00	0.01	-	-
	Zinc, secondary	1.0	0.6	1.00	0.01	-	-
Pulp and paper	Paper	5.5	1.9	1.00	0.01	-	0.01
	Chemical pulp	12.7	2.3	1.00	0.01	-	-
	Mechanical pulp	(2.0)	7.9	1.00	0.01	-	-
	Recovered fibers	0.5	0.9	1.00	0.01	-	-
Glass	Container glass	5.8	1.4	1.00	0.04	-	0.06
	Flat glass			1.00	-		0.06

Subsector	Process	Specific energy consumption [GJ/t]		Share for heating (1=100%)		Share for cooling (1=100%)	
		Fuels	Electricity	Fuels	Electricity	Fuels	Electricity
		10.9	3.3			-	
	Fiber glass	4.9	1.8	1.00	0.20	-	0.06
	Other glass	11.5	5.1	1.00	0.17	-	0.06
Ceramics	Houseware, sanitary ware	24.2	4.8	1.00	0.01	-	0.06
	Technical, other ceramics	12.1	3.2	1.00	0.01	-	0.06
	Tiles, plates, refractories	5.5	0.9	1.00	0.01	-	0.06
Cement	Clinker Calcination-Dry	3.5	0.1	1.00	-	-	-
	Clinker Calcination-Semidry	4.0	0.2	1.00	-	-	-
	Clinker Calcination-Wet	5.5	0.2	1.00	-	-	-
	Preparation of limestone	-	0.1	1.00	-	-	-
	Gypsum	1.0	0.2	1.00	-	-	-
	Cement grinding	-	0.2	1.00	-	-	-
	Lime milling	-	0.2	1.00	-	-	-
	Bricks	1.4	0.2	1.00	-	-	-
	Lime burning	3.7	0.1	1.00	-	-	-
Chemicals	Adipic acid	26.9	1.4	1.00	-	-	0.06
	Ammonia	11.3	0.5	1.00	-	-	0.06
	Calcium carbide	6.1	8.3	1.00	0.95	-	0.02
	Carbon black	64.8	1.8	1.00	-	-	0.06
	Chlorine, diaphragma	-	10.7	1.00	-	-	0.05
	Chlorine, membrane	1.9	10.0	1.00	-	-	0.05
	Chlorine, mercury	-	12.8	1.00	-	-	0.04
	Ethylene	35.9	-	1.00	-	-	-
	Methanol	15.0	0.5	1.00	-	-	0.04

Subsector	Process	Specific energy consumption [GJ/t]		Share for heating (1=100%)		Share for cooling (1=100%)	
		Fuels	Electricity	Fuels	Electricity	Fuels	Electricity
	Nitric acid	(0.1)	0.0	1.00	-	-	0.01
	Oxygen	-	1.0	1.00	-	-	0.96
	Poly carbonate	12.9	2.7	1.00	-	-	0.02
	Poly ethylene	0.6	2.0	1.00	-	-	0.02
	Poly propylene	0.8	1.1	1.00	-	-	0.04
	Poly sulfones	24.5	3.1	1.00	-	-	0.04
	Soda ash	11.3	0.3	1.00	-	-	-
	TDI	26.7	2.8	1.00	0.05	-	0.02
	Titanium dioxide	34.2	3.3	1.00	-	-	0.01
Food	Sugar	4.5	0.7	1.00	-	-	0.42
	Dairy	1.6	0.5	1.00	0.05	-	0.57
	Brewing	1.0	0.4	1.00	0.05	-	0.41
	Meat processing	2.0	1.5	1.00	0.05	-	0.61
	Bread & bakery	2.4	1.4	1.00	0.45	-	0.44
	Starch	3.1	1.4	1.00	0.10	-	0.11
Plastics	Extrusion	1.6	3.0	1.00	0.20	-	0.07
	Injection moulding	3.9	7.3	1.00	0.20	-	0.03
	Blow moulding	2.9	5.3	1.00	0.20	-	0.04

Source: Fraunhofer ISI: FORECAST-Industry model

The **share of heating/cooling** in the specific energy consumption (SEC) for each process is not expected to vary between countries because the technical process design is similar and the technologies used are traded internationally. The assumptions are shown in Table 12 together with the SEC. Note that the "share"-column indicates the proportion of the energy carrier group (fuel and electricity) that is used to supply heat/ cooling. For instance 100% of fuel and 45% of electricity used in the process "bread & bakery" supply heat.

The **share for each temperature level** in the SEC is also expected to remain constant across countries. An overview of the assumptions is provided in Table 13. For most countries, the bottom-up data in Table 12 and Table 13 explains more than 80% of total process heating and cooling demand.

Table 13: Temperature level of H/C demand as share of total H/C demand by process

Subsector	Process	Cooling [1=100%]			Heating [1=100%]			
		<-30°C	-30-0°C	0-15°C	<100°C	100-200°C	200-500°C	>500°C
Iron and steel	Sinter	-	-	-	0.00	-	0.20	0.80
	Blast furnace	-	-	-	0.01	0.01	0.01	0.97
	Electric arc furnace	-	-	-	0.01	0.00	0.00	0.99
	Rolled steel	-	-	-	0.00	-	-	1.00
	Coke oven	-	-	-	0.00	-	-	1.00
	Smelting reduction	-	-	-	0.00	-	-	1.00
	Direct reduction	-	-	-	0.00	-	0.20	0.80
Non-ferrous metals	Aluminum, primary	-	-	-	0.00	-	-	1.00
	Aluminum, secondary	-	-	-	0.28	-	0.30	0.42
	Aluminum extruding	-	-	-	0.00	-	1.00	-
	Aluminum foundries	-	-	-	0.00	-	-	1.00
	Aluminium rolling	-	-	-	0.00	-	1.00	-
	Copper, primary	-	-	-	0.00	-	-	1.00
	Copper, secondary	-	-	-	0.00	-	-	1.00
	Copper further treatment	-	-	-	0.00	-	1.00	-
	Zinc, primary	-	-	-	0.00	-	-	1.00
	Zinc, secondary	-	-	-	0.00	-	1.00	-
Pulp and paper	Paper	-	-	1.00	0.05	0.88	0.05	0.02
	Chemical pulp	-	-	-	0.00	1.00	-	-
	Mechanical pulp	-	-	-	1.00	-	-	-

Subsector	Process	Cooling [1=100%]			Heating [1=100%]			
		<-30°C	-30-0°C	0-15°C	<100°C	100-200°C	200-500°C	>500°C
	Recovered fibers	-	-	-	0.00	1.00	-	-
Glass	Container glass	-	-	1.00	0.02	0.19	0.19	0.60
	Flat glass	-	-	1.00	0.02	0.21	0.43	0.34
	Fiber glass	-	-	1.00	0.02	0.19	0.19	0.60
	Other glass	-	-	1.00	0.02	0.22	0.22	0.54
Ceramics	Houseware, sanitary ware	-	-	1.00	0.30	-	-	0.70
	Technical, other ceramics	-	-	1.00	0.30	0.15	0.15	0.40
	Tiles, plates, refractories	-	-	1.00	0.07	0.11	0.07	0.75
Cement	Clinker Calcination-Dry	-	-	-	0.00	-	0.10	0.90
	Clinker Calcination-Semidry	-	-	-	0.00	-	0.10	0.90
	Clinker Calcination-Wet	-	-	-	0.00	-	0.10	0.90
	Preperation of limestone	-	-	-	1.00	-	-	-
	Gypsum	-	-	-	0.00	0.50	0.30	0.20
	Cement grinding	-	-	-	1.00	-	-	-
	Lime milling	-	-	-	1.00	-	-	-
	Bricks	-	-	-	0.20	-	-	0.80
	Lime burning	-	-	-	0.00	-	-	1.00
Chemicals	Adipic acid	0.20	0.30	0.50	0.00	0.50	0.25	0.25
	Ammonia	0.20	0.30	0.50	0.00	-	-	1.00
	Calcium carbide	0.20	0.30	0.50	0.00	-	-	1.00
	Carbon black	0.20	0.30	0.50	0.00	-	-	1.00
	Chlorine, diaphragma	0.20	0.40	0.40	-	-	-	-
	Chlorine, membrane	0.20	0.40	0.40	0.00	1.00	-	-
	Chlorine, mercury	0.20	0.40	0.40	0.00	-	-	1.00

Subsector	Process	Cooling [1=100%]			Heating [1=100%]			
		<-30°C	-30-0°C	0-15°C	<100°C	100-200°C	200-500°C	>500°C
	Ethylene	0.15	0.50	0.35	0.00	-	-	1.00
	Methanol	-	0.40	0.60	0.00	-	-	1.00
	Nitric acid	0.20	0.30	0.50	-	-	-	-
	Oxygen	0.80	0.10	0.10	-	-	-	-
	Poly carbonate	-	0.40	0.60	0.00	1.00	-	-
	Poly ethylene	-	0.40	0.60	0.00	1.00	-	-
	Poly propylene	0.05	0.40	0.55	0.00	1.00	-	-
	Poly sulfones	-	0.40	0.60	0.00	1.00	-	-
	Soda ash	0.05	0.45	0.50	0.30	0.40	-	0.30
	TDI	-	0.30	0.70	0.00	1.00	-	-
	Titanium dioxide	-	0.40	0.60	0.00	0.30	0.23	0.47
Food	Sugar	-	0.20	0.80	0.10	0.60	-	0.30
	Dairy	-	0.30	0.70	0.90	0.10	-	-
	Brewing	-	0.35	0.65	0.55	0.45	-	-
	Meat processing	-	0.30	0.70	0.40	0.60	-	-
	Bread & bakery	-	0.10	0.90	0.20	0.33	0.47	-
	Starch	-	0.20	0.80	1.00	-	-	-
Plastics	Extrusion	-	-	1.00	0.20	0.50	0.30	-
	Injection moulding	-	-	1.00	0.20	0.50	0.30	-
	Blow moulding	-	-	1.00	0.20	0.50	0.30	-

Source: Fraunhofer ISI: FORECAST-Industry model

A major challenge of the approach is that for most countries there is no data on the total floor area in industrial buildings. We calculate the total floor area by country and sub-sector based on employment statistics from Eurostat and typical values for the specific floor area in m² per employee. Employment statistics distinguish between blue and white collar workers so based on this information we can allocate the building floor area to either production buildings or office buildings. These two types of buildings have fundamentally different needs in terms of space heating and cooling.

The resulting assumptions on the total floor area by country and by building type are provided in Table 14. For the model calculations, the floor area is further split by individual sub-sector.

It is principally a Eurostat publication (Eurostat 2007) available, which provides detailed data on energy demand in space heating by energy carrier for the industrial sector. However, a closer look at this data raises doubts about data quality. For example several countries have the same energy carrier shares (e.g. Spain, Greece, Italy, Portugal and France), and the shares for individual energy carriers for other countries are implausible (e.g. in the Czech Republic all solid fuels are used for space heating). Furthermore, the data is published in 2006 and probably provides information for 2004. Information about the quality of the data or its method of derivation is not provided by Eurostat (2007). Given these doubts over quality, we are not using this table for a detailed break-down of individual energy carriers. However, since we lack better data, we use the total proportion of space heating in final energy demand as provided by Eurostat, but allocate it to individual energy carriers based on model calculations. For countries where more precise values are available from national end-use energy balances, we use the country specific data rather than that of Eurostat (e.g. Austria, Germany, Switzerland and the United Kingdom).

The SEC for cooling and ventilation, and the share of the floor area cooled and ventilated, is aligned with the Tertiary-sector assumptions for public offices. Other more specific data sources are not available for industry. Only two countries provide information on space cooling and ventilation for industry: Germany and Switzerland. Germany reports about 5 TWh for space cooling in 2012 in industry. We estimate that this value is an overestimation, as it is based on the assumption that 33% of floor area is ventilated and/or cooled. For Switzerland 0.3 TWh are reported. Also here, our estimation is lower.

All figures in Table 14 are assumptions. There is hardly any statistical information available for buildings in the industrial sector. Accordingly, due to substantial uncertainty in these assumptions, the results have to be interpreted with caution. However, at the moment, these are the best figures available.

Table 14: Assumptions of floor area in industrial buildings, SEC and share floor area cooled and ventilated by country

Country	Floor area [Million m²] [1]		$SEC_{electricity}$ cooling and ventilation [kWh/m²]	Share floor area cooled and ventilated	SEC heating [kWh/m²]
	production	office			
Austria	41	25	21	8%	218
Belgium	33	23	11	9%	214
Bulgaria	14	9	29	13%	208
Croatia	7	4	29	6%	168
Cyprus	0	0	55	23%	188
Czech Republic	37	21	20	12%	231
Denmark	7	5	6	8%	240
Estonia	2	1	29	5%	282
Finland	67	39	5	18%	175
France	107	73	32	14%	201
Germany	178	107	18	8%	225

Country	Floor area [Million m²] [1]		$SEC_{electricity}$ cooling and ventilation [kWh/m²]	Share floor area cooled and ventilated	SEC heating [kWh/m²]
	production	office			
Greece	21	14	43	23%	115
Hungary	11	7	23	9%	217
Iceland²	13	11	5	15%	52
Ireland	10	7	6	11%	210
Italy	154	90	62	16%	161
Latvia	3	2	23	5%	248
Lithuania	4	3	23	5%	251
Luxembourg	3	2	23	18%	132
Malta	0	0	42	13%	149
Netherlands	48	33	9	9%	204
Norway	9	6	5	15%	221
Poland	20	13	23	5%	256
Portugal	28	17	43	14%	141
Romania	32	20	10	13%	228
Slovakia²	55	30	16	15%	89
Slovenia	4	3	26	13%	198
Spain	110	73	74	18%	152
Sweden	21	12	5	16%	206
Switzerland	8	5	20	9%	143
United Kingdom	114	73	10	11%	230

[1] We assume that the entire floor area is heated, while only a proportion of it is cooled and ventilated
Source: own calculation

Matching bottom-up and final demand

The temperature shares used to allocate the "gap" between bottom-up calculation and energy balances to temperature levels is shown in Table 15. The shares are applied by first calculating the remaining energy demand after subtracting the bottom-up estimation from statistical energy demand for each sub-sector and energy carrier. For all countries the same shares are taken, which clearly is a strong simplification, but not better data is available. Note, however, that the major share of process heat demand (for most countries > 80%) is calculated based on the bottom-up assumptions specified per process in Table 12 and Table 13.

Table 15: Temperature shares by sub-sector for gap calculations

Sub-sector	<100°C	<200°C	<500°C	>500°C
Chemical industry	5%	15%	5%	75%
Engineering and other metal	36%	48%	16%	0%
Food, drink and tobacco	65%	23%	8%	5%
Iron and steel	1%	3%	1%	95%
Non-ferrous metals	13%	24%	8%	55%
Non-metallic mineral products	9%	16%	5%	69%
Other non-classified	8%	69%	23%	0%
Paper and printing	8%	66%	22%	4%

Source: own calculation

Process cooling

The area of process cooling in the industrial and tertiary sectors of the European Union comprises cooling applications for industrial purposes (see Figure 13 below). These include cooling of processes in the chemical industry, the production of plastics, the production of food and its handling and other industrial processes. Further applications include cooling for meat production, bakeries or hotels, server cooling and supermarket cooling. There is a strong interaction of the cool supply (food industry) in which the cool supply chain is used along production, storage, transport, trade until reaching final consumers. The useful cooling energy is determined with the help of Coefficient of Performance (COP) and seasonal energy efficiency ratio (SEER) factors but contains a lot of uncertainty due to the real operating conditions of the cooling units.

Figure 13: Different process cooling applications across industry and tertiary sectors

Trade			Trade				Trade, Service Provider	"Leisure", Trade, Industry
Industry						Supermarket		
Production, Storage, Transport, Sale	Transport	Production	Storage	Production, Storage	Storage, Sale	Storage, Sale	Production, Storage	Miscellaneous
Agriculture Forestry Stock farming Poultry Eggs Corn Wine Fruit, Vegetables Meat Market Seet Seedling	Ship Train Truck Airplane Container Ice Production	Foodstuffs, Drinks and Tobacco Slaughterhouse Factory Ships Ice Products Frozen Food Convenience Foods Ice Cream Brewery Dairy Farming Mineral Water Bakery Products Chemistry Petrochemistry Pharmacy Tool Design Plastic Automotive Cement Electronics	Refrigerated Warehouses Container Refrigerated Ships Ice Boxes ...	Baker Butcher Pastry Cook ...	Baker Butcher Pastry Cook Florist Restaurants Hotels Factory Canteen Fish-Car Ice Production	Supermarket Department Store Hypermarkt Beverage Store ...	Restaurant Hotel Factory Canteen Fastfood ...	Scating Ring Bob Run ... Swimming Pools
						Special Sector Cryogenic Engineering Cryogenic Medicine Cryobiology Production Technical Gas		Laboratory Wind Tunnels Test Rooms
						Dry Ice Production Gas Liquefaction		

Source: IREES 2014

To illustrate the complexity of the data collection for each process, the example of process cooling demand for oxygen production is briefly discussed below.

There is a high diversity of cooling processes in the different branches of industry and the tertiary sector. For example, in the chemical industry, the case of air fractioning for the production of different gases, including oxygen, is rather energy intensive at low temperature. In this case the main driver for cooling demand is the production of oxygen at member state level (see Table 16).

Table 16: Annual production of Oxygen by country for 2008 and 2012 [t/a]

Country	2008	2012
Austria	1,201	1,177
Belgium	3,706	2,815
Cyprus		
Czech Republic	1,201	1,768
Denmark		
Estonia	14	8
Finland	1,583	1,330
France	5,004	500
Germany	10,303	8,689
Greece	133	106
Hungary	194	215
Ireland		
Italy	8,549	5,737
Latvia		
Lithuania	3	2
Luxembourg		
Malta		
Netherlands	4,026	4,026
Poland	2,498	2,379
Portugal	99	170
Slovakia	836	791
Slovenia		
Spain	1,696	2,008
Sweden		
United Kingdom		
Romania	771	596
Bulgaria	532	500
Norway	44	53
Switzerland		
Croatia	112	33
Iceland	1,201	1,177

Source: PRODCOM, UNProduction Statistics, EUROSTAT, Chemical Associations figures

The specific energy intensity for process cooling for this particular process has been discussed with experts and it is assumed that this industrial process is equivalent in all

EU countries which use similar oxygen production and air fractioning technologies.

Currently, most oxygen is produced in large cryogenic air fractioning plants in Europe, despite the fact that adsorptive and membrane applications have also been developed for air separation (Marscheider-Weidemann, 2008). The air is refrigerated at very low temperatures and purification follows after a distillation step. Oxygen, nitrogen and argon are produced for use as commercial commodities, primarily by the cryogenic fractionation of air.

In order to describe and analyse process cooling in industry (and the services sector), a combination of approaches was used for accessing or estimating relevant data:

1. As the area of process cooling is not represented in Eurostat Statistics, direct contact was made with relevant associations in Europe and at member state level together with cooling experts in some countries (Germany, Switzerland, the UK, Austria, Belgium), with the objective of collecting public and non-publically available data. A formal data request including a template of desired information was sent to over 25 different institutions. The response rate was reasonable (over 50%) however the requested data was, in almost all cases, nonexistent. The cooling process relies on very individual solutions for different types of clients and aggregated information has not been collected. An exception was found in some member states where studies on energy use and demand for process and space cooling had been conducted at sector level. Only stationary cooling units are analysed, while transport cooling applications are not included in this analysis. The data gap for this application is very high.
2. Detailed desk research and analysis of specific cooling studies for Germany, Switzerland and the UK was undertaken. On several occasions direct contact was pursued with the authors of these studies (cooling experts) as well as producers of particular chemicals (gases) with considerably high demand for cooling. The focus was on technological assumptions, allocated energy for process cooling, specific energy consumptions and analysis per branch, etc.
3. Specific studies related to the cooling market were acquired. Not many studies were found on the process cooling topic in the EU, but they were available for certain countries (e.g. Germany, Switzerland) complemented by expert interviews (see references). The commercially available studies rely on modelling for their results (Arnemann, 2015, VDMA 2012, Dengler, et. al.,2011, Jarn 2014, DECC, 2015, Dumortier, R., etl al., 2012, Heinrich, 2014, Reitze, F., 2012).
4. Companies dealing with cooling technologies offer different services for industry and tertiary users. These include the supply of components (e.g. heat exchangers), and appliances, as well as cooling plants and even complex industrial cooling plants. The spectrum of services includes planning, build up, manufacture, and installation including bringing up to service and dismantling of cool supplies in industry and service sectors. This means that individual solutions are developed for the particular cooling demands of their processes. It includes cooling applications in medical technologies, laser technology for the production of machines, server cooling, special cooling uses in creameries and breweries, cooling boards for retail or for industry such as chemical processes, plastics production and pharmaceuticals. Particularly energy intensive areas include cooling systems for air liquefaction or fractioning. The complexity of these solutions highlights the significance of the lack of data communicated to statistical agencies with respect to this useful energy.

Data gaps, in the case of process cooling are substantial. In order to produce analyses for the different EU member states we need to rely on modelling and assumptions for different industrial processes.

- The challenge in this approach has been to combine detailed production figures at country level with more aggregated knowledge of industrial processes and their demand for process cooling. This result is likely to be more homogeneous for the process and across the countries. It is very likely that processes in branches such as the food industry or chemical production do not differ much in their characteristics and use of the cooling process across Europe.
- The data availability at country level is rather poor, very difficult to access or non-existent. The quality of assumptions at the process level is good but has a high level of uncertainty due to the fact that the useful energy for process cooling varies considerably with the temperature of the process or the characteristics and adjustment levels of the cooling unit (regular maintenance, adjusted temperature level, and opening frequencies of doors of cooling rooms). These user and technology relevant aspects are broadly captured in the assumptions. This means that there is a high uncertainty of energy use for process cooling, with an uncertainty of over ±25%.

4.1.3 Quality of results

The quality of the results depends both on the input data as well as on the methodology used. Thus, before discussing the results, we start by discussing the quality of the input data.

An overview of the quality of the input data is given in Table 17. Accordingly, the coverage is complete in all input datasets. The activity drivers (production and employment) are the best quality indicators, because they are (mainly) provided by official statistics. Other technical data are not available in official statistics, and have not been broadly surveyed. However, particularly for the individual processes, input data such as the SEC, can be estimated with high certainty, because the technical features of the individual processes do not vary substantially between countries and plants. Thus, using individual case studies can still result in substantial robustness. Input data for space heating and cooling is more uncertain. Much less is known in this regard about the industrial sector than, for example, buildings in the tertiary or residential sectors. Accordingly, input data is rather uncertain, particularly for space cooling

Table 17: Estimation of input data quality for the industrial sector

	Input data set	Coverage	Empirical basis	Consistency	Robustness
Process H/C	Production				
	SEC				
	Share H/C				
	Share temperature level				
Space heating	Employment				
	Floor area per employee				
	SEC heating				
Space cooling	SEC cooling				
	Share cooled floor area				
Other	Share temperature for "gap"				

low
medium
good

The most interesting quality indicator is the **robustness** of the results. The robustness (high robustness is defined as low uncertainty) of the results can be discussed alongside the dimensions used: energy carriers, sub-sectors, countries and end-uses. As the Eurostat balances already provide final energy distinguished by energy carrier, sub-sector and country, we will only discuss the robustness with regard to the distinction of end-uses for these three categories and the total.

The structure of energy demand in the **sub-sectors** varies substantially, as does the robustness of results and importance of end-uses. In the energy-intensive sub-sectors such as iron and steel, non-metallic minerals, non-ferrous metals or pulp and paper that produce relatively few homogenous products, the large and relatively precise proportion of bottom-up calculation has a positive effect on robustness. In the chemicals and food sub-sectors, the share of bottom-up calculation is medium as is the robustness of the end-use results. The remaining sub-sectors comprise the light industries machinery and others. Although the proportion of bottom-up calculation for these sub-sectors is very low, some results are still very robust. For example the share of temperature levels is robust, as these industries do not use high-temperature heat.

The use of individual **energy carriers** is very different across the end-uses. **Coal** is mainly used in process heating (>100°C) and can be relatively accurately estimated. The use of **natural gas and oil** is more evenly spread across end-uses such as space heating and process heating, which makes the allocation to individual end-uses more uncertain. The allocation of **electricity** to end-uses is a special case, because it is used in all end-uses. While electricity is less used for heating, cooling is nearly exclusively provided from electricity, because compression cooling represents nearly the complete market. Also, the share used for space heating is largely unknown (besides a few exceptions like the United Kingdom), and, its use in high temperature process heat can be estimated relatively precisely (e.g. use in electric arc furnaces). **District heating** can technically only be used for low-temperature heat, which restricts the possible uses. Technically, it can be applied to cooling, however, the market share is still marginal – especially in the industry sector. **Biomass and renewable waste** are the only RES that can be used for high temperature process heating as seen, for example, in the cement industry. The RES for the provision of low temperature heat, such as **geothermal and solar energy but also ambient heat via heat pumps,** currently have very low market shares in industry and are not available in most statistics for the industrial sector (also not in Eurostat). Thus, the data availability is not good, but it can be said with high certainty that the share is extremely low in the industrial sector for all countries.

Robustness does not vary significantly across the **countries.** We only used country specific values in a few cases, (e.g. space heating in the United Kingdom, Germany, Switzerland and Austria). Assumptions are expected to be more robust for these countries.

The **total FED** per end-use can be regarded as relatively robust. This is especially valid for the process heating and cooling demand by temperature level (+/- 10%), because input data such as SEC and production are relatively precise. The demand for space heating and space cooling is more uncertain (+/- 30%), as hardly any empirical information is available for the input data such as m^2 floor area and the specific energy demand even in country specific sources.

Table 18: Overview of robustness of results for the industry sector

Energy carrier	Space heating	Process heating (<100°C)	Process heating (>100°C)	Space cooling	Process cooling
Coal					
Fuel oil					
Natural gas					
Other fossil fuels					
Electricity					
District heating					
Waste non-RES					
Waste RES					
Biomass					
Geothermal					
Solar energy					
Ambient heat					
Total					

Sub-sector	Space heating	Process heating (<100°C)	Process heating (>100°C)	Space cooling	Process cooling
Iron and Steel					
Chemical and Petrochemical					
Non-ferrous metals					
Non-metallic minerals					
Paper, Pulp and Printing					
Food, Beverages and Tabacco					
Machinery and transport					
Other Industry					
Total					

high uncertainty
medium uncertainty
low uncertainty
Combination not relevant

Finally, the main advantages of our model-based approach have to be underlined. The criteria of **completeness, coherence and comparability,** used by the Eurostat approach (European Commission 2014) to assess the quality of national energy balances, illustrate the strengths of our approach very well.

First, the model calculations fill a complete dataset without leaving empty cells. Second, the comparability and coherence across countries, sub-sectors, energy carriers and end-uses is very high, because the same methodology has been used for all countries. This is not the case when, for example, comparing national energy balances.

In order to improve the robustness of the results, the most important measure is to improve the empirical foundation of the model input data. In the following suggestions for **future research** are made that would substantially improve the robustness of the calculated end-use balance in industry.

1. Conducting a broad survey on non-residential space heating and space cooling demand to improve the knowledge base on specific energy consumption and floor area of different building types.
2. Taking measurements of the energy demand by end-use from individual companies to validate model results.

4.2 Tertiary sector

4.2.1 Approach

The model FORECAST Tertiary (see also Jakob et al (2012)) is used to fill data gaps within the services sector. The model is a coherent bottom-up model which allows for simulating the energy demand of the tertiary sector of the EU27+3 up to 2050 by country, by 8 sub-sectors, and by 14 end-uses including heating and cooling end-uses such as space heating, water heating, cooking as well as ventilation, space cooling and refrigeration. To close energy balances also remaining end-uses such as lighting, ICT in offices and data centres with servers and others are covered.

Energy demand of the tertiary sector includes building-related energy use of these sub-sectors and other energy use such as street lighting, ventilation of tunnels, public transport infrastructure and others. An exception is the sub-sector "Traffic and data transmission," where the transportation energy for trains, subways, trams etc. is – as it is usual in energy economic analysis – not accounted for in the tertiary sector.

The model adopts a bottom-up methodology which consists of global drivers such as the number of employees or floor area, specific energy service drivers (specific equipment or diffusion rates, e.g. share of cooled floor area, number of computers per employee) and specific energy consumption indicators. The latter consist of technical data on the end-uses such as installed power per unit of driver. Energy services and their techno-economic description represent a key element of the modelling approach.

Energy demand of a given year is determined as the product of the specific energy demand per unit of energy service driver (e.g. floor area heated, floor area cooled and/or ventilated, etc.) multiplied by the quantity of the given driver. Energy service drivers are related to global driver (e.g. floor area or number of employees). Specific energy demand is calculated as the product of installed (full load) power and the annual utilization rate (annual full load hour equivalent).

Specific energy demand varies over time due to the diffusion of new technologies and/or energy-efficiency options (EEOs). These EEO such as building insulation, heating and cooling systems and controls etc. are represented in terms of discrete technologies that are characterized by their techno-economic characteristics such as output power, end-use conversion efficiencies, costs etc.

The tertiary sector, also referred to as the service or commercial sector, covers all the economic sectors not part of the primary economic sector (agriculture, forestry, fishery etc.) or the secondary economic sector (industry). Hence, the tertiary sector comprises the NACE sub-sectors G to S (NACE rev. 2.0) as also shown in the table below.

Table 19: Considered economic sub-sectors of the tertiary sector

Economic subsector	Nace (2.0)	Description
Trade	G	Wholesale and retail trade
Hotel and restaurant	I	Hotels and restaurants, camping sites, mountain refuges, bars, canteens, catering
Traffic and data transmission	H, J	Transport (railway, road, water, air), storage and communication, cargo handling, post, telecommunications,
Finance	K	Finance and insurance
Health	Q	Health and social work, hospital activities, social work activities with accommodation

Economic subsector	Nace (2.0)	Description
Education	P	Primary and secondary education, higher education, driving school activities
Public administration	O	Public administration and defence, compulsory and social security
Other services	L,M,N,R,S	Other services (waste, sport, social services) + real estate and other services

The main drivers are employees and floor area. The number of sub sectoral employees is constructed with the aid of different regression models: The first step calculates the potential active population, according to projected population (total, and per age group) and supposed evolution of retirement ages. The second step calculates the share of tertiary employment, using the potential population, total population and GDP per capita. As a last step, the shares of sub-sectors are calculated, using sub sectoral specific regression models.

The floor area is calculated from the just calculated employee per subsector and an expected specific floor area (scenario dependent). The final specific floor area will smooth the changes in floor area, because the building dynamic is much slower than economy changes. Additionally, the floor area is divided by construction periods.

Several energy services are defined for each of the subsectors. These energy services represent distinct appliances as well as building-related and other technologies which are responsible for the energy demand in the tertiary sector.

Most energy service drivers are related to the floor area or the number of employees in the respective subsectors and countries (see Table 7). For energy services that are assumed to be independent of these two global drivers (such as street lighting or cooking), only the energy service driver is used and the respective technological parameters are chosen accordingly. By using energy service drivers, it is assured that the calculated energy consumption is based on a realistic technological structure on a micro-level.

While heating and lighting are found in buildings across all subsectors, not all buildings of a given subsector are equipped with all the other energy services considered. Each energy service is related to the specific energy service driver representing a diffusion, penetration or ownership rate of the respective technology in each of the subsectors. The data is explicitly differentiated between sub-sectors and countries. When implementing the described bottom-up-modelling approach in the FORECAST model, new and existing buildings are also differentiated (as the incentives and costs for equipping new buildings are quite different from upgrading existing ones).

Table 20: The energy services considered and their related energy service driver

Type	Energy service	Description	Energy service driver (D)	Related global driver (G)
Th	Space heating	Space heating for rooms	Floor area of building	Floor area
Th	Hot water	Hot water and process heat (e.g. cleaning)	Floor area of buildings	Floor area
El/Th	Direct electric space heating	Fuel heating excluded, this energy service covers heat pumps and electric heating	Share of floor area with electric heating	Floor area
El/Th	Ventilation and cooling	Ventilation and cooling of rooms and buildings	Ventilated and cooled floor area of buildings	Floor area

Type	Energy service	Description	Energy service driver (D)	Related global driver (G)
Th/El	Laundry	Laundry, particularly in the hotel and health sectors	No. of beds/guests	None
Th/El	Cooking	Cooking in restaurants, health sector, large office buildings	No. of meals, no. of beds/guests	None
El	Refrigeration/freezing	Cooling of products (particularly retail sector)	No. of employees	Number of employ-ees
El: specific electricity-based energy service (hardly substitutable) Th: thermal energy service (might be substituted by other energy types)				

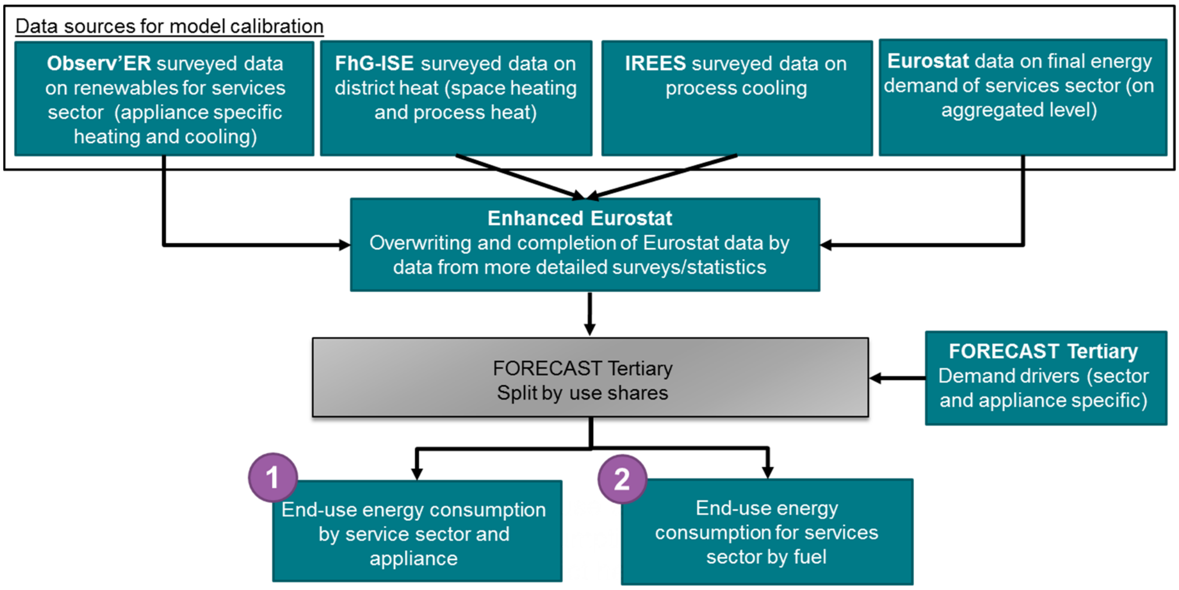
Each energy service in each sector is characterized by a specific energy demand. These specific demand values are the product of the installed power of a technology and its utilisation in full-load hours per year. These values are explicitly differentiated between subsectors, countries and, whenever possible, implicitly between new and existing buildings and between already installed systems and those that are retrofit-ted. Based on the calculation scheme, the total bottom-up energy demand for the ter-tiary sector can be calculated and differentiated by either sub-sector or energy ser-vice.

For the starting year, the model is calibrated to the statistical values of the calibration year in an iterative approach. This means that model parameters and input data en-dowed with uncertainty are adjusted in order to decrease the difference between model output and statistical data base. Data used is defined in more detail in the next section 4.2.2.

4.2.2 Data used

Eurostat provides a final energy balance on country level for the services sector on an aggregate level for a set of energy carriers [nrg_100a]. This data is used as the main dataset which is completed by additional sources for renewable energy (RES) and dis-trict heat (see sections 4.4 and 4.5). This means that Eurostat data is replaced and complemented by data from the more detailed surveys (see Figure 10 for the flow chart). The enhanced dataset is then used to calibrate the model FORECAST Tertiary as described in section 4.2.1.

Figure 14: Flow chart, describing the dataset used to calibrate the FORECAST Tertiary model



As a result of the FORECAST Tertiary model, final energy consumption and useful energy demand are calculated for the different end-use categories, fuel type, and sub-sectors. Hence, useful energy demand is derived from the model directly, using heating and cooling system and appliance-specific efficiency factors. Where the data availability for country-specific efficiency factors is scarce, consistent assumptions are used to calculate useful energy demand figures.

Primary energy demand is calculated based on final energy demand by energy carrier, using the country and fuel-specific conversion mixes and efficiencies based on Eurostat data.

4.2.3 Quality of Results

An overview of the quality of the input data is given in Table 21. Due to previous and ongoing work, the coverage is complete in all input data sets. Relevant global drivers (number of employees) based on official statistics offer a good empirical basis with a high consistency. Coverage of floor area is less complete and thus missing values are imputed with the aid of specific indicators (floor area per employee). Other data such as more technical parameters formally have a less consistent data base since the available information is based on a variety of sources. Additionally, such drivers might be adjusted on expert assumptions. As compared to cooling the robustness of the input data is higher for data regarding space heating and hot water due to a higher data availability and fewer uncertainties. Data assumptions on space cooling are less robust since in most of the member states, less information is available on the use and distribution of cooling (although evidence from the preparatory studies of the EU Ecodesign Directive was taken into account).

Table 21: Estimation of input data quality for the services sector

	Input data set	Coverage	Empirical basis	Consistency	Robustness
Space heating	Floor area of buildings	medium uncertainty	medium uncertainty	low uncertainty	low uncertainty
	Share of floor area with different heating technologies	medium uncertainty	high uncertainty	low uncertainty	medium uncertainty
	Heating technology parameters	low uncertainty	low uncertainty	low uncertainty	low uncertainty
	Building stock data	medium uncertainty	medium uncertainty	low uncertainty	low uncertainty
Hot water	Floor area of buildings	medium uncertainty	medium uncertainty	low uncertainty	low uncertainty
	Number of employees / guests	low uncertainty	low uncertainty	low uncertainty	low uncertainty
Process heating	Number of employees / guests	low uncertainty	medium uncertainty	medium uncertainty	medium uncertainty
	Diffusion (usages/applications)	high uncertainty	high uncertainty	medium uncertainty	medium uncertainty
Space cooling	Air conditioned floor area	low uncertainty	medium uncertainty	medium uncertainty	medium uncertainty
	Stock/Technology parameters	medium uncertainty	low uncertainty	medium uncertainty	medium uncertainty
Process cooling	Diffusion in subsectors	high uncertainty	medium uncertainty	medium uncertainty	medium uncertainty
	Stock/Technology parameters	high uncertainty	medium uncertainty	medium uncertainty	medium uncertainty

high uncertainty	low uncertainty
medium uncertainty	Combination not relevant

The main interesting quality indicator is the **robustness** of the results. As indicated above, Eurostat balances already provide final energy for most energy carriers, differentiated by sub-sector and country. The robustness of the results is indicated along the following parameters.

- Across the different **sub-sectors** final energy demand is heterogeneously distributed. However, due to the availability of data regarding space heating and water heating, the robustness of total consumption is high in all subsectors. For sub-sectors where process cooling and process heating is of high importance (e.g. trade or hotels & restaurants, finance), better results are obtained compared to sub-sectors where less information is available or the processes are negligible (see Table 22). The results of the other services are the least robust compared to the other sectors, given the circumstances that little reliable information is available on specific energy demands for the related end-uses.
- The uses of the different **energy carriers** are also heterogeneously distributed across all end-uses. Since **natural gas, fuel oil** and **electricity** are the main energy carriers in the tertiary sector, the robustness of the results for their use in all sub-sectors is higher compared to other fuels such as renewable energy sources (in total) and district heating. Note, however, that some of respective data gaps could be overcome with this project. Robustness is also medium to low in terms of energy carrier break down by different end-uses. Yet some boundary conditions are considered due to technological reasons (e.g. cooling and ventilation almost exclusively is provided by electricity and other energy sources are negligible). However, the final energy carrier mix is hardly differentiated across sub-sectors (as opposed to the industry sector for which such sub-sector specific data is available).
- For some of the **countries**, the robustness is slightly higher than in the case of the bulk of the countries, since available end-use balances allow a better quality review and comparability (e.g. space heating in United Kingdom, Germany, Switzerland and Austria).

Table 22: Overview of robustness of results for the tertiary sector. The importance of the different fuels is included in the uncertainty evaluation

Energy carrier	Space heating	Hot water	Process heating	Space cooling	Process cooling
Coal					
Fuel oil					
Natural gas					
Other fossil fuels					
Electricity					
District heating					
Waste non-RES					
Waste RES					
Biomass					
Geothermal					
Solar energy					
Ambient heat					
Total					

Sub-sector	Space heating	Hot water	Process heating	Space cooling	Process cooling
Trade					
Hotel and Restaurants					
Traffic and data transmission					
Finance					
Health					
Education					
Public administration					
Other services					
Total					

high uncertainty	low uncertainty
medium uncertainty	Combination not relevant

The statement regarding advantages of our mixed data and model-based approach as mentioned in section 4.1.3 is also valid for the tertiary model.

The model calculations fill a complete data set which allows a first analysis of the different energy uses. The comparability and coherence when comparing countries, sub-sectors, energy carriers or end-uses is very high. In order to improve the robustness of the results, the most important measure is to improve the empirical foundation of the model input data.

4.3 Residential sector

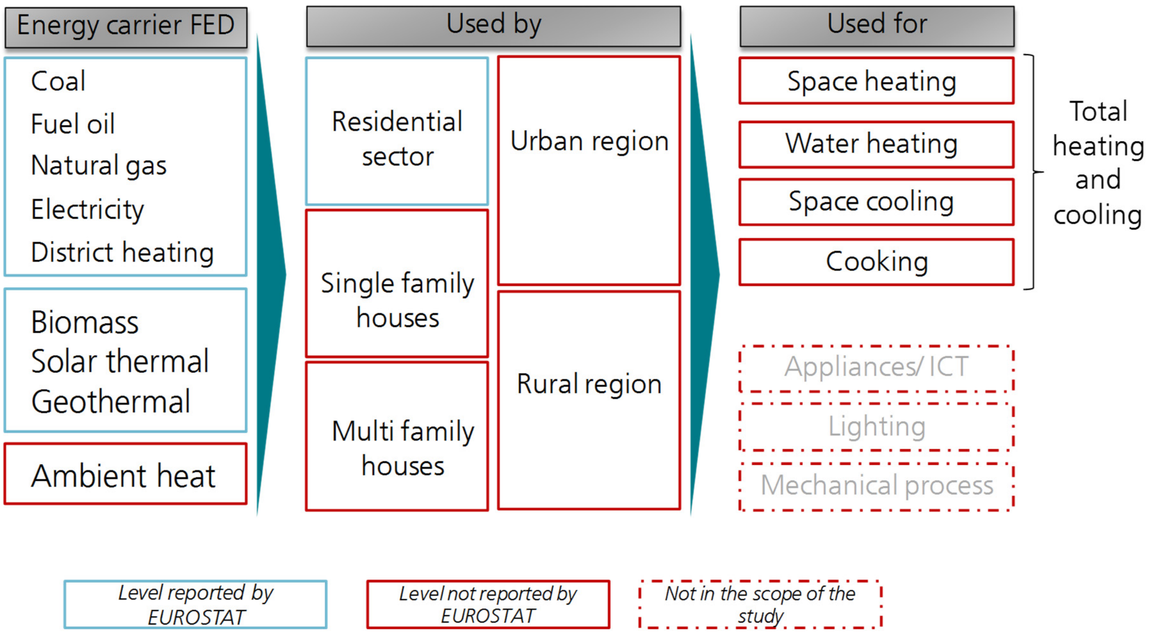
4.3.1 Approach

The end-use balance of the residential sector comprises five dimensions:

- Country
- Energy carrier
- Building category
- Region type
- End-use

As for the other sectors, the differentiation provided by EUROSTAT is not sufficient to derive overall heating and cooling demand and to differentiate among the relevant end-uses and building categories (Table 15). However, the disaggregation of final energy demand (FED) by energy carriers acts as a reference for the total heating and cooling balance.

Figure 15: Structure of residential sector end-use balance



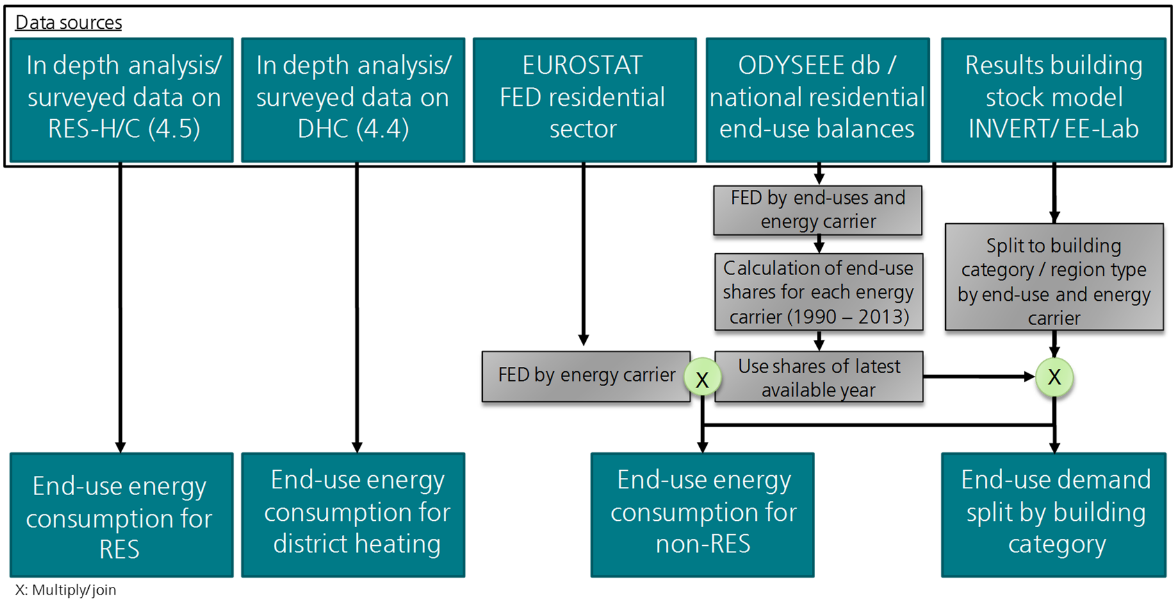
FED: Final energy demand

Source: Fraunhofer ISI

The analysis performed in this study disaggregates the energy carriers to cover the levels not reported by EUROSTAT. Furthermore, in depth analysis is conducted for certain energy carriers which either suffer from a higher uncertainty in the available data (e.g. biomass) or are not reported in EUROSTAT (see 4.4 and 4.5). Figure 16 shows the main data sources and methods used in this study to derive the end-use balance for the residential sector.

The data used comprise own analysis and surveys, existing national energy balances (see section 2), data provided by the ODYSSEE databases, as well as modelled data using the building stock model INVERT/EE-Lab. The following section describes the main data sources in detail. In depth analysis of renewable energy sources (RES) and district heating (DHC) are covered in sections 4.4 and 4.4, respectively.

Figure 16: Data compilation for heating and cooling end-use balance in the residential sector



Source: Fraunhofer ISI

4.3.2 Data used

National end-use balances and ODYSEEE Database

As the first step, available national data sources are compiled (see 2.2). This includes data on household energy consumption which are surveyed regularly from national statistic offices as well as one time surveys commissioned by national ministries. For an overview of available national end-use balances of the residential sector refer to Table 2.

Additional country data on the distribution of household energy consumption to end-use categories are available from EUROSTAT. In preparation of the future requirement on Member States to report household energy consumption not only by type of fuel but also by type of use, voluntary reports are already available for nine Member States[11] (EUROSTAT 2015a). However, some of these countries also report an official end-use balances for the residential sector and data reported to EUROSTAT and not fully in line with the official national for some of the countries. Therefore, national statistics are used as primary data source if available.

Another important data source is the ODYSSEE database. Within the ODYSSEE-MURE project[12], there is an ongoing collection of comprehensive data on end-uses in the residential sector by 33 national partners which are primarily the energy agencies or their

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11 Austria, Bulgaria, France, Latvia, Luxembourg, Portugal, Romania, Slovenia, United Kingdom

12 The ODYSSEE-MURE project is co-ordinated by ADEME with the technical support of Enerdata, Fraunhofer ISI, ISIS and ECN. It is supported by the Intelligent Energy Europe program. http://www.odyssee-mure.eu

representatives within the *European network of energy efficiency agencies*. Thus, it is not only data of published national end-use balances that are considered in the ODYSSEE database but also data from the national energy statistics experts and associations.

The database comprises EU-28 countries, and Norway and Switzerland. The heating and cooling demand of the following end-uses are differentiated in the residential sector:

- Space heating
- Water heating
- Space cooling
- Cooking
- However, not all end-use data are available either for all countries or for all years.

Furthermore, comparing the final energy demand by energy carrier with the EUROSTAT energy balance reveals deviations for certain energy carriers in some countries. Thus, ODYSSSEE data are used to calculate the split of each energy carrier into the individual heating and cooling end-uses. These shares are subsequently applied to the absolute values reported by EUROSTAT to derive consistent residential end-use balances. For a complete overview of the used data sources, refer to the result data sheets provided in excel.

Application of the building stock model Invert/EE-Lab to fill data gaps

The Invert/EE-Lab model is used to fill data gaps, especially for the split of end-use energy demand by building category. Data on the EU Building stock have been collected within the ENTRANZE[13] project using 2008 as the reference year. Invert/EE-Lab is used to extrapolate these data up to 2012. For this purpose, the model, which is usually used to develop scenarios of energy demand and energy carrier mix for future decades, is only applied for the period 2008-2012. Current policies were applied in order to ensure the modelling of a realistic development in this period.

The model follows a building physics approach to calculate the energy demand for space heating, water heating and space cooling. The main input data are geometry data and heat transfer coefficients (u-values)[14] of building components as well as installed heating systems and heat distribution systems. The levels of detail, and the number of building types, vintages, etc. considered, depend on the data availability and structure of national statistics. Data from EUROSTAT, national building statistics the BPIE data hub as well as the ODYSSEE database have been taken into account. For a detailed overview of the sources regarding building stock data, refer to the ENTRANZE database (Sebi et. al 2013).

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13 IEE project *Policy to enforce the transition to nearly zero energy buildings* (Entranze). http://www.entranze.eu/

14 Measure of thermal resistance used to calculate energy demand in buildings

Invert/EE-Lab models the uptake of different levels of renovation measures and the diffusion of efficient heating and hot water systems. Standard outputs from the Invert/EE-Lab on an annual basis are:

- Installation of heating and hot water systems by energy carrier and technology (number of buildings, number of dwellings supplied)
- Refurbishment measures by level of refurbishment (number of buildings, number of dwellings)
- Total delivered energy by energy carrier and building category (GWh)
- Total energy need by building category (GWh)
- Policy programme costs, e.g. support volume for investment subsidies (M€)
- Total investment (M€)

Data sources and model application to calculate space cooling demand

Not for all countries, data from national statistics and surveys are available for space cooling energy demand in the residential sector. Therefore, data gaps are closed by other literature together with the modelling approach.

Modelling the development of energy demand for space cooling in INVERT/EE-Lab is largely based on diffusion theory. The cooled floor area in a defined type of building in a certain year t is determined by the following logistic function:

$$x(t) = \frac{x_{inf}}{(1 + e^{-\lambda t})}$$

Thereby, x_{inf} is the maximum penetration of cooled floor area in this type of buildings and *lambda* (λ) is the rate of diffusion, which is based on the development of the cooled areas in different types of buildings in each country over recent decades. In general the logistic diffusion model assumes that the diffusion of technology over time is fully reflected in its historical developments. Major changes in parameters influencing the decision of whether or not to install a technology are reflected as far as these changes are already represented in the calibration period for determining the values of lambda. Increased renovation activities and high energy efficiency standards for new construction in the building stock may influence the diffusion of space cooling devices. In order to quantify these possible effects the logistic diffusion approach is extended.

Important parameters for the decision of whether or not to install a cooling device in a building are the emerging cooling loads and their frequency in the summer period. The higher these values, the higher the probability of installing a cooling device.

In INVERT/EE-Lab these parameters are not calculated. This model uses a monthly time resolution to determine the useful energy demand for space cooling of the buildings. The resulting annual useful space cooling demand per area for a certain cluster of buildings and its change over time is then used to recalculate the respective rate of diffusion *lambda* according to the following formula:

$$\lambda_{adapt} = \lambda_{calibr\ period} * (demand\ ratio_{renovation\ class} * demand\ ratio_{construction\ period})^2$$

The correlation between cooling loads and their frequency of appearance in the summer period and the resulting useful cooling demand over the year is estimated to be quadratic. The demand ratio in the case of renovation (demand $\text{ratio}_{\text{renovation class}}$) is defined as the relative change of the annual useful cooling demand per area in a cluster of buildings undergoing the same renovation, against buildings of the same type and construction period which are not being renovated. The demand ratio for newly constructed buildings in the simulation period (demand $\text{ratio}_{\text{construction period}}$) reflects the relative changes against the average useful space cooling demand for the same type of building over all construction periods.

The main input parameters for the calculation of the diffusion of cooling devices and the resulting electricity demand in the buildings are as follows:

- the maximum penetration levels,
- the current state of diffusion in the base year of simulation,
- its historical developments,
- the annual useful cooling demand as well as the development of the efficiency of the installed devices over the simulation period.

While the useful cooling demand for each year of simulation is determined endogenously in the model the other parameters are exogenous input. These values are estimated for different types of buildings in each country based on an intensive literature review.

The main sources that have been analysed are the preparatory studies for the *Ecodesign Directive* (Riviere et al. 2008, 2012) as well as Pout et al. (2012), who analysis barriers and opportunities to improve energy efficiency in cooling appliances in Europe, together with Hitchin et al. (2013), Adnot et al.(1999), Adnot et al. (2003), Pardo et al. (2012) and Gruber et al. (2007). Furthermore country specific information collected within the ENTRANZE database has also been used[15] The parameters derived have also been compared to results of other studies and databases namely HARMONAC[16], ECOHEATCOOL (Euroheat & Power 2006), INSPIRE (EURAC et al. 2014) and ODYSSEE..

Table 23 gives an overview of the type of data sources used to derive the space cooling demand in the

15 see "The challenges, dynamics and activities in the building sector and its energy demand" reports for 10 countries at www.entranze.eu/pub/pub-data

16 Harmonizing air-conditioning inspection and audit procedures in the tertiary buildnig sector (HARMONAC). https://ec.europa.eu/energy/intelligent/projects/en/projects/harmonac

Table 23: Categorisation of data source used to derive space cooling demand

Country	Data source
Belgium	Modelled data /ENTRANZE
Bulgaria	ODYSEEE / European Environmental Agency
Czech Republic	Modelled data /ENTRANZE
Denmark	Modelled data /ENTRANZE
Germany	Modelled data /ENTRANZE
Estonia	Modelled data /ENTRANZE
Ireland	Modelled data /ENTRANZE
Greece	ODYSEEE / National experts
Spain	National or official statistics / survey
France	National or official statistics / survey
Croatia	National or official statistics / survey
Italy	ODYSSEE / National experts
Cyprus	National or official statistics / survey
Latvia	Modelled data /ENTRANZE
Lithuania	Modelled data /ENTRANZE
Luxembourg	Modelled data /ENTRANZE
Hungary	Modelled data /ENTRANZE
Malta	National or official statistics / survey
Netherlands	ODYSSEE / National experts
Austria	National or official statistics / survey
Poland	Modelled data with INVERT/EE
Portugal	National or official statistics / survey
Romania	Modelled data /ENTRANZE
Slovenia	ODYSSEE / National experts
Slovakia	Modelled data /ENTRANZE
Finland	Modelled data /ENTRANZE
Sweden	Modelled data /ENTRANZE
United Kingdom	National or official statistics / survey
Iceland	Modelled data /ENTRANZE
Norway	Modelled data /ENTRANZE
Switzerland	National or official statistics / survey

Split heating and cooling demand between urban and rural regions

The differentiation between urban and rural areas is defined by the OECD methodology with a two step approach. Firstly, local administrative units level 2 (LAU2)[17] with a population density below 150 inhabitants per km² are classified as rural areas (EUROSTAT 20015b). Secondly, regions are classified as predominantly urban, inter-

[17] Municipality level, previous denoted as NUTS 5

mediate and predominantly rural base on the share of population living in rural units:

- Predominantly urban: share of population living in rural LAU2 is below 15 %
- Intermediate: share of population living in rural LAU2 is between 15% and 50%
- Predominantly rural: share of population living in rural LAU2 higher than 50%

Up to now, EUROSTAT applies the OECD approach to classify regions. However, a new typology has been developed which will likely be used in the future. Thereby, only urban and rural areas are distinguished and instead of administrative units geographical grid cells are used as clusters. This new approach defines an urban cluster "as cluster of continuous grid cells of 1 km² with a density of at least 300 inhabitants per km² and a minimum population of 5000" (EUROSTAT 2015c). Areas outside the urban clusters are identified as rural areas.

In order to derive the heating and cooling end-use balance for urban and rural areas, the EUROSTAT *database on housing and living conditions* [18] is used which applies the OECD approach to classify regions. The dataset on the *"Distribution of population by degree of urbanisation, dwelling type and income group"* indicates the proportion of the population living in multi-family houses (MFHs) and single family houses (SFHs) in urban and rural regions[19]. Based on this distribution the derived final energy demand by end-use and building category (SFHs, MFHs) - as described above – is subsequently split into urban and rural regions using the proportions illustrated in Table 24. This shows the share of each building type in each regional classification for 2012; for example, the first row indicates that 61% of all MFHs in EU 28 Member States are located in urban areas while 72% of SFHs are located in rural and intermediate regions. This distribution of building types between urban and rural regions varies significantly across the 31 countries covered in this study with shares of between 35% and 93% of MFHs in urban regions and from 16% to 93% of SFHs in rural and intermediate regions.

Using these data together with the split of final energy demand to the building categories as described above, the derived end-uses are disaggregated to urban and rural areas resulting in the following dimensions:

- Final energy demand for [end-use][20] in SFH, urban region
- Final energy demand for [end-use] in SFH, rural region
- Final energy demand for [end-use] in MFH, urban region
- Final energy demand for [end-use] in MFH, rural region

18 http://ec.europa.eu/eurostat/web/income-and-living-conditions/data/database

19 The share of the population living in regions classified as "intermediate" was added to dwellings in "rural" regions. For a discussion on the typology used in by Eurostat see: http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology

20 Space heating, water heating, space cooling, cooking

Table 24: Share of population by building category and region type in 2012

	Multi-family Houses		Single Family Houses	
	Urban	Rural and Intermediate	Urban	Rural and Intermediate
European Union (28 countries)	61%	39%	28%	72%
Belgium	83%	17%	46%	54%
Bulgaria	75%	25%	18%	82%
Czech Republic	48%	52%	11%	89%
Denmark	65%	35%	20%	80%
Germany	50%	50%	18%	82%
Estonia	55%	45%	16%	84%
Ireland	66%	34%	34%	66%
Greece	66%	34%	20%	80%
Spain	66%	34%	21%	79%
France	78%	22%	30%	70%
Croatia	68%	32%	18%	82%
Italy	59%	41%	26%	74%
Cyprus	76%	24%	44%	56%
Latvia	58%	42%	21%	79%
Lithuania	62%	38%	15%	85%
Luxembourg	30%	70%	9%	91%
Hungary	63%	37%	15%	85%
Malta	93%	7%	84%	16%
Netherlands	75%	25%	40%	60%
Austria	59%	41%	9%	91%
Poland	58%	42%	13%	87%
Portugal	67%	33%	26%	74%
Romania	69%	31%	12%	88%
Slovenia	38%	62%	11%	89%
Slovakia	42%	58%	7%	93%
Finland	49%	51%	15%	85%
Sweden	35%	65%	11%	89%
United Kingdom	75%	25%	54%	46%
Iceland	80%	20%	50%	50%
Norway	79%	21%	47%	53%
Switzerland	36%	64%	12%	88%

Source: Eurostat (2015b)

4.3.3 Quality of results

The most interesting quality indicator is the **robustness** of the results; high robustness is defined as low uncertainty. The robustness of the results can be discussed in terms of the dimensions used: energy carriers, building category, region types and end-uses. Table 25 shows a qualitative assessment of the results regarding the robustness which is discussed below.

Table 25: Overview of the robustness of results for the residential sector

Energy carrier	Space heating	Water heating	Space cooling	Cooking
Coal				
Fuel oil				
Natural gas				
Other fossil fuels				
Electricity				
District heating				
Waste non-RES				
Waste RES				
Biomass				
Geothermal				
Solar energy				
Ambient heat				
Total				

Sub-sector	Space heating	Water heating	Space cooling	Cooking
SFH Total				
MFH Total				
SFH Urban				
MFH Urban				
SFH Rural				
MFH Rual				

high uncertainty
medium uncertainty
low uncertainty
Combination not relevant

Energy carrier end-use split

The disaggregation of energy carrier data by end-use is mainly based on empirical data provided by official statistics or national experts of energy agencies or associations. Furthermore, some energy carriers can only be used for certain end-uses due to the technologies available increasing the robustness of the total heating and cooling demand. For instance, solid fuels and heating oil are only used for heating purpose. In addition the large majority of space cooling is provided by electric-driven appliances with a very low proportion being provided by gas-driven absorption cooling devices.. However, there is greater uncertainty in the absolute numbers of non-grid based energy carriers since the consumption cannot be measured directly. This causes uncertainty in national energy balances as well as in EUROSTAT which is especially relevant for biomass, a large proportion of which is not officially traded.

Robust empirical data are particularly available for space heating and domestic hot water (see ODYSSEE Database), whereas the availability of official statistics on space cooling demand in residential sector is very low. Nevertheless, the applied approach which combines a literature review on installed technologies with modelling of space cooling demand based on climate conditions and building types is evaluated as robust.

Split by building category: SFHs and MFHs

The split of end-uses by building type is based on the model approach using building stock data. The methodology of the Invert/EE-Lab model accepts that model-based energy demand does not equate to real consumption and considers the influence of user behaviour. However, there are still uncertainties which cannot be fully covered by the model. Furthermore, the model requires detailed input data on the building stock that inherit higher uncertainties.

Split by region type: urban and rural

The input data used to derive end-use energy balances for rural and urban areas are robust since data on population and building category by region have been collected within national census surveys. Nonetheless, there are uncertainties in the resulting energy demand. Since the results are based on the split of end-use energy demand by building category, the split between urban and rural end-uses exhibit the same uncertainties as the modelled results for the building categories. Furthermore, the only differences between urban and rural regions considered, are those between building categories. Potential differences in the energy supply between urban and rural regions for the same building category are not considered due to a lack of data.

4.4 District heating systems

4.4.1 Approach and data used

In order to describe the district heating and cooling sector, a combination of three different approaches was used to access the relevant data:

- Online desk research of publicly available data. Statistics regarding the district heating/cooling sector are often collected at national level by associations of district heating operators, national statistical offices or other national authorities. In addition, data from other studies/ projects (e.g. ´IEE Project Tabula´, ´RESCUE´) was employed when appropriate.
- Direct contact with the above mentioned associations in order to access data not publicly available. In order to facilitate communication as well as data transfer, a questionnaire in template form was developed and sent to the relevant contacts. This opportunity was also used to gather data relevant for ´WP2 – District Heating and Cooling´ as well as to ask for clarifications when needed. The overall response rate was good (around 70%), but the requested data were often not available.
- Purchase of reports from relevant European/ international associations. In this regard, ´District heating and cooling, Country by Country, 2015 Survey´ by Euroheat & Power (EHP) was one of the main data sources (Euroheat & Power, 2015).

Evaluation of quality/ availability of data

The availability of data and its **level of detail** depend strongly on the country as countries with a more developed or growing district heating sector are generally able to provide in-depth analyses and reports on this topic. No data or only partial data could be retrieved for the UK, Belgium, Luxembourg, Portugal and Greece.

The data on the **final consumption** of district heating and its **division into sectors** (residential, industrial and tertiary & others) can be found through desk research, but its detailed **division into subsectors and end uses** was only rarely available, because this is normally not collected by the responsible associations. A notable exception is the residential sector, for which it was often possible to retrieve the final consumption for space heating and water heating. The data about the **energy carrier** composition for district heating was largely taken from the EUROHEAT and Power(EHP) report.

Only limited information can be found about **district cooling** (mainly final consumption and installed cooling capacity), because this technology is not widespread.

As mentioned before, one of the main data sources was EHP, which relies on the voluntary support of its members. However, even though EHP assumes the role of the central data collecting unit, for some aspects, the national associations do not employ a common **methodology for the preparation of statistics** at European level (e.g. energy supply composition for district heating). Moreover, a comparison between the data gathered during this task and the values accessible in Eurostat under the category ´**Derived Heat**´ highlighted consistent differences between the two, in both relative and absolute terms. As EHP reports, "*it is highly inaccurate to assess the district heating delivery by summing up the heat delivery from CHP plants and heat-only plants on the basis of ´derived heat´ category within Eurostat*".

Data gaps

In its report, EHP provides mainly data for 2011 and 2013. Since 2012 was chosen as the baseline year in this project, it was necessary to derive the value for 2012 through interpolation. A country-specific climate correction based on heating degree days was applied to district heat sales. Whenever it was possible to acquire data directly for 2012, this was given preference.

In many cases, the fuel composition of the energy supplied to district heating systems was available. If there were only absolute values for the delivered energy to district heating systems available, the generation plants for district heating were analysed. The portion of installed capacities by energy carrier was used to disaggregate the total delivered energy in order to obtain the fuel allocation for district heat. This approach implies the assumption of equal full-load hours for the different generation plants in the respective countries.

Whenever the heat input to the heat networks was unknown, it was calculated based on the final consumption and assuming an arbitrary 15% loss in the distribution network.

When appropriate, data gaps were filled using correlations based on temporal data series or other reference countries.

If these methods or climate correction was applied, the data is marked with the letter ´a´ for ´ad hoc calculation´ in the ´Notes & Methodology´ column in Tables 36 and 37.

Findings/Recommendation:

In order to obtain a more comprehensive picture of district heating/cooling, the following suggestions are made.

1. The collection of the relevant statistics should be clearly assigned to an association/ organization operating at national level in each country.
2. A common methodology should be defined for statistics preparation in order

to harmonize the data at European level (e.g. energy supply composition for district heating). In this regard, EHP prepared a document "Detailed comments on the EU heat statistics´ in December 2014", which provides a list of problems (in part also encountered during this task) and valid suggestions.

3. The newly defined methodology should stipulate all the relevant parameters, data and indicators.
4. The ´derived heat´ category should be divided into heat for industrial processes and district heating.

4.4.2 Quality of results

The quality of the input data is pictured in Table 26. As mentioned above, there is data with good quality for several aspects of district heating like final consumption. A detailed sectoral breakdown (including the defined sub-sectors) is usually not available and model results had to be used in order to achieve the aspired level of detail. A major difficulty concerning the quantification of derived heat and therefore also for the share of CHP in the heat supply is that there are differing statistical methodologies in national and European statistics (see above). The data availability for district cooling is also very limited as it is not widespread in the European Union. There is only data on the final consumption in district cooling systems and the overall installed capacity (see work package 2).

The available statistics cover almost all analysed countries and topics, especially on district heating. The main reason is that district heating is a wide-spread way for providing heat, especially in urban areas and there is a monitoring and reporting infrastructure and procedure established. Furthermore, there are national and European district heating associations collecting and providing data since decades. However, the data is usually not available in the level of detailed needed for this project. This is especially the case for the breakdown into subsectors (for the main sectors households, industry and tertiary data is available in most countries) and area of application (space or process heating, hot tap water etc.). For these breakdowns, established models had to be used.

The data collected in this project are slightly below the district heating statistics published by Eurostat. According to EHP (see "Detailed comments on the EU heat statistics") one major source of differences between statistics is the category 'derived heat' in Eurostat statistics and the missing sub-division of the category into heat for industrial processed and district heating. EHP only collects district heating data. The absolute differences are given in the data template provided.

Concerning district cooling, the coverage and level of detail in data bases and reports is lower than for district heating. One major reason is that district cooling is not as widespread as district heating. Furthermore, data on district cooling is not yet reported separately in energy statistics by Eurostat.

Table 26: Estimation of input data quality for the district heating and cooling sector

	Input data set	Coverage	Empirical basis	Consistency	Robustness
District heating	Final consumption				
	Sectoral breakdown				
	Percentage of citizens served				
	Share of CHP				
	Energy supply composition				
District cooling	Final consumption				

high uncertainty
medium uncertainty
low uncertainty

4.5 Renewable energy sources (cross-sectoral)

4.5.1 Approach

In contrast to the other sectors discussed in section 4.1 to 4.4 this chapter deals with a cross-cutting topic. The collection of empirical data is fed into the methodology for developing end-use balances for the sectors industry, tertiary and residential. Accordingly, the results of the RES-assessment in this chapter might change slightly when being processes in the context of the entire energy balance for the individual sectors.

The aim of this work task was to collect data on the breakdown of RES final energy consumption according to the application sectors (industry, residential, services) and the types of final uses (space heating, water heating space cooling, process heating, process cooling and other uses). As these figures are not available in the Eurostat database, the relevant data were collected by Observ’ER.

Table 27: Details of the RES sectors and sub-sectors covered

Renewable energy	Renewable energy sectors and sub-sectors	
Solar energy		
	Solar thermal	
Biomass and renewable waste		
	Solid biomass (excluding charcoal)	
		Fuelwood, wood residues and by-products
		Wood pellets
		Bagasse
		Black liquor
		Other vegetal materials and residues
		Animal waste
	Biogas	
		Landfill gas
		Sewage sludge gas
		Other biogases from anaerobic fermentation
		Biogases from thermal processes
	Municipal waste	
		Renewable Municipal Solid Waste (RMSW)
	Liquid biofuels	
		Biogasoline
		Bioethanol
		Biodiesels
	Other liquid biofuels	
Geothermal energy		
	Deep geothermal sector	
	Ambient aerothermal applications	
	Ambient geothermal applications	

Source: Observ'ER 2015

New technologies such as PV-to-heat were not included.

The breakdown of final energy consumption required for this project is not available in Eurostat databases. Eurostat provides details of consumption by sector (residential, industry and services), but does not collect information on possible end-uses (heating, hot water, process heat, etc.). The main objective of this task was to close this data gap by collecting these data for the different RES sources for as many countries as possible.

Observ'ER used a two-stage procedure: data collection based on a specific questionnaire and desk research of Internet sources.

Data collection based on a specific questionnaire

Observ'ER compiled a draft questionnaire to collect the data needed. This questionnaire covered the main information requested in the Mapping project and was addressed to the national authority in charge of the official statistics for RES sectors.

The draft questionnaire was tested by two persons working for official statistics agencies in Europe (SOeS in France and CBS in the Netherlands) in order to ensure that the format of the data requested could be easily understood by the relevant contacts.

The final questionnaire comprised the following table to be completed:

Table 28: RES Final energy consumption breakdown per end uses in industry sector

Industry (1)	**Total final energy consumption in TJ (2)**	**Final energy consumption breakdown**		
		Space heating	Process heating	Process cooling
Solid biomass				
Liquid biofuels				
Biogas				
Renewable municipal solid waste				
Solar thermal				
Geothermal				
Total	0	0	0	0

Source : Observ'ER 2015

(1) The industries covered: Iron & steel industry, chemical and petrochemical industry, non-ferrous metal industry, non-metallic minerals, transport equipment, machinery, mining and quarrying, food and tobacco, paper, pulp and print, wood and wood products, construction, textile and leather, non-specified industry.

(2) The term final energy consumption (equal to the sum of all consumption in the end-use sectors) implies that energy is excluded that is used for transformation processes and for their own use by energy-producing industries. Final consumption reflects, for the most part, the energy delivered to final consumers.

Table 29: RES Final energy consumption breakdown per end uses in residential sector

Residential	Total final energy consumption in TJ	Final energy consumption breakdown			
		Space heating	Space cooling incl. ventilation used for cooling purposes	Water heating	Other uses
Solid biomass					
Liquid biofuels					
Biogas					
Renewable municipal solid waste					
Solar thermal					
Geothermal					
Total	0	0	0	0	0

Source : Observ'ER 2015

Table 30: RES Final energy consumption breakdown per end uses in services sector

Services	Total final energy consumption in TJ	Final energy consumption breakdown			
		Space heating	Space cooling incl. ventilation used for cooling purposes	Water heating	Other uses
Solid biomass					
Liquid biofuels					
Biogas					
Renewable municipal solid waste					
Solar thermal					
Geothermal					
Total	0	0	0	0	0

Source : Observ'ER 2015

Data were requested for 2 years: 2012 and 2013.

As the questionnaire was sent to the persons responsible for the respective national figures for the Eurostat database, the Eurostat methodology was used as a basis (definition of final energy, breakdown of the RES sector).

Observ'ER used its own contacts list compiled in the European programme: EurObserv'ER barometers. All the main persons responsible for the national statistics on the RES sectors in Europe have been identified and contacted within this project, which has been running and led by Observ'ER since 1999.

Table 31: Contacted authority per country

Country	Authority	Website
Austria	Statistik Austria	www.statistik.at
Belgium	Energie Observatorium	www.economie.fgov.be
Bulgaria	National Statistical Institute (NSI)	www.nsi.bg
Croatia	Croatian Bureau of Statistics (DZS)	www.dzs.hr
Cyprus	Statistical Service (mof)	www.mof.gov.cy
Czech Republic	Ministry of Industry and Trade (MPO)	www.mpo.cz
Denmark	Danish Energy Agency - Energistyrelsen (ENS)	www.ens.dk
Estonia	Statistics Estonia (ES)	www.stat.ee
Finland	Statistics Finland	www.stat.fi
France	Service de l'Observation et des Statistiques (SOeS)	www.statistiques.developpement-durable.gouv.fr
Germany	Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) Baden-Württemberg	www.zsw-bw.de
Greece	Center for Renewable Energy Sources (CRES)	www.cres.gr
Hungary	Hungarian Central Statistical Office (KSH)	www.ksh.hu
Ireland	Sustainable Energy Authority of Ireland (SEAI)	www.seai.ie
Italy	Ministero dello sviluppo economic	www.sviluppoeconomico.gov.it
Latvia	Central Statistical Bureau of Latvia (CSB)	www.csb.gov.lv
Lithuania	Statistics Lithuania (LS)	www.stat.gov.lt
Luxembourg	Institut national de la statistique et des études économiques du Grand-Duché du Luxembourg (STATEC)	www.statistiques.public.lu
Malta	National Statistics Office (NSO)	www.nso.gov.mt
Netherlands	Statistics Netherlands (CBS)	www.cbs.nl
Poland	Central Statistical Office of Poland (GUS)	www.stat.gov.pl
Portugal	Direçao Geral de Energia e Geologia (DGEG)	www.dgeg.pt
Romania	Institutul National de Statistica (INSSE)	www.insse.ro
Slovakia	Ministry of Economy of the Slovak Republic (MHSR)	www.mhsr.sk
Slovenia	Statistical Office of the Republic of Slovenia	www.stat.si
Spain	Instituto para la Diversificacion y Ahorro de Energía (IDEA)	www.idae.es
Sweden	Statistics Sweden (SCB)	www.scb.se
United Kingdom	Department of Energy & Climate Change (DECC)	www.gov.uk
Norway	Statistik Sentralbyra (Statistic Norway)	www.ssb.no
Iceland	Statistics Iceland	www.statice.is
Switzerland	Swiss Federal Office of Energy (SFOE)	www.bfe.admin.ch

Source : Observ'ER 2015

Specific desk research

Desk research formed the second part of the approach. This was also based on Observ'ER's experience from the EurObserv'ER barometers. Research specifically targeted the national RES sectors' associations, the European RES sectors' associations (e.g. AEBIOM, EHPA, ESTIF, etc.), and national energy agencies (e.g. Ademe, Dena, etc.). This research also targeted the websites of the statistical agencies covered in the first part of the approach. Indeed, some studies and uploaded on these sites were unknown by persons contacted.

4.5.2 Data used

The following table presents the results of the data collected via the questionnaires or desk research. The countries are ranked according to their amount of RES final energy consumption in TOE from high to low.

The 15 first countries account for 90% of the total EU28 final energy consumption from RES sectors.

Blue cells indicate that the requested data were collected.

The needed data that have not been found through data collection were evaluated taking as a reference a similar country profile for which data were obtained. The table shows country profiles used to estimate the missing data.

Table 32: Details of the EU28 countries treatment

	Industry	Residential	Services
Germany			
France			
Italy	France		France
Sweden	Germany		Germany
Finland	Germany		Germany
Poland			
Spain	France		France
Romania	Czech Rep.	Czech Rep.	Czech Rep
Austria	Germany		Germany
Portugal			France
Czech Republic			
Greece			
Belgium	France	France	France
Denmark	Germany		
Bulgaria	Czech Rep		Czech Rep
Latvia	Czech Rep	Czech Rep	Czech Rep
Hungary	Czech Rep	Czech Rep	Czech Rep
United Kingdom			
Lithuania	Czech Rep	Czech Rep	Czech Rep
Slovenia	Czech Rep		Czech Rep
Estonia	Czech Rep	Czech Rep	Czech Rep
Croatia	Czech Rep	Czech Rep	Czech Rep
Netherlands			
Slovakia	Czech Rep	Czech Rep	Czech Rep
Ireland	U.K		U.K
Cyprus	France	France	France
Luxembourg			
Malta			

	Industry	Residential	Services
Switzerland			
Norway	Germany	Germany	Germany
Iceland	Germany	Germany	Germany

Source : Observ'ER 2015

The residential sector is the best-covered sector. Following the request of Eurostat, most of the EU Member States have initiated specific studies of this application sector. This is not the case for the industry and services sectors.

All the data collected represent 69% of the total final energy consumed from RES in the EU28 in 2012.

The data collected enabled the breakdown of the final energy consumption from RES according to the different application sectors and different uses.

Table 33: Details of the data collected for 5 main countries

	Industry	Residential	Services
France	Space heating 8% Process heating 92%	Space heating 84% Water heating 16%	Space heating 85% Water heating 15%
Germany	Space heating 23% Process heating 77%	Space heating 92% Water heating 8%	Space heating 72 % Water heating 14% Other uses for H&C : 14%
Poland	Space heating 23% Process heating 77%	Space heating 71% Water heating 15% Other uses 14%	Space heating 72% Water heating 14% Other uses 14%
U.K	100 % space heating	Space heating 77 % Water heating 23 %	Space heating 88 % Water heating 11 % Other uses for H&C 1%
Netherlands	Space heating 10% Process heating 90%	Space heating 84% Water heating 16%	Space heating 100 %

Source : Observ'ER 2015

If data were not available for a specific country, the breakdown of final RES energy consumption was estimated. This estimation was based on the shares of a geographically and economically similar country for which data were available Quality of results.

The quality of data and results is very diverse across the RES, end-uses and sectors.

Apart from the situation of the solar thermal sector, which benefits from a relatively detailed monitoring, RES sectors such as heat pumps and biomass are particularly difficult to assess. Especially with regard to the individual end-uses.

For the heat pump sector, the situation incorporates an additional factor with the fact that the European countries do not tackle this sector with the same methodology. Some countries, among which the most important are Italy and France, are counting in their national statistics all types of heat pumps including those used mainly for cooling while most other countries do not include them and are mainly focused on heat pumps with space heating as the main function.

Comparing the sectors, for the residential sector most data is available for RES, whereas for industry and the tertiary sector substantially less is available.

Table 34: Overview of result quality for RES data collection

Energy carrier	Biomass	Geothermal	Solar	Ambient	Waste RES	Total RES
Space heating						
Water heating						
Process heating						
Space cooling						
Process cooling						

Sector	Biomass	Geothermal	Solar	Ambient	Waste RES	Total RES
Industry						
Services						
Residential						
Total						

high uncertainty
medium uncertainty
low uncertainty
Combination not relevant

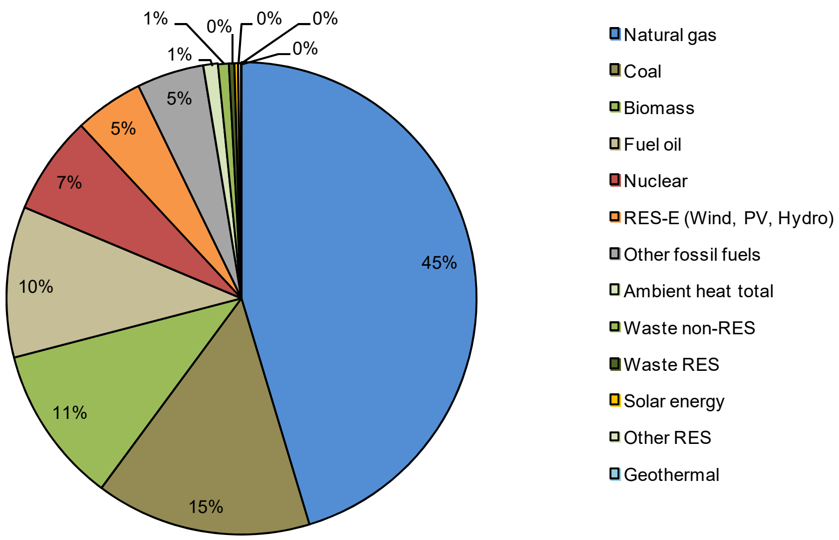
5 Results

5.1 Overall

5.1.1 EU28

In 2012, about 8000 TWh primary energy demand were used in the EU28 for H/C purposes. Thereof 45% was natural gas which is the individual most important energy carrier for the supply of heating and cooling in the EU28. It is followed by coal with about 15%. Biomass and fuel oil both account for about 11%. Nuclear energy for 7% and RES (wind, PV and hydro) for 5%, both are used for electricity generation which in turn is used for heating and cooling. Other RES like solar (thermal) energy, ambient heat and geothermal energy in sum account for 1.5%. Across all energy carriers, RES account for 18% of primary energy supply for H/C, whereas fossil fuels account for the major share of 75%.

Figure 17: Primary energy demand for EU28 by energy carrier for H/C in all sectors in 2012 [TWh]



Source: own calculation

Overall, final energy demand in the EU28 accounted for about 12,821 TWh in 2012. Thereof around 6,500 TWh were used for heating and cooling (H/C) purposes, which equals a share of about 51%[21]. The final energy for H/C is used for a variety of different end-uses. Space heating is the most relevant end-use with a share of 52% of the total final energy demand for H/C (~3250 TWh), followed by process heating which

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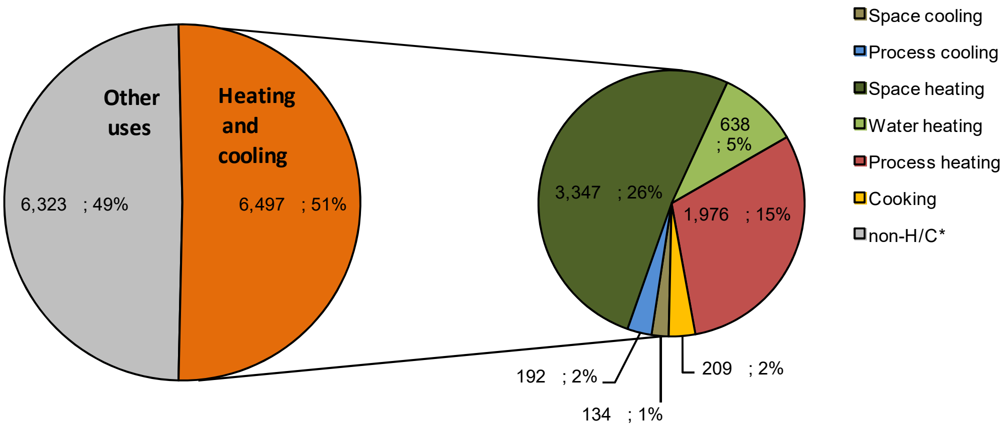
[21] The remaining 49% not used for heating and cooling is mainly used for transportation, mechanical energy in industry as well as household and service sector appliances.

makes up for 30% (~2000 TWh). Water heating (sanitary hot water) accounts for about 10% (~640 TWh), cooking in the residential sector for about 3% (~210 TWh) and cooling uses 5% in total. Cooling is distributed to space cooling (~130 TWh) and process cooling (~190 TWh) as illustrated in Figure 18.

Figure 18: Final energy demand for EU28 by end-use for H/C in all sectors in 2012 [TWh]

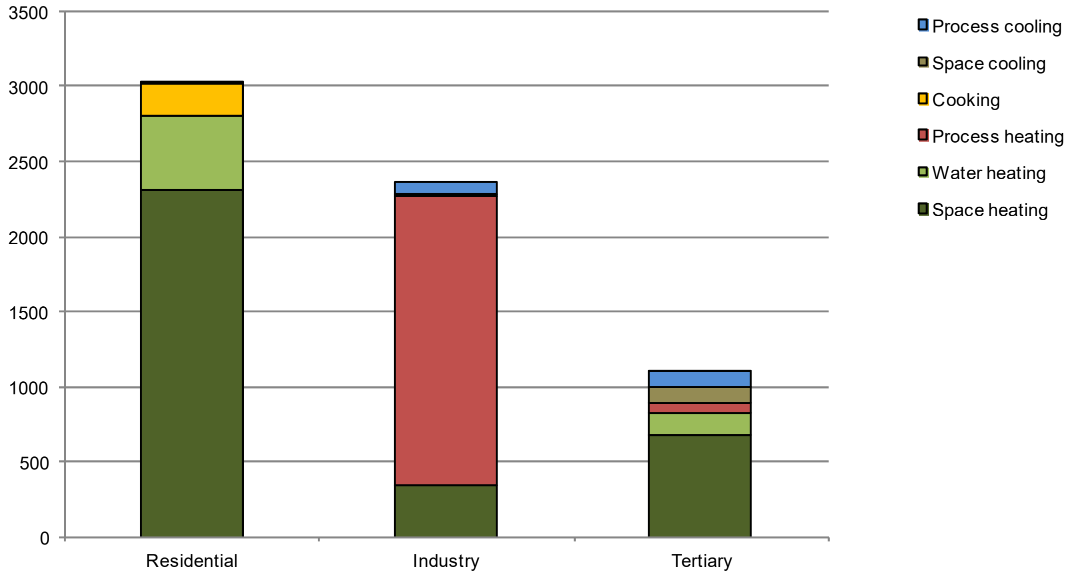


* Non-H/C comprises end-uses like transportation, mechanical energy in industry as well as residential and service sector appliances

Source: own calculation

The allocation of end-uses to the sectors residential, industry and tertiary is shown in Figure 19. Accordingly, H/C demand in the residential sector is dominated by space heating with a share of 78%. While also water heating has a substantial share of 16%, the remaining end-uses cooking and space cooling account for only 6% and 1%, respectively. In the industrial sector, process heating makes up for the major share with about 82%. Also in the tertiary sector, space heating has the major share, but other end-uses such as water heating, (14%), process cooling (10%) and space cooling (9%) also show relevant shares.

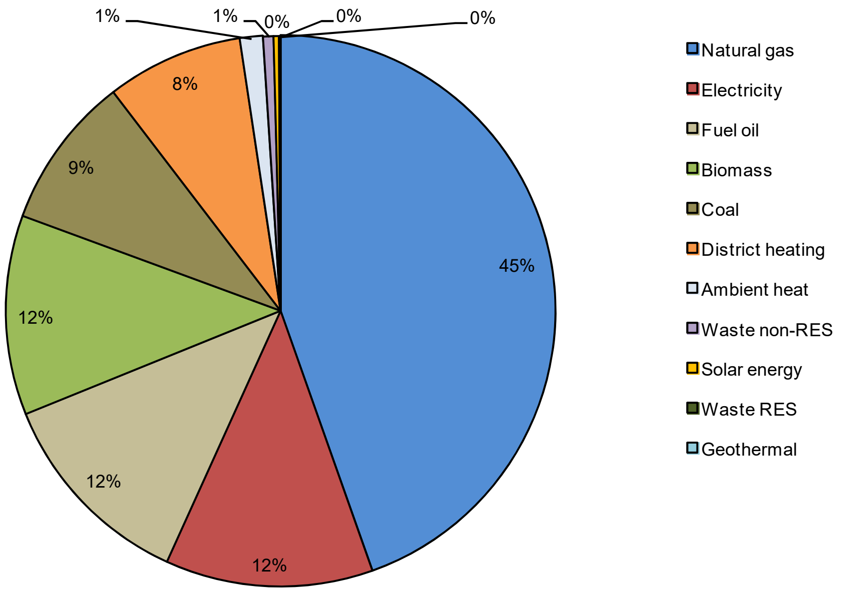
Figure 19: Final energy demand for EU28 for H/C by end-use and sector [TWh]



Source: own calculation

Splitting up the final energy demand for H/C by energy carrier reveals the huge importance of natural gas with a share of 45% (~2670 TWh) as shown in Figure 20. Other energy carriers are relatively equally distributed: Electricity with 12%, fuel oil with 12%, biomass with 12%, coal with 9% and district heating with 8%. Less important are ambient heat and waste non-RES with about 1% and solar energy, waste RES and geothermal energy, all with below 1%. In total, 66% of final energy for H/C is supplied by fossil fuels and 14% by RES. The remaining 20% are based on the secondary energy carriers electricity and district heating, which both consist of a country-specific mix of fossil fuels and RES. The analysis of primary energy demand also breaks down the secondary energy carriers to the individual fuels (see Figure 17).

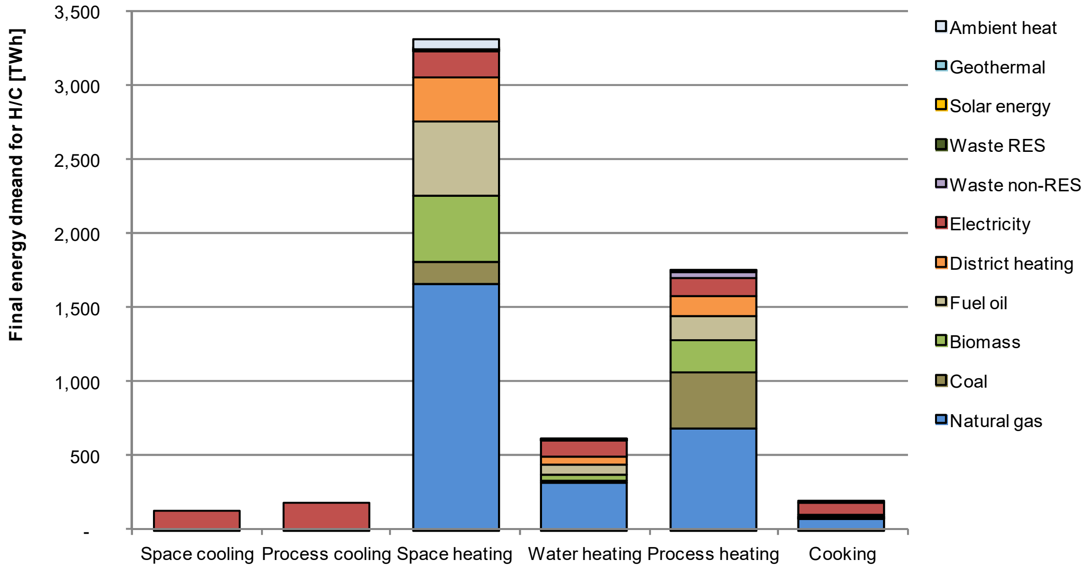
Figure 20: Final energy demand for EU28 by energy carrier for heating and cooling [TWh]



Source: own calculation

A breakdown of energy carriers by end-use is provided in Figure 21. Accordingly, there are substantial variations across energy carriers and end-uses. Still, for most end-uses natual gas is the dominant energy carrier. For instance it accounts for 50% of final energy use in space heating, 51% in hot water, 39% in process heating and 38% in cooking. Coal on the other hand is mainly used in process heating, whereas electricity is used throughout all end-uses. With regard to renewable energy, biomass is the most used RES with a share of 14% in space heating and 12% in process heating. Solar energy accounts for about 2% in water heating, but only below 0.3% in space heating, whereas ambient heat (via heat pumps) arrives at about 2% in space heating and 1.5% in water heating. Solar energy, geothermal energy and ambient heat together only have amarginal share in process heating with in total below 0.1%.

Figure 21: Final energy demand for EU28 by end-use and energy carrier in 2012 [TWh]

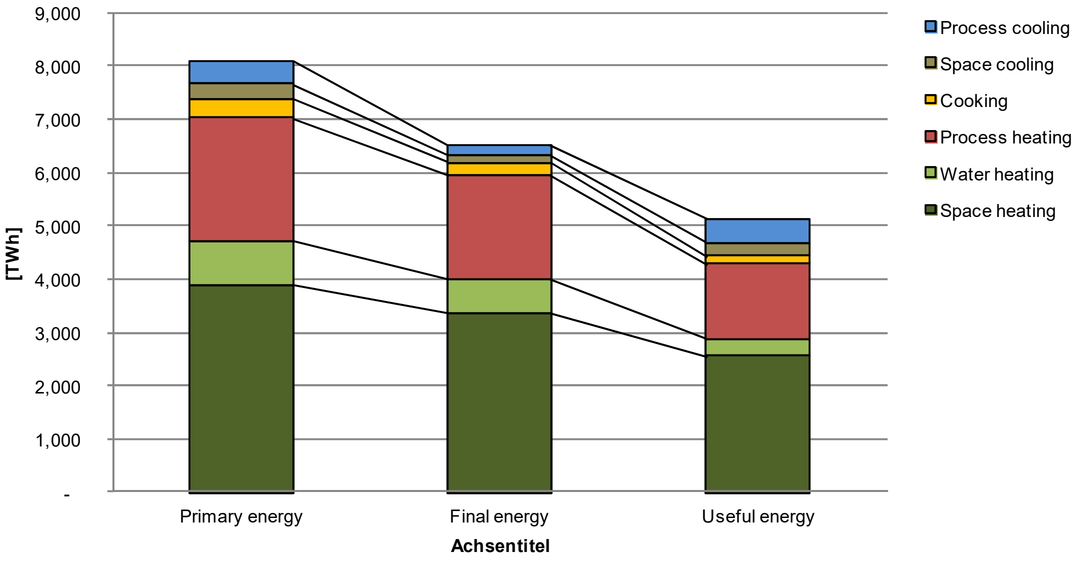


Source: own calculation

Finally, a comparison of the total energy demand for H/C between primary energy, final energy and useful energy is provided in Figure 22. As can be seen, substantial energy losses occur from primary to useful energy. 20% of primary energy are lost in the conversion to final energy and further 21% are lost in the conversion to useful energy. In contrast to the heating applications, which experience conversion losses from final to useful energy, the supply of useful energy for cooling is even higher than the final energy demand in the form of electricity. The technical reason is that ambient heat is used in compression cooling, but not accounted for in the energy balance. In total, space plus process cooling increase in shares from 5% for final energy to 13% for useful energy.

Particularly useful energy has to be interpreted with caution. Many different definitions are used in the literature and they result in very different conversion efficiencies. Our definition considers the generation, storage and distribution of the useful energy (e.g. from the boiler to the radiator) as described in chapter 3. The useful energy demand is not to be confused with a minimum energy demand. Many possibilities exist to reduce the useful energy demand without affecting the user needs, by e.g. insulating a building, improving the control of a heating system, reducing the indoor temperature, etc. In the definition we used, all these measures would reduce the useful energy demand but do not affect the conversion losses from final to useful energy.

Figure 22: Useful, final and primary energy demand for H/C in the EU28 by end-use in 2012 [TWh]



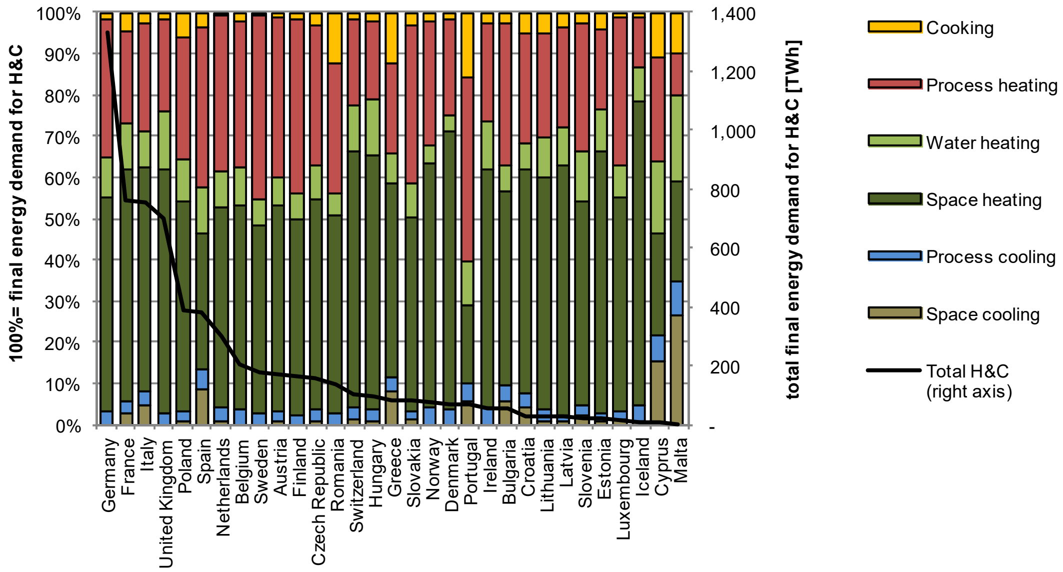
Source: own calculation

5.1.2 Country comparison

In the following, H/C demand is compared across countries. Included are EU28 member states plus Norway, Switzerland and Iceland.

A comparison of final energy demand for H/C by end-use reveals substantial differences across countries (see Figure 23). For instance, the share of process heating varies from about 15% in Estonia to 56% in Portugal. Although space cooling shows clear peaks in Mediterranean countries, its share arrives at a maximum of 9% (Greece) of total final energy demand for H/C - excluding the very small member states Malta and Cyprus where space cooling makes up 19% and 33%, respectively. Process cooling, on the other hand, is more evenly distributed across countries as it does not so much depend on the outdoor temperature, especially in very low temperature applications in the chemical sector such as air fractioning. Despite these differences, the general pattern is still comparable: Space heating and process heating account for the major share in most countries and all end-uses are represented in each country.

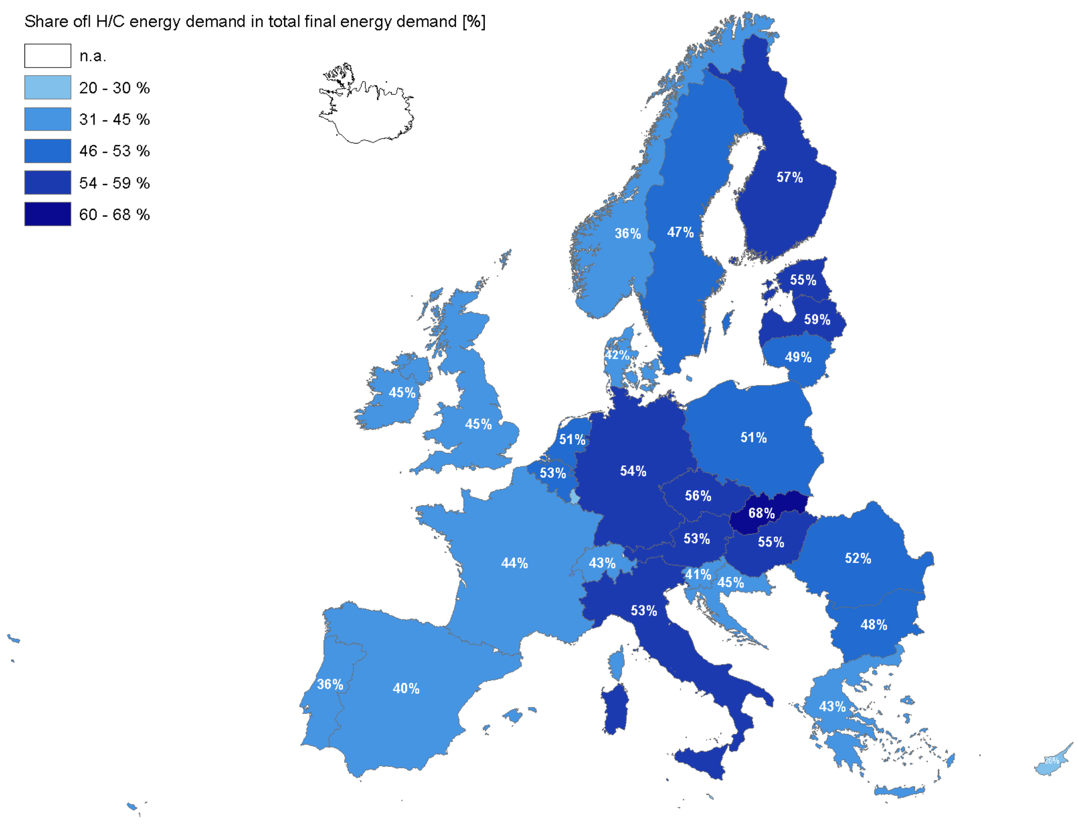
Figure 23: Final energy demand for EU28+3 countries by end-use in 2012 [TWh]



Source: own calculation

While the total EU28 energy demand for H&C equals about 51% of the total final energy demand in 2012, this share deviates substantially across countries as illustrated in Figure 24. The share ranges between 36% in Norway and Portugal and exceptionally high value of 68% in Slovakia. The values are on the one side mainly influenced by the presence of energy intensive industry and space heating demands, but also by the importance of energy demand in non-H/C sectors, mainly transport.

Figure 24: Share of H&C energy demand in total final energy demand in 2012



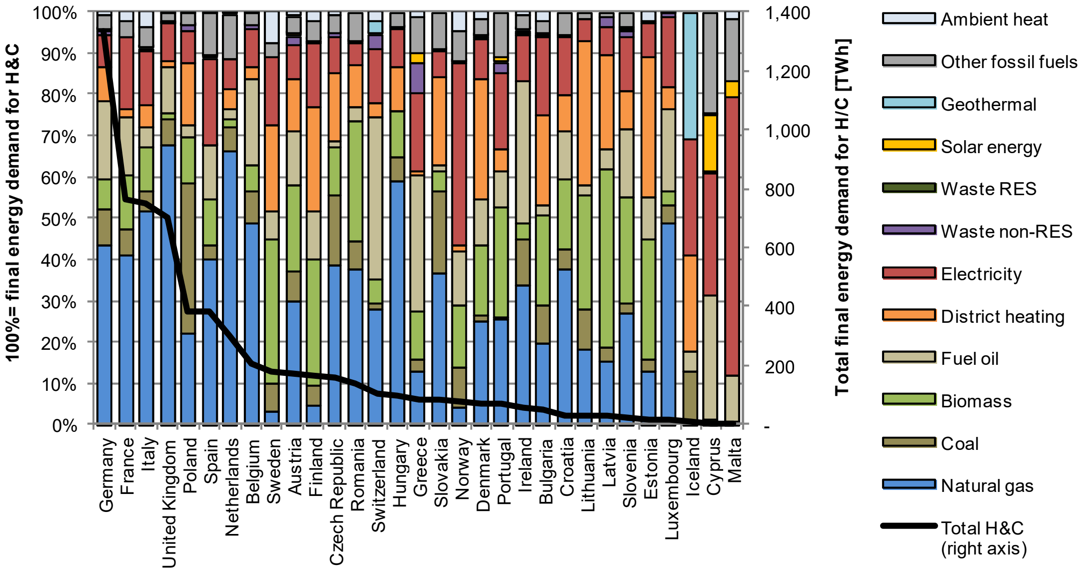
* No data available for Iceland

The picture is a lot more diverse when looking at the individual energy carriers used to provide H/C, as illustrated in Figure 25. The countries shown are sorted according to their total final energy demand for H/C in 2012, starting with the largest consumer, Germany, on the left. Natural gas is the major energy carrier for H/C in many countries (and in the EU as a whole). It even reaches 68% in the United Kingdom, 66% in the Netherlands and 59% in Hungary. Countries with a natural gas share of below 5% are the Nordic countries Finland, Sweden, Norway and Iceland plus Malta and Cyprus. Poland is the country with an exceptionally high share of coal with 38%, followed by Slovakia (20%) and the Czech Republic (17%). On the other side, in 24 out of 31 countries the share of coal is below 10%.

District heating has particularly high shares in northern and eastern countries. Lithuania (36%), Estonia (34%) and Denmark (29%) have the highest shares. Electricity has high shares of above 20% in countries with high space cooling demand, which are mainly the Mediterranean countries. Exceptions are Norway and Iceland, which also arrive at 45% and 28%, respectively.

The proportions of RES to some extent reflect the natural resources of the respective countries. In the Baltic countries plus Sweden and Finland the share of biomass is exceptionally high with more than 28% compared to an EU average of 12%. Cyprus on the other hand has the highest share of solar energy with about 14% followed by Malta with 4%. Iceland is the only major user of geothermal energy with a proportion of about 30%.

Figure 25: Final energy demand for H/C in the EU28+3 countries by energy carrier in 2012 [TWh]

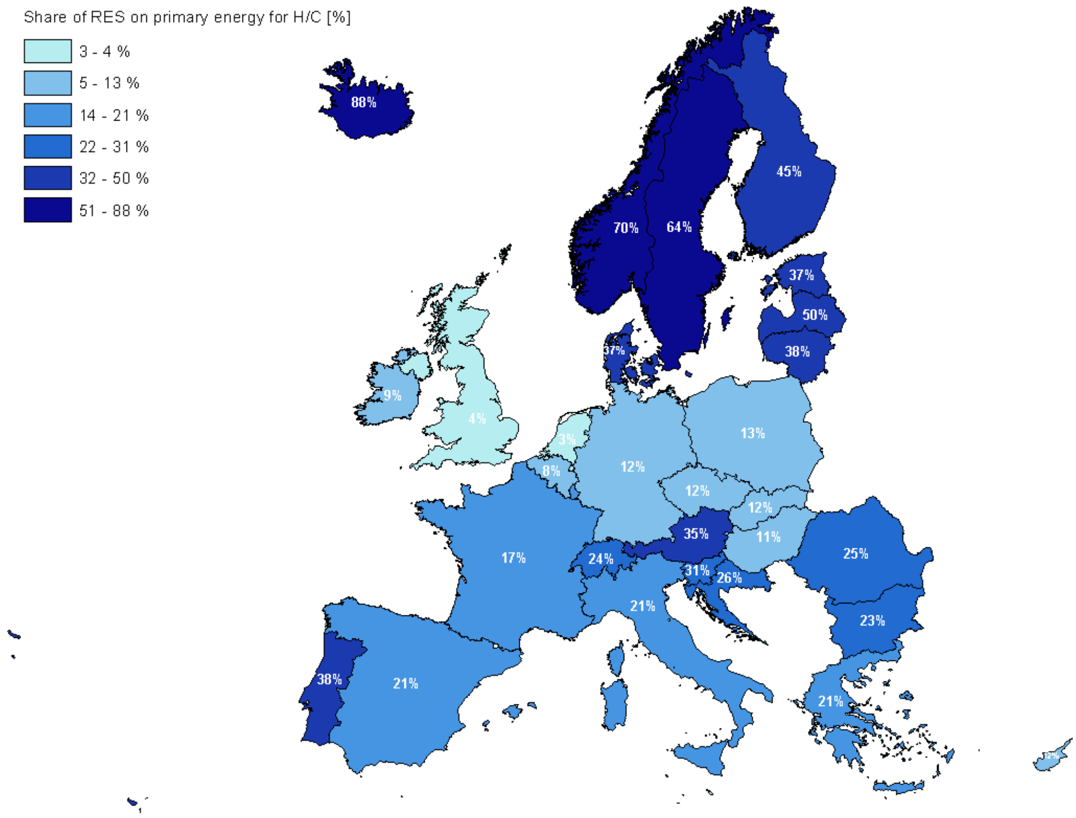


Source: own calculation

While Figure 25 shows the contribution of energy carriers as final energy, the maps below relate the importance of energy carriers and groups of energy carriers (RES) to the primary energy demand. Thus, secondary energy carriers as electricity and district heating are broken down to their fuel mix. The resulting share of RES in 2012 ranges between 3% (Netherlands) and 88% (Iceland). Additionally, particularly countries with large wood reserves show high RES shares, i.e. the Baltic and the Scandinavian countries.

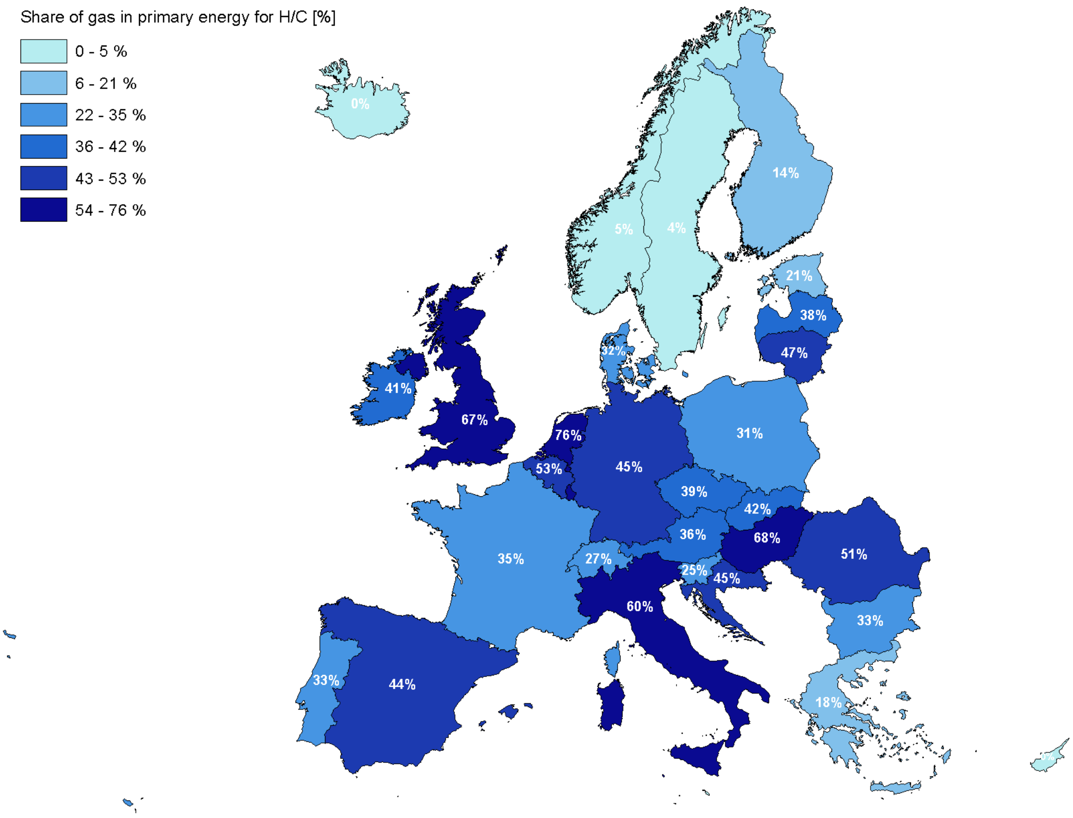
This calculation is different to the methodology applied in the SHARES tool used by EUROSTAT (EUROSTAT 2014b) which calculates RES-H&C share on the level of final energy. Thereby derived heat from renewables (district heating) is considered but RES used to generate electricity is not taken into account.

Figure 26: Share of RES in total primary energy demand for H&C in 2012



Despite the high share of RES in some countries, also fossil fuels such as fuel oil, coal and natural gas play an important role in many countries. The importance of natural gas is shown below also as share of total primary energy demand for H/C.

Figure 27: Share of natural gas in total primary energy demand for H&C in 2012



5.2 Industry sector

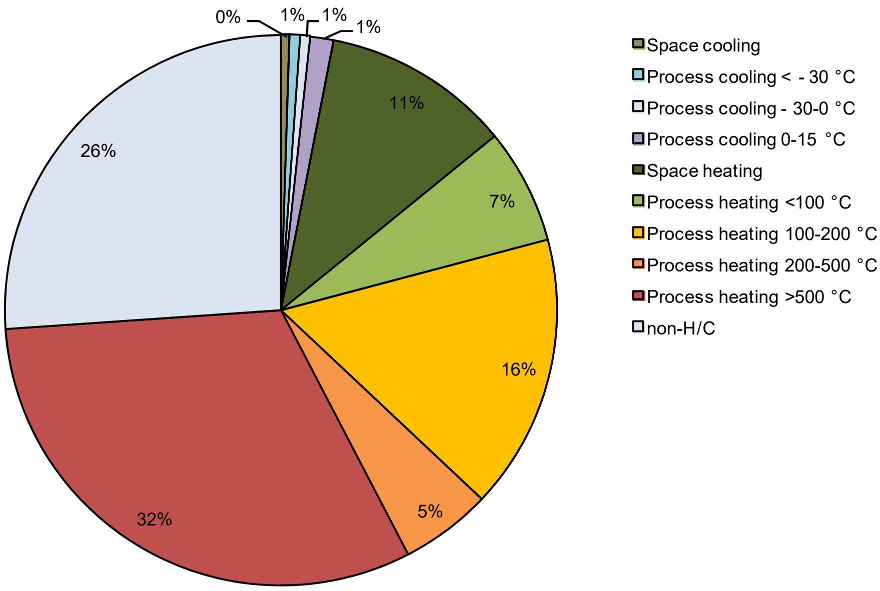
5.2.1 EU28

In the following, the final energy demand for H/C has been analysed in detail. In contrast to primary energy, final energy includes the secondary energy carriers district heating and electricity.

Figure 28 shows a decomposition of the total industrial final energy demand by end-use and temperature level for the EU28 in the year 2012. In total, the industrial sector used 3,200 TWh, of which 74% (2,365 TWh) are used for H/C.

With a total of 60% of the total final energy demand, process heating is the major end-use. It splits nearly equally into heat demands above and below 500°C. Heat demands > 500°C are provided by industrial furnaces, while heat demands below 500°C are mostly provided by steam boilers and CHP units. With a share of 11% also space heating is a relevant end-use. Process cooling accounts for about 3%, of which half is used for temperatures between 0 and 15°C. The 26% of final energy demand not used for H/C is mainly used for mechanical applications driven by electricity.

Figure 28: Final energy demand for EU28 by temperature level for process heating and cooling in industry in 2012 [TWh]



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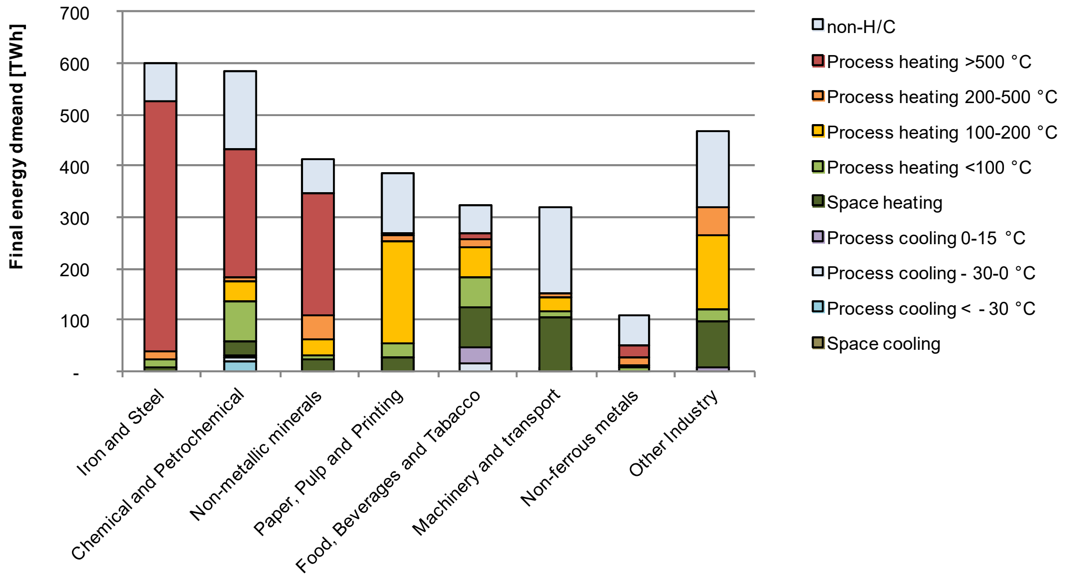
Source: own calculation

While Figure 28 provides the EU average, the distribution of H/C demands of individual end-uses varies substantially among the sub-sectors as can be seen in Figure 29. High temperature process heating is mostly needed in the iron and steel, the chemical and the non-metallic minerals (cement and glass) industries. Also non-ferrous metals (main demand in aluminium) has a high share of process heat >500°C, although in lower total numbers. Process heat in the form of steam between 100 and 200°C is mostly needed in the pulp and paper industry and the “others” sub-sectors, but to some extent in all sub-sectors. Space heating has high shares in the light industries (machinery and transport, food and tobacco and others). Process cooling is mainly used in the chemicals industry (mostly for air fractioning at very low temperatures) and in the food industry.

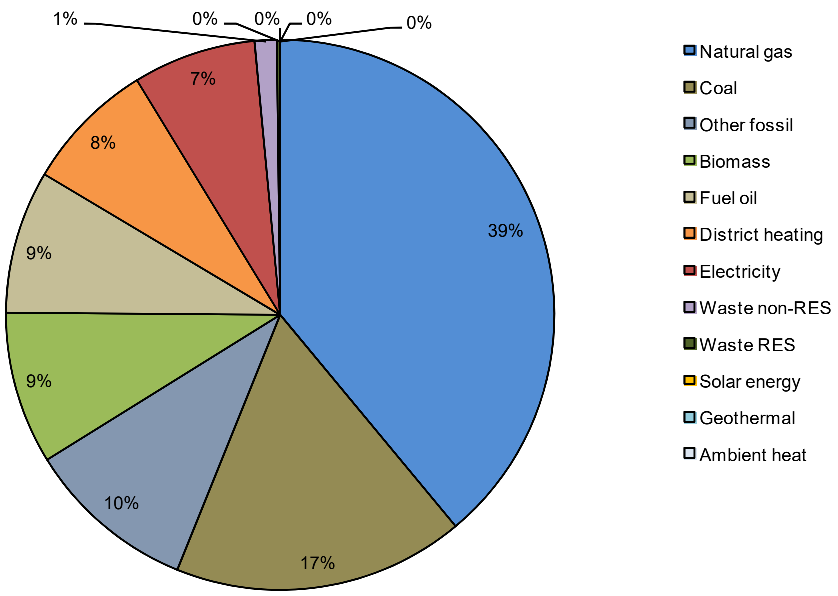
Figure 29: Final energy demand for EU28 by temperature level and sub-sector for heating and cooling in industry in 2012 [TWh]



Source: own calculation

Among the individual energy carriers used to supply H/C in the EU28, natural gas is the most dominant with a share of 39% of the total final energy demand for H/C in 2012 (see Figure 30). It is followed by coal (17%) and other fossil fuels (10%). In total, fossil fuels account for 76% and RES for about 9% of the energy supply for H/C in the EU28 industry in 2012. The remaining demand is allocated to biomass (9%), district heating (8%) and electricity (7%). RES

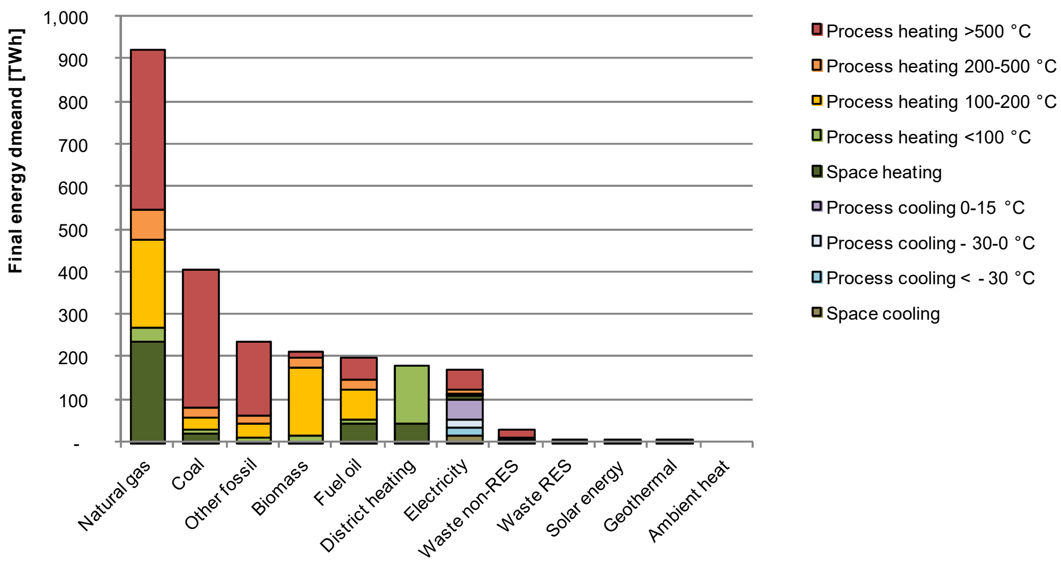
Figure 30: Final energy demand for EU28 by energy carrier for heating and cooling in industry [TWh]



Source: own calculation

Figure 31 shows the end-uses for each energy carrier. Accordingly, natural gas is mainly used for space heating, medium temperature heat and high temperature heat, whereas coal and other fossil fuels are mainly used for high temperature heat (mostly in the iron and steel industry). Biomass is mainly used to supply steam between 100 and 200°C, mostly in the pulp and paper industry. District heating is restricted in terms of the temperature levels provided and, consequently, is mostly used for low-temperature process heat below 100°C as well as space heating. Electricity has mostly diverse uses, first of all for all cooling applications, which are nearly completely based on compression cooling, but also for process heating (e.g. induction and electric arc furnaces).

Figure 31: Final energy demand for H/C in industry by energy carrier and end-use for the EU28 in 2012 [TWh]

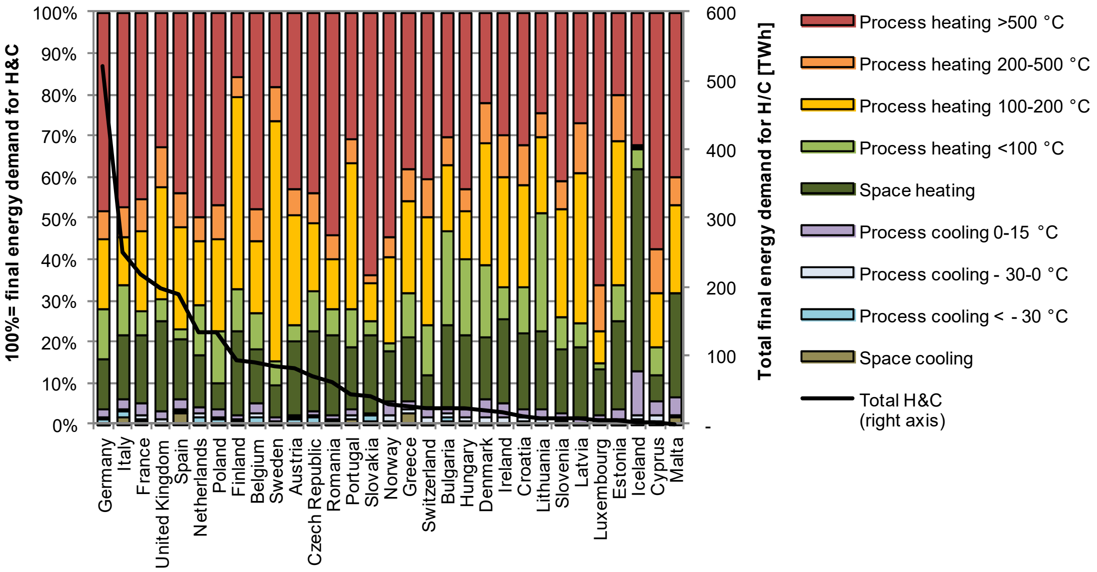


Source: own calculation

5.2.2 Country comparison

The distribution of individual end-uses across the European countries shows some diversity, but also some common patterns. For example process heating is an important end-use in all countries, even for temperatures > 500°C. The shares of end-uses are mainly influenced by differences in the industrial structure. Countries with higher shares of basic industries like iron and steel or non-metallic minerals (cement and glass) principally have higher shares of a demand for high temperature process heat, whereas countries with more light industries like transport and machinery tend to have higher shares of space heating. Process and space cooling only accounts for a smaller share in all countries, mostly below 5% in total. Steam demand between 100 and 200°C is high in countries with a large pulp and paper industry such as Sweden and Finland.

Figure 32: Final energy demand for H&C in industry by country and temperature level



Source: own calculation

Figure 33 zooms into the final energy demand for cooling by country.

The estimated electricity demand for process cooling amounted to 83 TWh in 2012. For space cooling in industry it is about 16 TWh. The top six countries with higher cooling use are Germany (19%), Italy (15%), France (11%), Spain (11%), UK (7%), and the Netherlands (6%).These countries represent 69% of total process and space cooling in the EU28+3 countries.

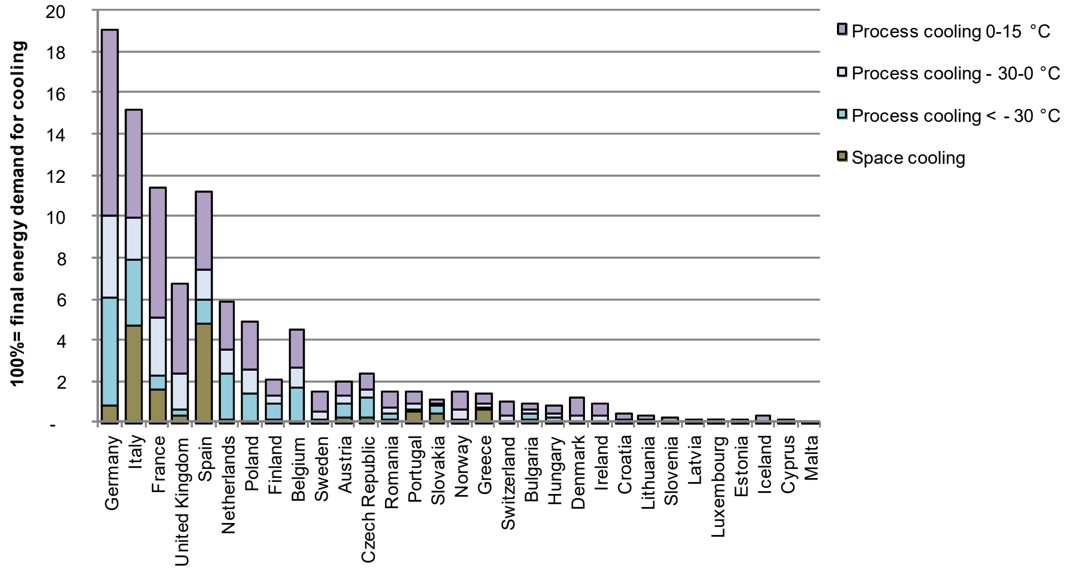
Process cooling between 0°C and 15°C amounts to 46 TWh (54% of total process cooling) in Europe and stresses the importance of the industrial food cool supply along its supply chain. Additional requirements for the food industry with respect to freshness, reduction or complete avoidance of the use of additives, sustainability, increased quality, and hygiene increase the importance of process cooling technologies in the processing of foodstuffs. The storage of products before production and after production of foodstuffs in cold storage houses is central for process cooling. Centralised cooling technologies for storage are found across Europe with relevant capacity sizes. These examples highlight the diversity of cooling uses in the food industry.

The demand for process cooling between 0°C and -30°C reaches 19 TWh. This corresponds to processes of deep cooling in different food processes (see above) and chemical industries. The use of cooling is very diverse in the chemical industry and includes the cooling down of different types of fluids as well as gases, and the direct cooling of processes. At this temperature level different cooling machines are used in auxiliary processes or in integrated cooling machines in laboratories. In addition, freeze-drying processes require deep freeze temperatures relevant for pharmaceuticals and medicine production. This is particularly needed for the storage of final products and climate chambers also relevant in bio-technology.

Process cooling at very low temperatures below -30°C down to about -190°C amounts to 20 TWh in 2012 in Europe and is only needed for the refrigeration of a portion of the processes and products of the chemical industry. The largest proportion arises from air fractioning and deep temperature gases liquefaction processes carried out in the basic chemicals industry. A small proportion arises in research and development processes or military uses.

Space cooling is mainly used in the Mediterranean countries, Italy, France, Spain, Portugal and Greece and only to a very low extent in the northern European countries.

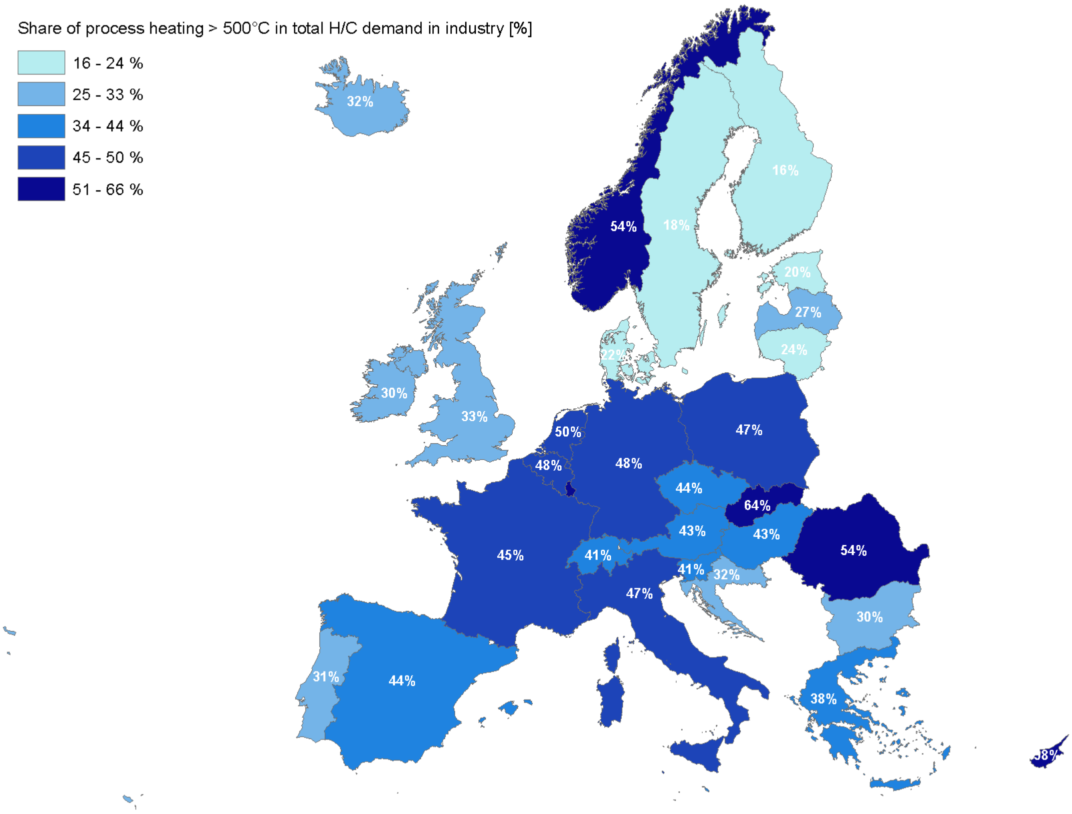
Figure 33: Final energy demand for cooling in industry by country and temperature level



Source: own calculation

The structure of end-uses for heating and cooling in industry varies substantially by country as shown above. The share of process heat above 500°C provides an indication for the importance of heavy industry (iron and steel, cement, glass)in a country as illustrated in the map below.

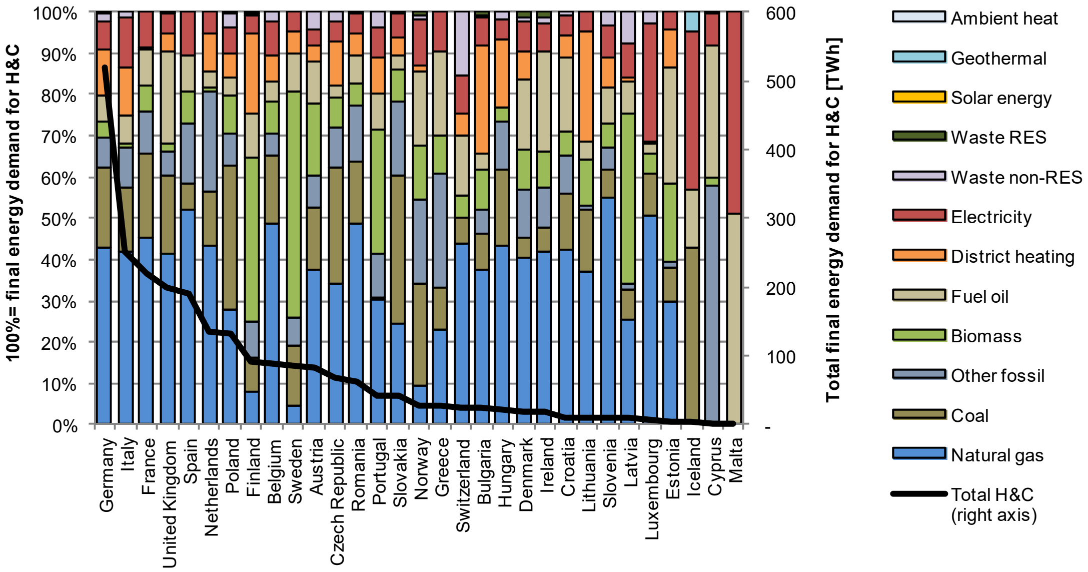
Figure 34: Share of process heat demand above >500°h in total industrial H&C final energy demand in 2012



Comparing the use of energy carriers for the provision of H/C across countries reveals even larger variations than it is observed for the end-uses. Figure 35 illustrates the importance of natural gas in most countries: In 14 countries the share of natural gas ranges between 40 and 55%. Only 6 countries have natural gas shares of less than 10% (Norway, Finland, Sweden, Iceland, Cyprus and Malta). The use of coal ranges between 0% (Cyprus and Malta) and 44% (Iceland). Many eastern countries show high shares of coal, but also countries with large iron and steel industries like Germany, France, Italy and the United Kingdom.

Biomass is by far the most important RES in industry. Its use ranges from less than 5% (Netherlands, Italy, United Kingdom, Hungary, Germany, etc.) to 55% in Sweden. High shares are also observed in Latvia with 41%, Finland with 40% and Portugal with 30%. Other RES only have marginal shares.

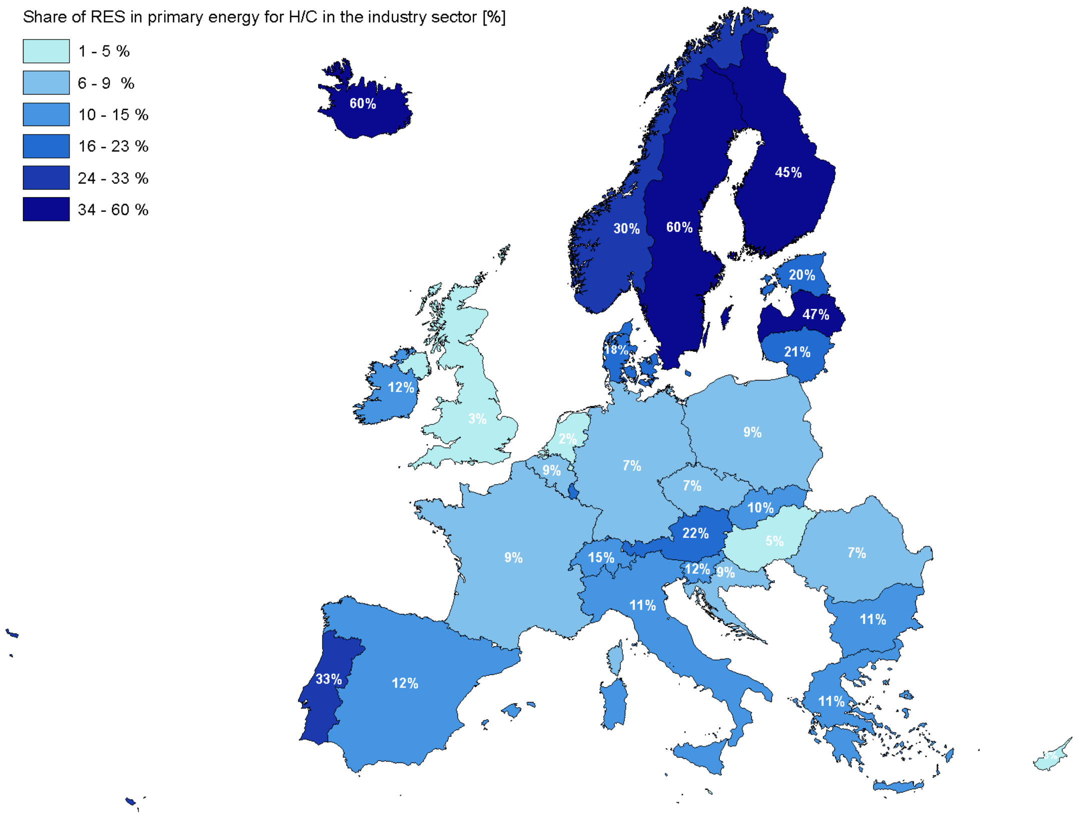
Figure 35: Final energy demand for H&C in industry by country and energy carrier



Source: own calculation

Figure 36 shows the share of renewable energy sources (RES) in total primary energy demand for heating and cooling in industry in 2012. For all countries, biomass is the dominant RES source in industry, which also explains why particularly countries with large wood reserves have high RES shares.

Figure 36: Share of renewable energy sources in heating and cooling primary energy demand in industry in 2012



5.3 Residential sector

The following figures represent a small extract of the detailed results of the data analysis which is provided by the additional excel files. The aim is to show interesting results regarding the shares of heating and cooling end-uses as well as the applied energy sources. Beside cumulative numbers on the whole heating and cooling sector in the EU-28, figures with comparisons of all countries[22] within the scope of the study are included in this section as well.

5.3.1 EU28

The dominant end-use of the residential sector in Europe is space heating which accounts for 68 % of the total final energy demand in Europe (Figure 39). Only 11 % of the final energy demand is used for non heating and cooling purposes. Space cooling is a relevant end-use category for certain countries in Europe (Figure 42), however, the overall share of the final energy demand in the European residential sector is negligible.

22 EU 28 Member States, Norway, Switzerland and Iceland

Figure 37: Shares of end-uses on total residential sector final energy demand in EU-28

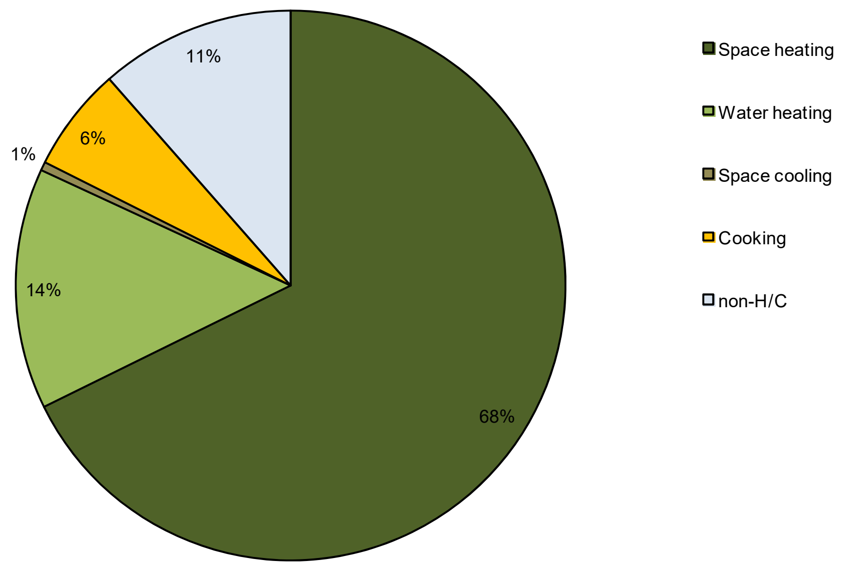
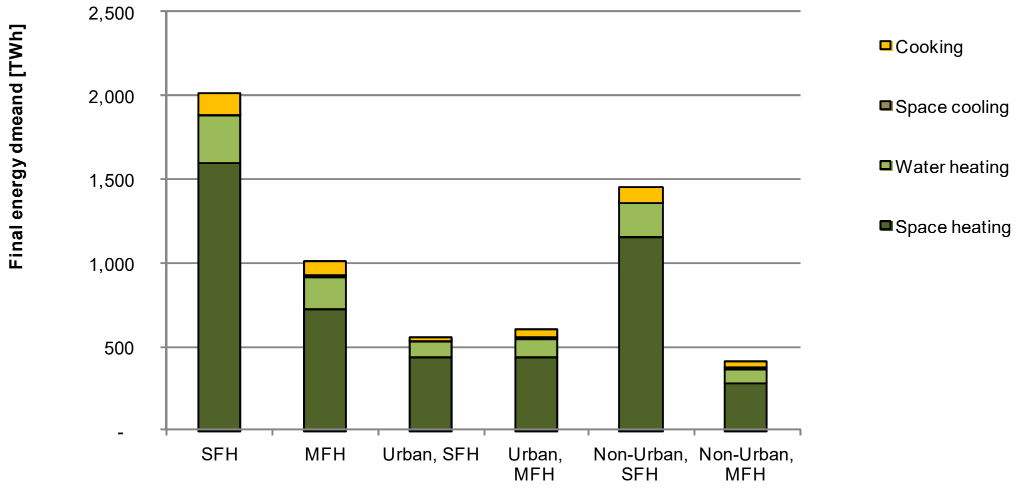


Figure 38 shows the final energy demand for heating and cooling end-uses by building categories and region types of all countries within the scope of the study. The heating and cooling energy demand of all single family houses is twice as high as that of all multi-family houses. The regional disaggregation reveals that 72 % of the heating and cooling demand of single family houses is consumed in non-urban regions[23]. Heating and cooling demand in urban regions is equally distributed among single and multi-family houses.

23 Rural and intermediate

Figure 38: Final energy demand of residential end-uses by building category and region type in EU-28



The dominant energy carrier applied to heating and cooling uses in the residential sector is natural gas (Figure 39,Figure 40) , followed by biomass with 16 % of heating and cooling demand even exceeding the total usage of fuel oil (12 %). In total, 61 % of heating and cooling uses are provided by directly burning fossil fuels whereas decentralised RES-H/C account for 20 %, electricity and district heating for 11 % and 9%, respectively.

Figure 39: Final energy demand by end-uses and energy carriers in EU28

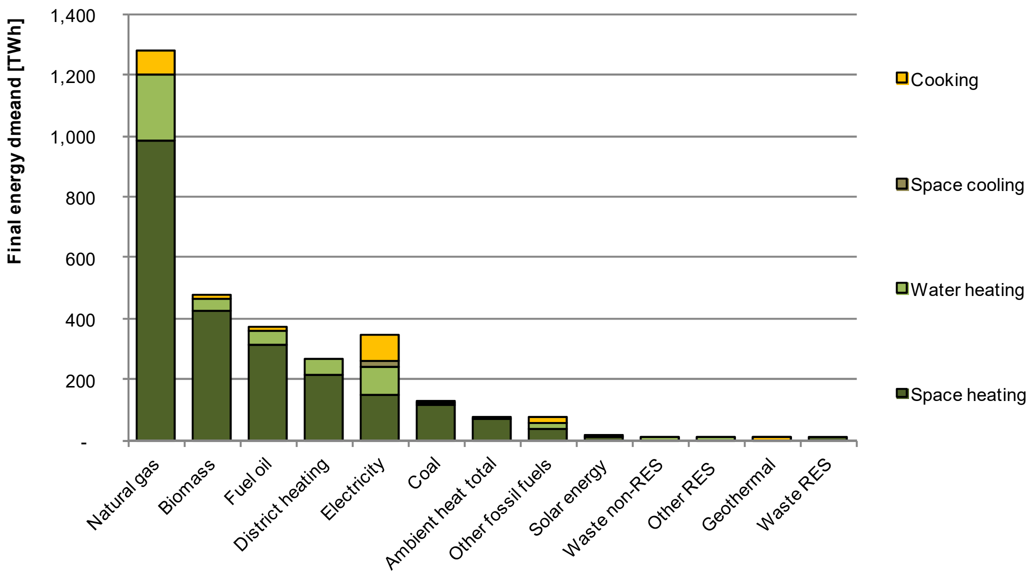
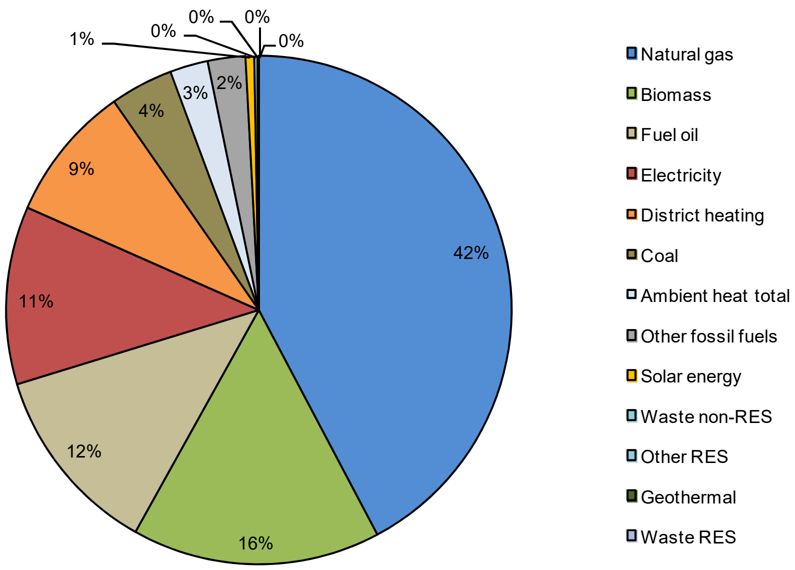


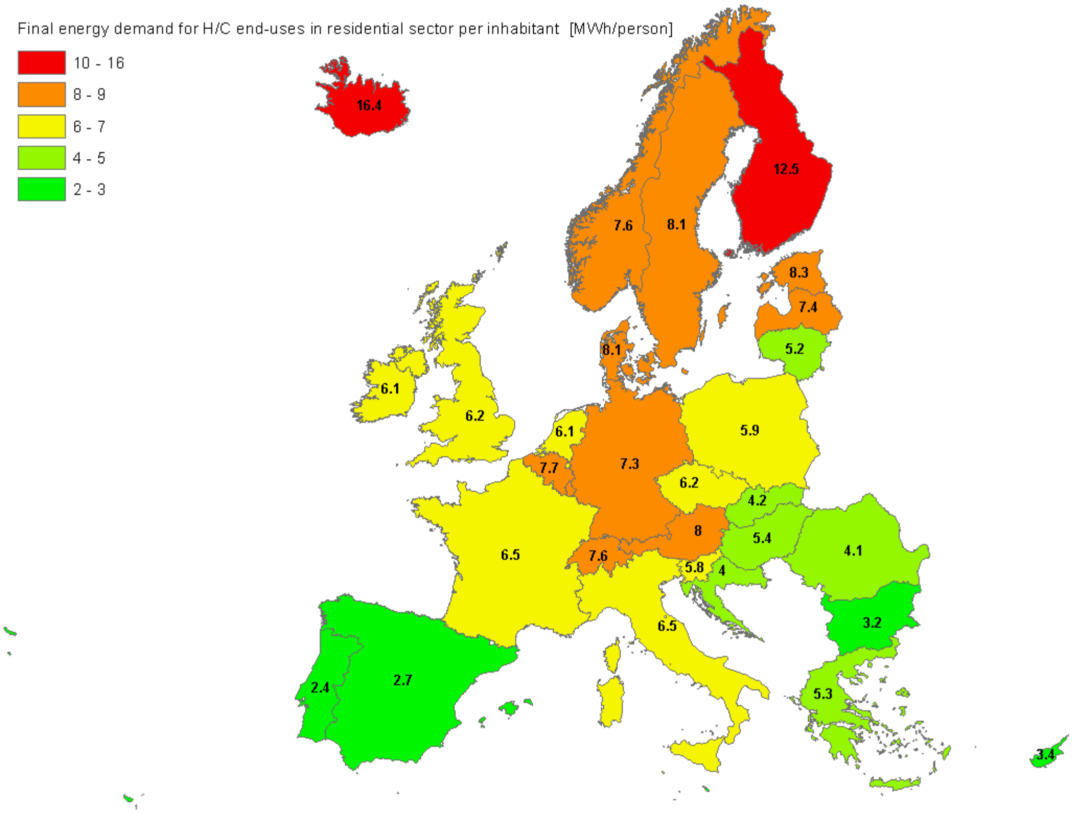
Figure 40: Share of energy carriers on final heating and cooling demand (EU-28, Norway, Switzerland, Iceland)



5.3.2 Country comparison

The end-use category with the highest share on total heating and cooling demand is space heating in almost all countries. Figure 41 compares the countries within in the scope of this study by the annual space heating energy demand per inhabitant for the year 2012.

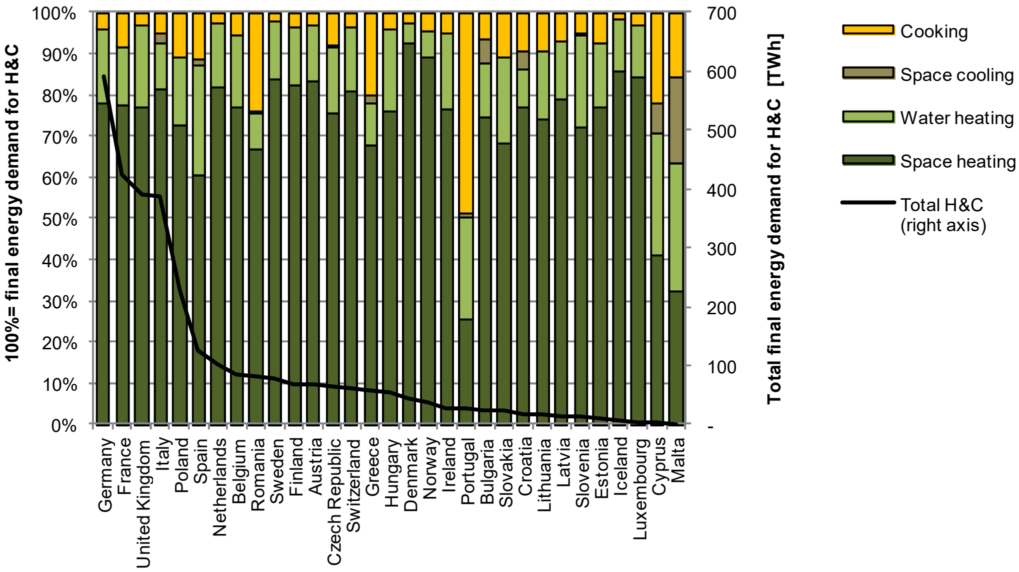
Figure 41: Comparison of specific energy demand for space heating in 2012



Source: Fraunhofer ISI

Figure 42 compares the shares of all end-uses for the total heating and cooling demand.The average share of the final energy demand for water heating of the total heating and cooling demand accounts for 16% whereas the share of the final energy for cooking is between 5 and 10% in most countries. Most of the countries show a similar picture regarding the distribution of energy demand on the different end-use categories. However in Cyprus and Malta the energy demand for water heating and space cooling dominates. Portugal exhibits a very high share of the final energy demand for cooking accounting for 49% of the total heating and cooling demand or 39% of the total final energy demand in the residential sector (see also Sousa 2011, Instituto Nacional de Estatística 2011).

Figure 42: Share of heating and cooling end-uses per country



The total energy demand for space cooling of EU 28 member states accounts for 17.4 TWh in 2012. The calculation of Werner (2015) results in a similar number for EU 28 of 14.5 TWh. However, there are some deviations in the country specific results. The paper estimates cooling demands based on total floor areas, average specific cooling loads and shares of cooled floor areas[24] and is therefore similar to the modelling approach used in this analysis. As described in section 4.3.2, our results are partly based on national statistics and surveys as well as modelled data. compares the results derived in this analysis with the calculation of Werner (2015). Relevant differences occur for Bulgaria, Spain and Italy. The data used for these countries in our analysis originate from national statistics and the ODYSSEE database.

[24] Werner (2015: 6,table 3) calculates cooling demands. In order to derive electricity consumption, the results need to divided by the average COP of 3.1 assumed by Werner (2015).

Figure 43: Comparison of results for space cooling energy consumption

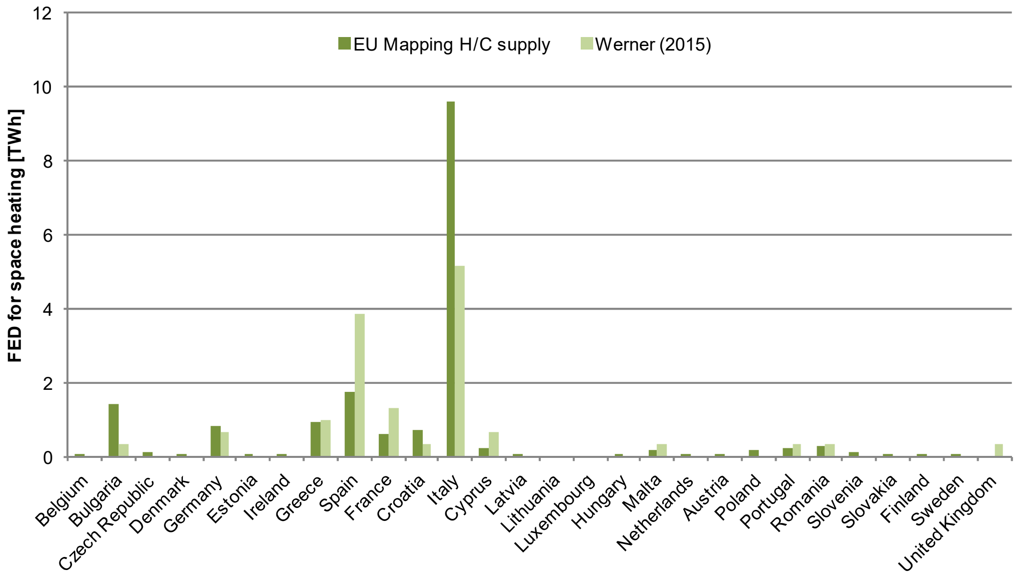
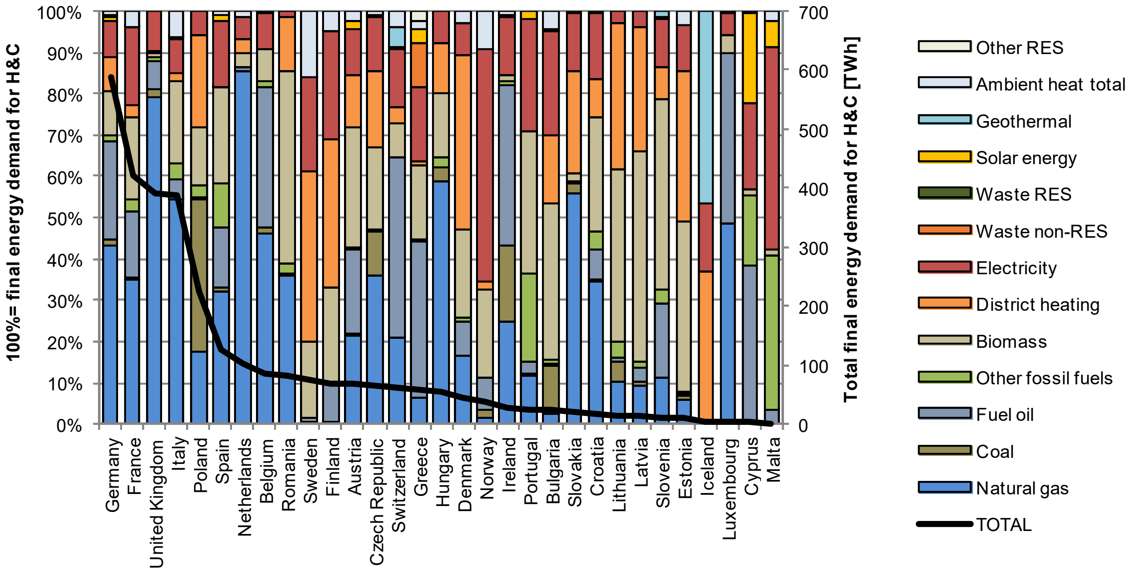


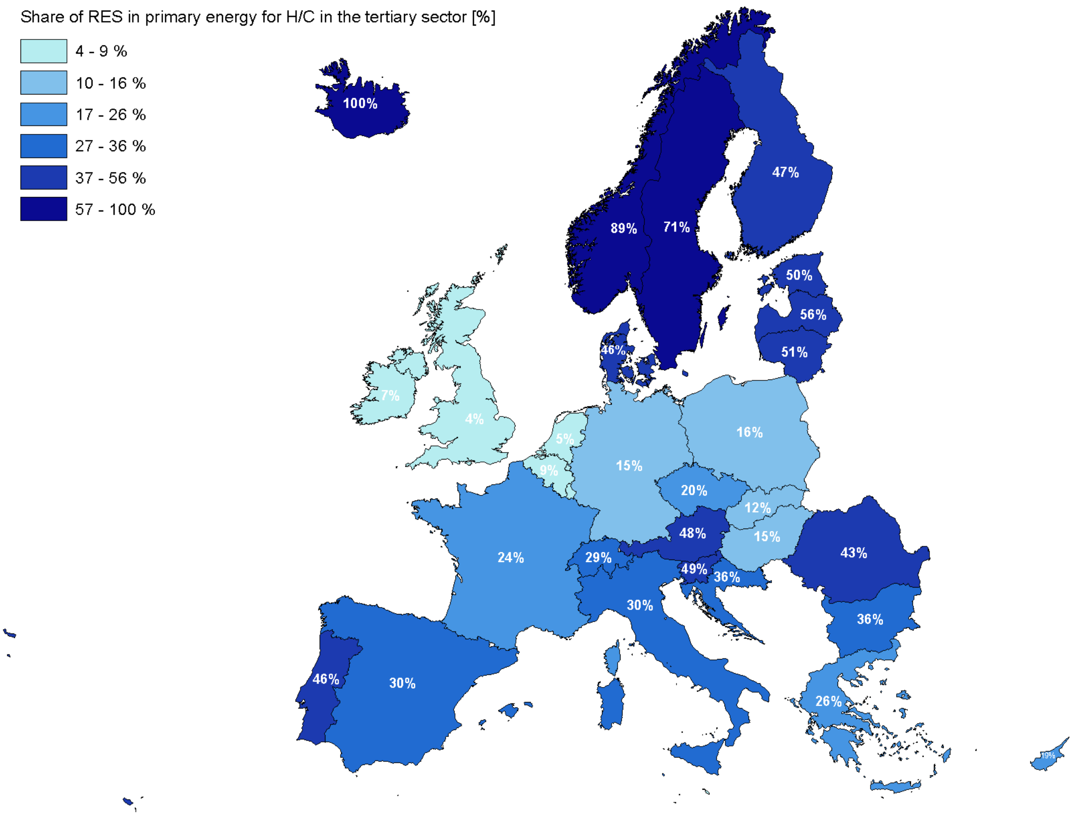
Figure 44 compares the applied energy carriers for the heating and cooling demand of the individual countries. The comparison shows that clustering countries is possible with regard to their energy supply for heating and cooling. Countries such as the UK, the Netherlands, Slovakia and Hungary rely mainly on a gas-grid based energy supply with shares of above 50% of their energy supply. Another group of countries exhibits a higher diffusion of district heating networks such as Sweden, Denmark, Finland and the Baltic states. Electricity for heating and cooling has a high share especially in Norway, Bulgaria, Cyprus and Malta whereas the biomass consumption is high in Eastern Europe as well as the Baltic States. A significant share of fuel oil usage for heating is observed in Belgium, Greece, Switzerland, Ireland, Luxembourg and Cyprus.

Figure 44: Share of energy carriers on total heating and cooling demand by country



In order to derive the total RES share on heating and cooling consumption, a comparison on the level of primary energy consumption is performed. Since most countries exhibit a significant share of use of electricity and district heating in the supply of heating and cooling, a comparison on the level of final energy would neglect RES deployed in the transformation sectors. The results depicted in Figure 51 show that the Northern European countries exhibit a very high RES share on primary energy for heating and cooling from above 50% which is mainly a result of the high share of RES-E and RES deployment in district heating.

Figure 45: Share of RES in total primary energy demand for heating and cooling in the residential sector in 2012



Source: Fraunhofer ISI

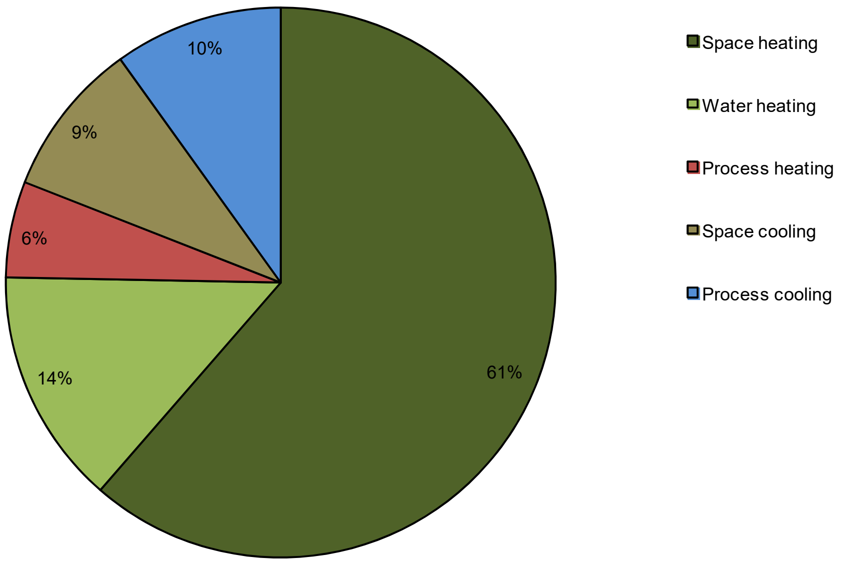
5.4 Tertiary sector

5.4.1 EU28

In addition to the total results, additional sub-sector results for the tertiary sector are introduced here. The focus is on the results for final energy consumption whereas primary and useful energy demand results may be found in the complete data set delivered to the Commission.

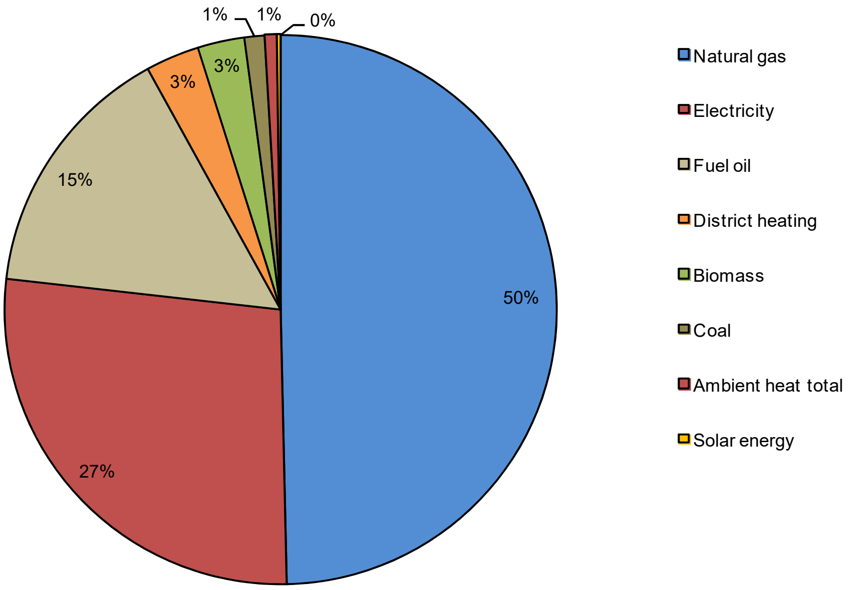
The main part of the energy demand for heating and cooling purposes is dominated by end-uses for space heating, which make up 61% of the total demand (see Figure 46). Together with the demand for warm water, the two main end-uses cover 75% of the final energy demand in the tertiary sector for heating and cooling. The remaining 25 % are defined by process cooling (10% of final energy demand), space cooling, and process heating.

Figure 46: Share of final energy demand per end uses for all services sub-sectors of EU28



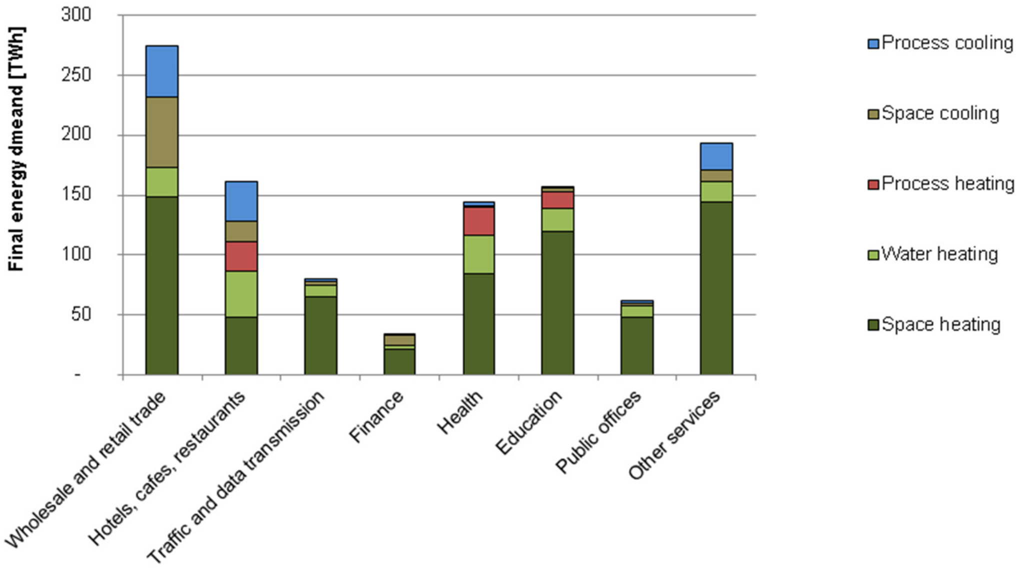
The distribution of the energy carriers which are needed to cover the above-mentioned final energy demand is dominated by natural gas (see Figure 47). With 50% natural gas is the main energy source for heating and cooling purposes. Fuel oil, the second most relevant fossil energy carrier covers 15% of the demand. Therefore, 65% of demand is covered by fossil sources. Renewable energy sources such as biomass, solar energy or ambient heat only cover 4% of the total heating and cooling demand in the services sector in 2012. The remaining 30% are covered by the secondary energy carriers' electricity and district heat.

Figure 47: Fuel shares to cover final energy demand for heating and cooling in the services sector



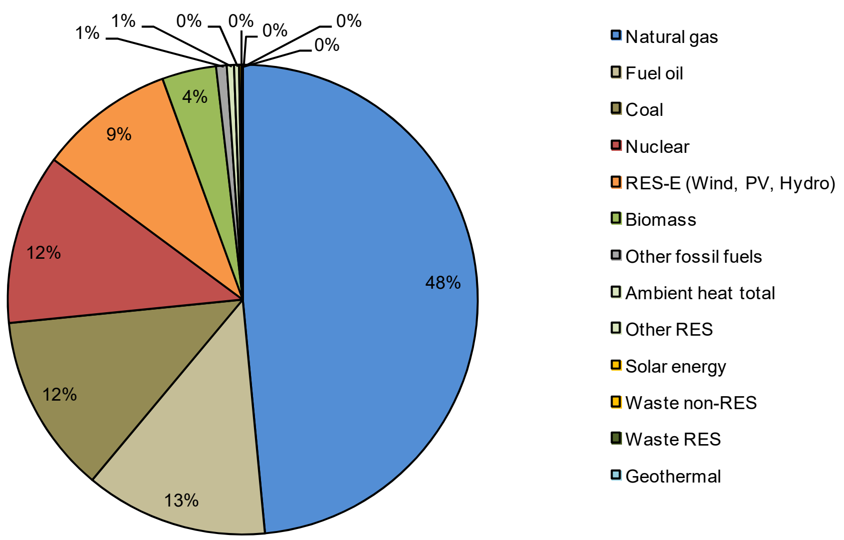
The final energy demand for heating and cooling varies across sub-sectors (see Figure 48). The dominating sub-sector is the wholesale and retail trade sector covering 25% of the total demand, followed by other services sub-sector with 17% of total demand. The highest demand for space heating can be found in the wholesale and retail trade sub-sector together with the education and other services sub-sectors (412 TWh or 61% of total heating demand). The wholesale and retail trade sub-sector is also dominating the demand for space cooling (58 TWh in total or 57% of total space cooling demand) and process cooling (43 TWh in total or 39% of total process cooling demand) although to a lesser extent. The demand for process heating is mainly driven by the subsectors hotels & services and health (together 49 TWh or 78% of total process heating demand).

Figure 48: Final energy demand of the different sub-sectors in the tertiary sector



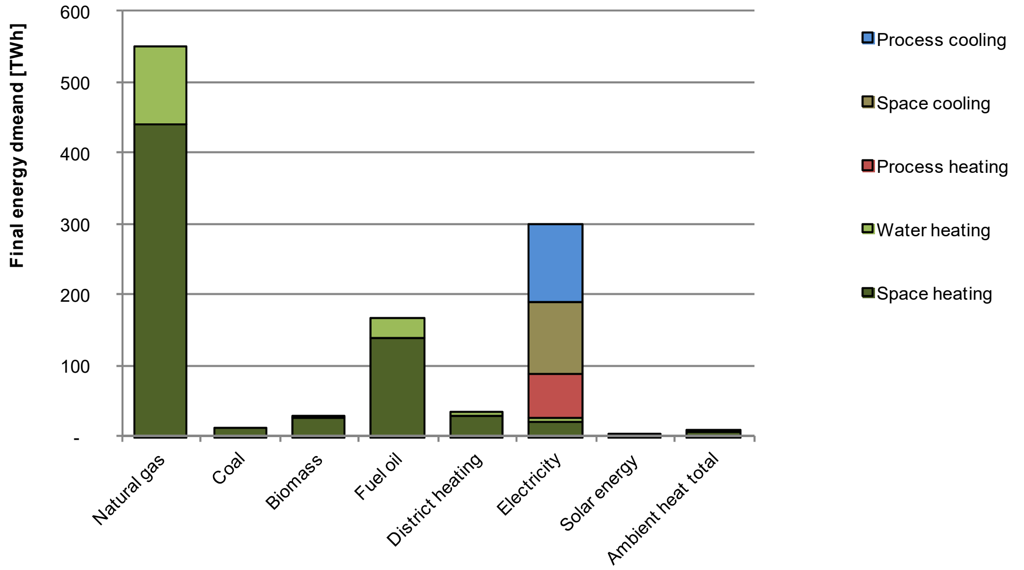
On the level of primary energy, the renewables share is slightly higher compared the final energy demand shares (see Figure 49). This is due to the fact that electricity and district heat are weighted based on country-specific electricity and district heat generation input mixes and conversion factors. Renewable energy sources (RES) cover 13% of the primary energy demand for H/C in the services sector. Fossil fuels make up 74% of the primary energy demand of which 48% are based on natural gas. The remaining primary energy is covered by nuclear energy (12%) and negligible amounts of waste products.

Figure 49: Primary energy demand for H/C in the services sector



Regarding the use of the different energy carriers per end-use, it is found that natural gas and fuel oil are mainly used for heating purposes (space heating and water heating together 718 TWh) whereas electricity is used mainly for process cooling and heating and space cooling (together 274 TWh, see Figure 50).

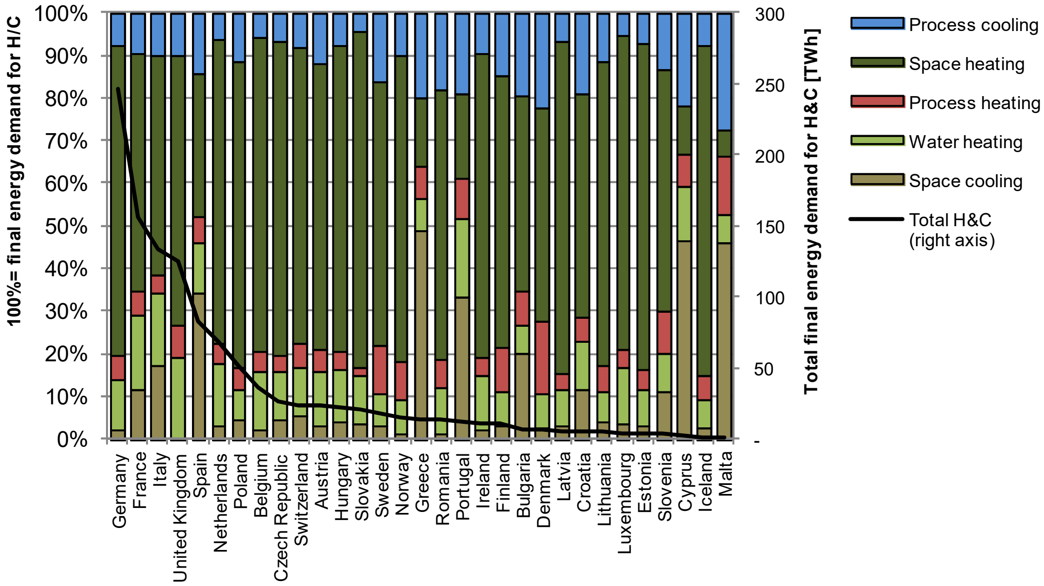
Figure 50: Final energy demand per fuel type and end use in [TWh] for H/C in the services sector



5.4.2 Country comparison

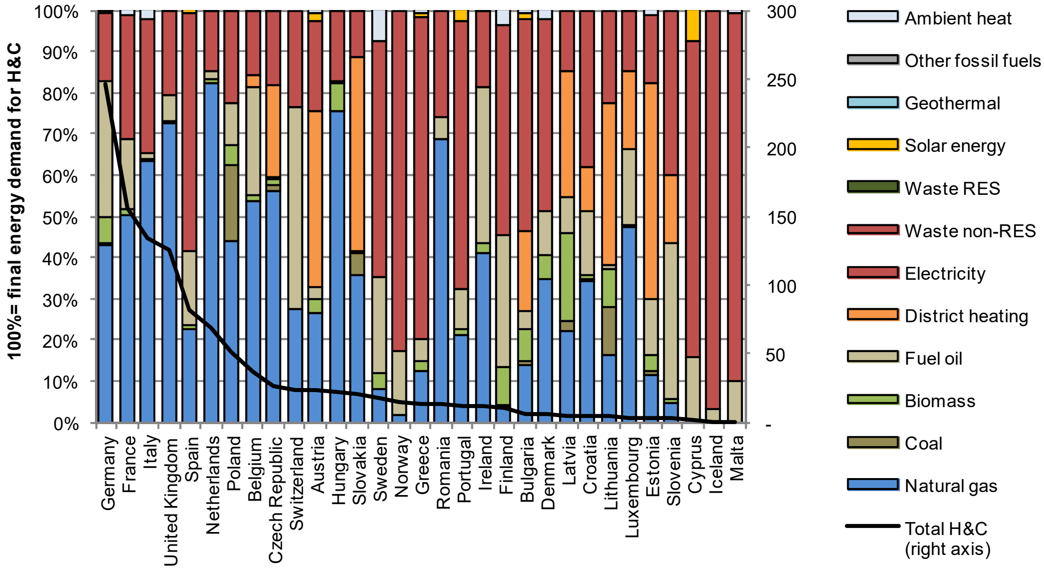
On a country level, a clear distribution between climatic zones can be distinguished regarding H/C (see Figure 51).

Figure 51: Share of different end-uses in comparison to the total H/C demand per country. On the secondary axes (right) the sum of H/C demand per country is shown in TWh



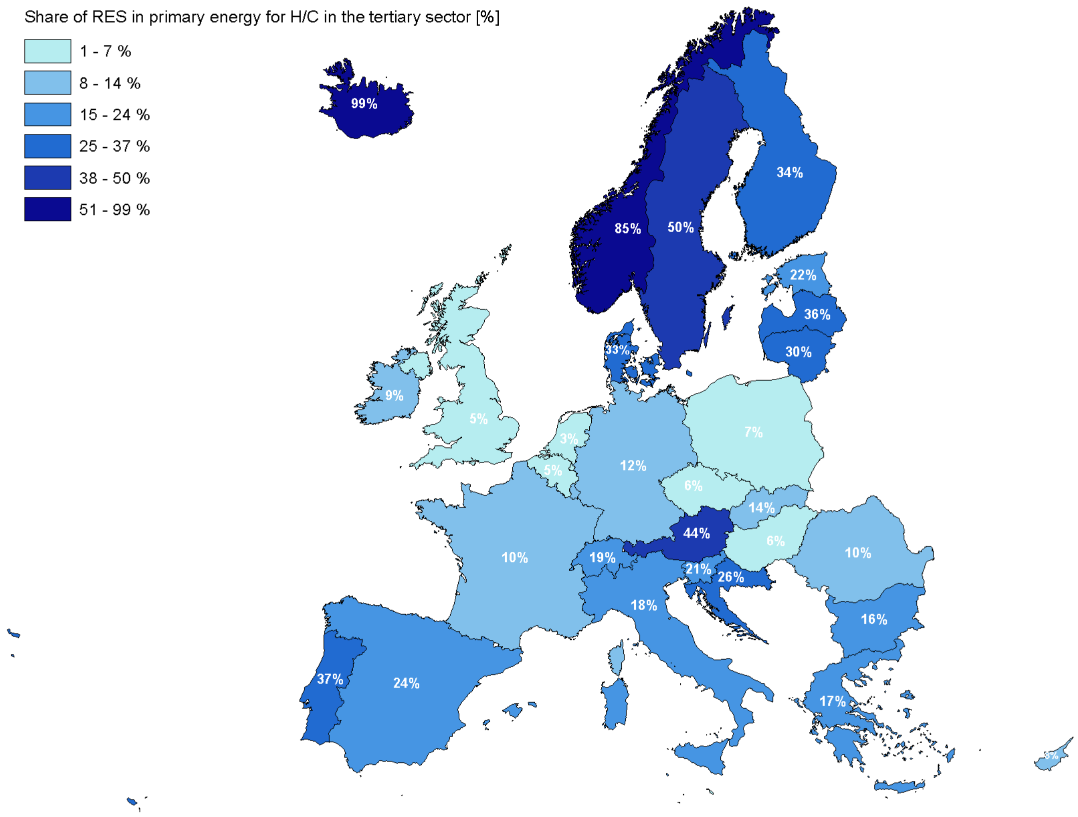
A broad variety of fuel mixes is used to cover H/C demand, depending on the country-specific energy infrastructure and available energy resources. Countries with direct access to gas resources (such as the UK and the Netherlands, see Figure 52) mainly use this energy carrier for heating purposes, other countries rely heavily on secondary fuels or other fossil sources.

Figure 52: Share of energy carriers to cover H/C demand per country. On the secondary axes (right) the total demand per country is shown in TWh



The total share of all RES in the total tertiary sector primary energy demand of a country deviates strongly. Figure 52 illustrates this share by country. It ranges from 3% (Netherlands) to 99% (Iceland).

Figure 53: Share of RES in total primary energy demand for heating and cooling in the tertiary sector in 2012



5.5 District heating and cooling

5.5.1 Final consumption – district heating and cooling

As can be seen in Figure 54, Poland, Germany, Sweden and Finland are the countries with the highest heat sales from district heating and together they represent around half of total district heat sales in the considered countries.

District heat is used mainly in the residential sector (45%) and the tertiary sector (24%), while only 11% is in the industry sector. Approximately 20% of the final consumption is used in not specified sectors.

The penetration of district heating in the residential sector is highest in Iceland, where more than 90% of the population were served by district heating networks in 2013 (Figure 55 and Figure 56). In Iceland, the possibility to exploit geothermal energy enabled the extensive diffusion of district heating systems based on 100% renewable energy. High shares of the population are also served by district heating in the Scandinavian and Baltic countries, while the percentages decrease drastically in Southern Europe. In Eastern Europe, the use of district heating is also widespread, but in some countries (e.g. in Romania), the systems are old and in need of modernisation.

The district cooling sales for 2012 are presented in Figure 57. It is immediately obvious that district cooling is still not a widespread technology and many countries lack DC systems. The highest district cooling sales were registered in Sweden and France in 2012. It also has to be remarked that the statistics regarding district cooling are much less detailed than those for district heating.

Figure 54: District heating final consumption in 2012

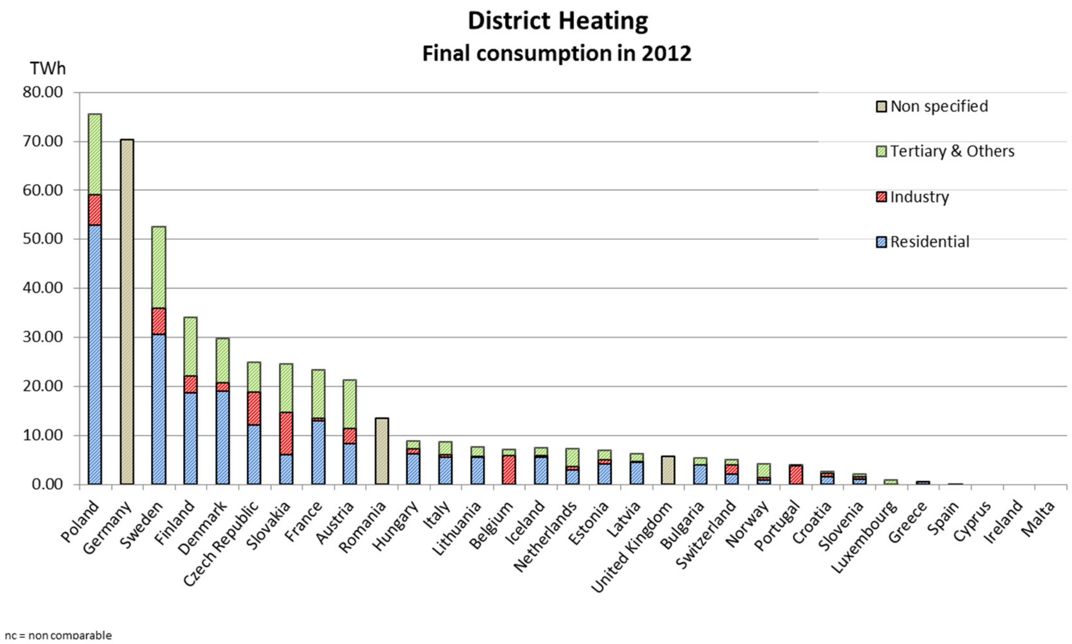
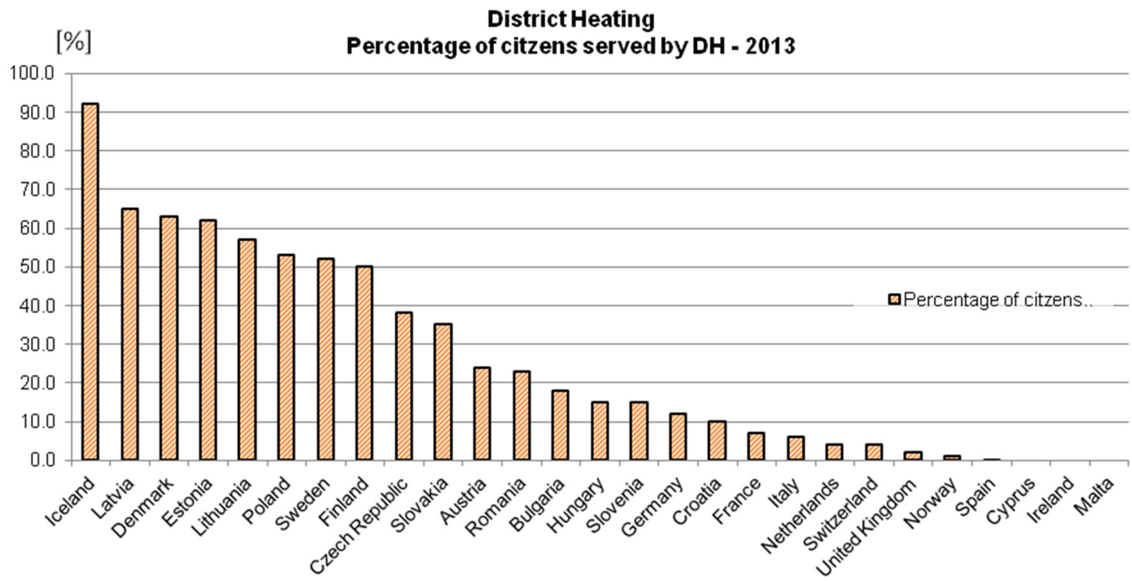
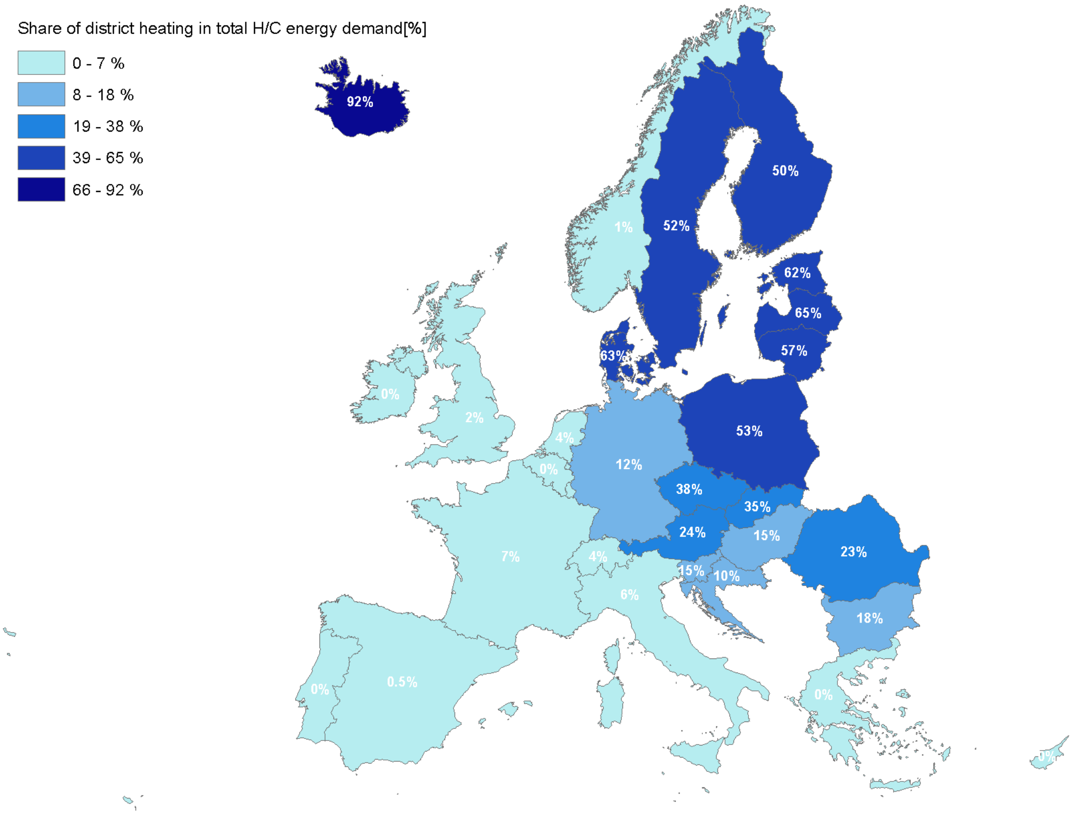


Figure 55: Percentage of the population served by district heating in 2013



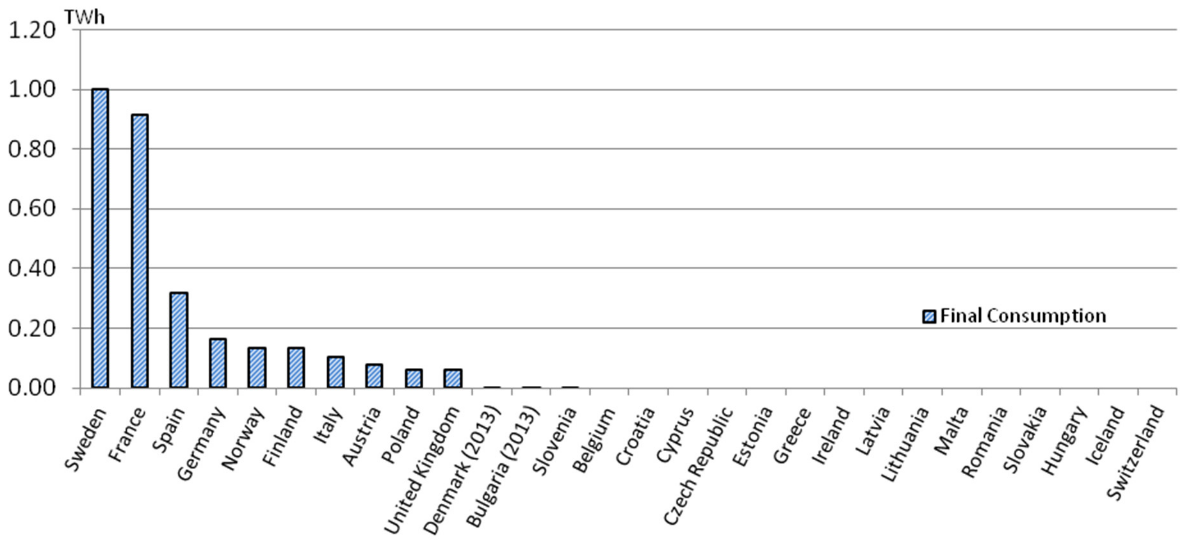
Source: CODE2, 2013; ADHAC, 2014; CODE2a, 2014; CODE2b, 2014; Euroheat & Power, 2015

Figure 56: Percentage of the population served by district heating in 2013



Source: Fraunhofer ISI/ISE based on CODE2, 2013; ADHAC, 2014; CODE2a, 2014; CODE2b, 2014; Euroheat & Power, 2015

Figure 57: District cooling final consumption in 2012



Source: Table 35

Table 35: District heating and cooling – final consumption in 2012

	District heating					District cooling		Total DHC
	Total	Residential	Industry	Tertiary & Al.	Notes & methodology	Total	Notes & methodology	
	[TWh]	[TWh]	[TWh]	[TWh]		[TWh]		[TWh]
Austria	21.37	8.29	3.18	9.80	s	0.07	s	21.44
Belgium	7.45	0.08	5.86	1.08	s (1)	0.00	s (3)	7.45
Bulgaria	5.37	3.96	0.09	1.32	x/a	0.00	s (4)	5.37
Croatia	2.66	1.60	0.59	0.47	s	0.00	s	2.66
Cyprus	0.00	0.00	0.00	0.00	s	0.00	s (3)	0.00
Czech Rep.	24.86	12.04	6.86	5.97	x/a	0.00	s (3)	24.86
Denmark	29.75	19.08	1.73	8.94	s	0.00	s (4)	29.76
Estonia	6.99	4.22	0.79	1.97	x/a	0.00	s	6.99
Finland	34.05	18.73	3.40	11.92	s	0.13	s	34.18
France	23.36	12.90	0.54	9.92	s	0.91	s	24.27
Germany	70.30	n.a.	n.a.	n.a.	x/a	0.16	s	70.46
Greece	0.52	0.52	0.00	0.00	s (1)	0.00	s (3)	0.52
Hungary	8.75	6.17	1.15	1.43	x/a	0.00	s	8.75
Iceland	7.43	5.58	0.23	1.63	x/a	0.00	s	7.43
Ireland	0.00	0.00	0.00	0.00	s	0.00	s (3)	0.00
Italy	8.60	5.55	0.43	2.62	x/a	0.10	s	8.70
Latvia	6.26	4.58	0.11	1.57	x/a	0.00	s (3)	6.26
Lithuania	7.52	5.45	0.31	1.76	s	0.00	s (3)	7.52
Luxembourg	0.86	0.00	0.13	0.72	s (1)	n.a.		0.86
Malta	0.00	0.00	0.00	0.00	s	0.00	s (3)	0.00
Netherlands	7.17	2.92	0.64	3.62	x/a	n.a.		7.17
Norway	4.22	0.91	0.48	2.83	s	0.13	s	4.36
Poland	75.54	52.88	6.25	16.42	x/a	0.06	x	75.60
Portugal	4.01	0.08	3.70	0.17	s (1)	n.a.		4.01
Romania	13.43	n.a.	n.a.	n.a.	x	0.00	s (3)	13.43
Slovakia	24.48	6.04	8.61	9.83	x/a	0.00	s (3)	24.48
Slovenia	2.16	0.96	0.66	0.54	s	0.00	x	2.16
Spain	0.41	0.10	0.04	0.26	s	0.32	a	0.72
Sweden	52.50	30.60	5.26	16.63	x/a	1.00	s	53.50
Switzerland	5.02	2.08	1.81	1.12	s	0.00	s	5.02
UK	5.76	n.a.	n.a.	n.a.	a (2)	0.07	a (3)	5.83

n.a. = not available

Methodology	Notes
x = interpolation / extrapolation	(1): OECD statistics, heat category
a = climate correction and interpolation between 2011 and 2013	(2): Rough approximation
s = direct use of the source	(3): Source updated till 2011
m = modelling	(4): Values provided for the year 2013

Source: (Statistik Austria; Finnish Energy Industries; SURS; Statistics Norway; RESCUE, 2012./2013; LDHA, 2013; DECC, 2013; CODE2, 2013; AGFW, 2013; AIRU, 2013; BASREC, 2014; IEA, 2014; SNCU, 2014; CODE2a, 2014; BFE, 2014; CODE2b, 2014; Euroheat & Power, 2015; Persson, Urban, 2015; Finnish Energy Industries, 2015; Dansk Fjernvarme, 2015; EIHP, 2015; ADHAC, 2015; Danish Energy Agency, 2015)

5.5.2 Energy supply composition for district heating

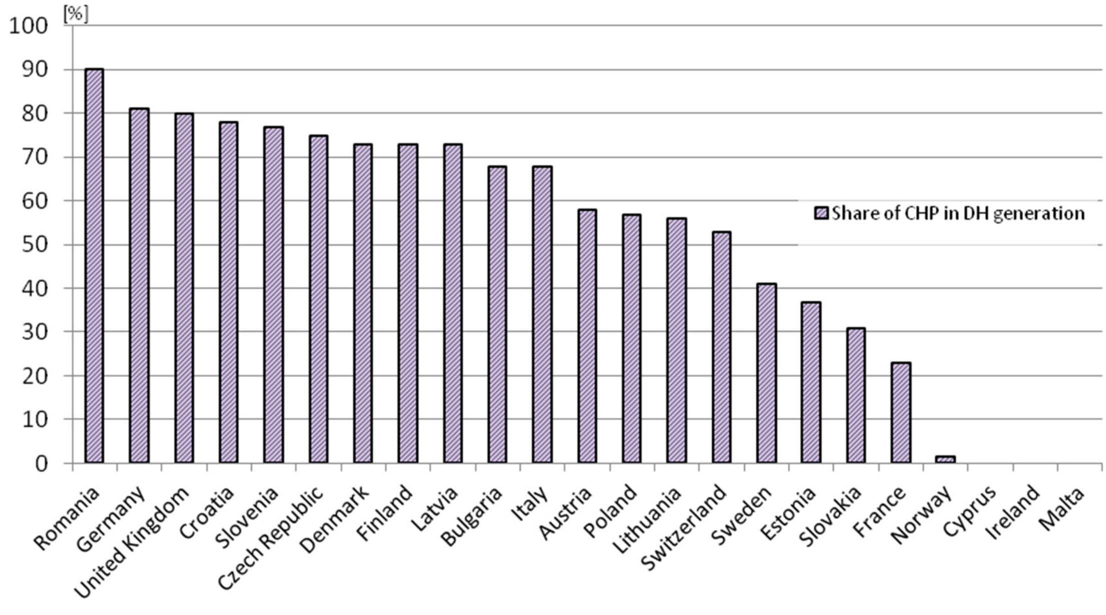
The energy supply composition for district heating presented in Table 36 is very country-specific and inhomogeneous. The development of the district heating supply has been influenced by a multitude of factors (such as e.g. national funding schemes, political decisions, availability/ price of fuels).

Nevertheless, it can be noticed that fossil fuels (mainly natural gas and coal) covered a share of between 80% and 100% of the energy supply for district heating in Eastern Europe countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia) in 2012. Biomass played a prominent role in Sweden (49%) as well as in Austria (41%) and Estonia (35%). In contrast, solar thermal and heat pumps play only a minimal role in district heat production.

As mentioned above, Iceland has a unique energy supply for district heating, with 97% of the heat coming from geothermal sources and the rest from renewable electricity.

Figure 58 shows the share of CHP in district heating generation for 2013. As can be seen, CHP is the main way to generate heat for district heating in many countries.

Figure 58: Share of CHP in district heating generation in 2013



Source: CODE2 (2013); AGFW (2013); CODE2a (2014); CODE2b (2014); Euroheat & Power (2015)

Table 36: Energy supply composition for district heating generated in 2012

	Total	Coal		Fuel oil		Natural gas		Other fossil fuels		Electricity		Waste non RES		Waste RES		Biomass		Geothermal		Solar energy		Heat pumps		Other RES		Notes & methodology
	[TWh]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	[TWh]	[%]	
Austria	23.4	0.9	3.9	1.3	5.6	9.4	39.9	0.4	1.7	0.0	0.0	1.6	6.8	0.2	0.7	9.5	40.7	0.0	0.0	0.2	0.7	0.0	0.0	0.0	0.0	x/a (2)
Belgium	n.a.																									
Bulgaria	6.8	0.8	11.3	0.0	0.0	6.0	88.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (2)
Croatia	3.6	0.0	0.0	0.5	12.6	3.0	83.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (1)
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	s
Czech Republic	28.6	20.2	70.7	0.2	0.5	6.3	21.9	0.2	0.5	0.0	0.0	0.4	1.3	0.4	1.3	1.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (2)
Denmark	37.9	9.0	23.7	0.7	1.8	9.1	24.0	0.0	0.0	0.0	0.0	3.0	7.8	3.6	9.6	10.9	28.8	0.0	0.1	0.1	0.2	0.2	0.5	1.4	3.6	s (2)
Estonia	8.0	0.0	0.2	2.0	24.9	2.8	34.8	0.4	4.9	0.0	0.0	0.0	0.0	0.0	0.0	2.8	35.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (2)
Finland	37.8	8.9	23.5	1.4	3.8	9.5	25.1	6.3	16.8	0.0	0.0	0.5	1.2	0.1	0.2	9.9	26.1	0.0	0.0	0.0	0.0	0.4	0.9	0.9	2.4	x/a (2)
France	27.7	2.5	9.1	1.6	5.7	12.4	44.8	0.0	0.0	0.0	0.0	0.1	0.2	7.1	25.6	2.3	8.4	1.0	3.5	0.5	1.7	0.0	0.0	0.3	1.0	x/a (2)
Germany	119.1	48.1	40.3	0.9	0.7	56.2	47.2	1.4	1.2	0.0	0.0	6.4	5.3	0.6	0.5	3.3	2.7	0.1	0.1	0.0	0.0	0.0	0.0	1.3	1.1	x/a (1)
Greece	n.a.																									
Hungary	17.6	0.9	4.8	0.0	0.3	14.3	81.0	0.0	0.3	0.0	0.0	0.9	5.1	0.0	0.0	1.3	7.6	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	a (1)
Iceland	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.3	0.0	0.0	0.0	0.2	0.0	0.0	7.7	97.4	0.0	0.0	0.0	0.0	0.0	0.0	a (2)
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	s
Italy	10.1	0.3	2.7	0.0	0.4	6.5	64.7	0.0	0.0	0.0	0.0	0.3	2.7	0.8	8.2	1.9	18.8	0.2	1.9	0.0	0.0	0.1	0.5	0.0	0.2	x/a (2)
Latvia	13.8	0.2	1.1	0.1	0.9	10.5	76.1	0.0	0.0	0.0	0.0	0.5	3.4	0.0	0.0	2.6	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (1)
Lithuania	9.0	0.0	0.2	0.3	3.4	6.1	67.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.6	28.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	x/a (1)
Luxembourg	n.a.																									
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	s
Netherlands	9.5	1.1	11.9	0.0	0.1	7.7	80.3	0.0	0.0	0.0	0.0	0.3	3.3	0.0	0.0	0.1	0.8	0.0	0.0	0.0	0.5	0.0	0.4	0.3	2.6	x/a (2)
Norway	5.1	0.1	1.4	0.3	5.0	0.3	5.2	0.8	16.3	1.3	24.6	0.0	0.0	1.3	24.4	1.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.5	x/a (2)
Poland	79.5	58.9	74.2	3.2	4.1	5.9	7.4	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.1	8.2	10.4	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.7	x/a (2)
Portugal	n.a.																									
Romania	52.4	21.5	41.1	1.7	3.3	28.1	53.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	s (2)
Slovakia	33.0	12.3	37.4	2.1	6.4	10.6	32.3	0.7	2.2	0.0	0.0	0.1	0.4	0.0	0.1	7.0	21.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	x/a
Slovenia	5.0	2.5	50.5	0.1	1.2	1.6	30.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	14.8	0.0	0.2	0.0	0.0	0.0	0.0	0.1	2.4	x/a (1)
Spain	0.5	0.0	0.0	0.0	2.0	0.2	48.7	0.0	0.0	0.1	19.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	29.7	a (2) (3)
Sweden	64.6	3.3	5.1	2.5	3.8	3.9	6.0	2.5	3.8	0.0	0.0	9.4	14.5	3.4	5.3	31.4	48.6	0.0	0.0	0.0	0.0	4.2	6.5	4.1	6.4	x/a (1)
Switzerland	5.3	0.0	0.0	0.1	2.7	1.6	30.0	0.4	7.6	0.0	0.0	1.2	23.6	1.1	20.7	0.8	15.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	x/a (2)
United Kingdom	n.a.																									
Total	606.3	191.4	31.6	19.0	3.1	211.9	35.0	13.4	2.2	1.5	0.3	24.5	4.0	18.7	3.1	98.4	16.2	9.2	1.5	0.8	0.1	4.9	0.8	11.6	1.9	

n.a. = not available

Methodology Notes

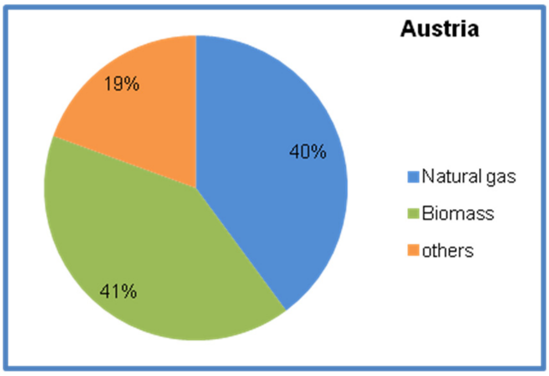
x = interpolation / extrapolatior (1): The ´Energy supply consumption´data refers to the end supply into the heat/CHP plants allocated per energy carrier

a = ad hoc calculation (2): The ´Energy supply consumption´data refers to the end supply to the district heating network allocated per energy carrier

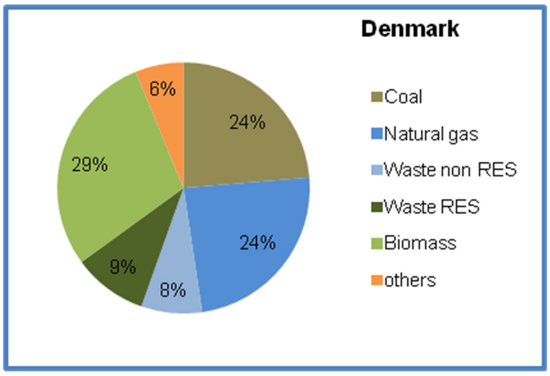
s = direct use of the source (3): RES not divided for energy carrier. The total value for RES is set under ´Other RES´

m = modelling

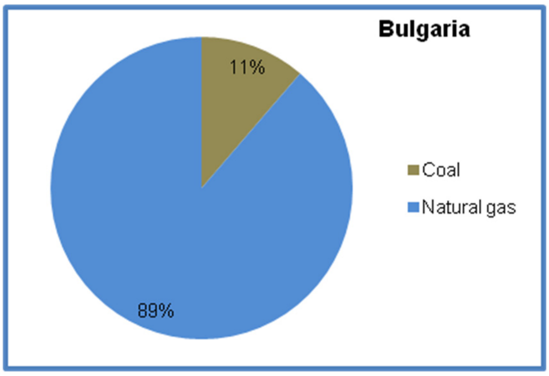
Source: CODE2, 2013; CODE2a, 2014; CODE2b, 2014; Euroheat & Power, 2015; ADHAC, 2015; Danish Energy Agency, 2015



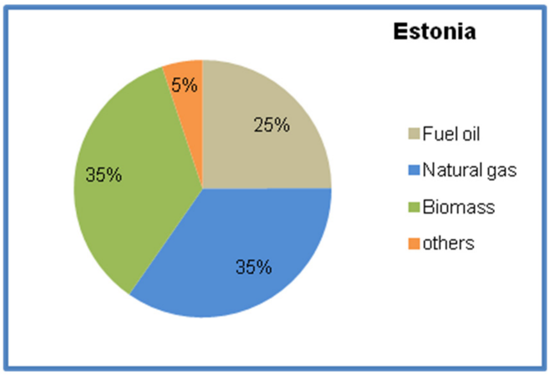
*Biomass and natural gas are the main fuels for district heat generation in Austria



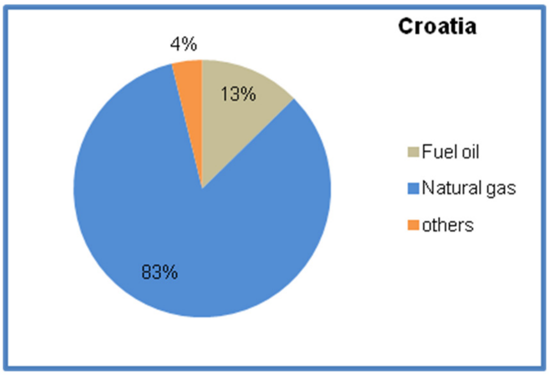
*In Bulgaria 100% of the energy supply for district heating comes from fossil fuels



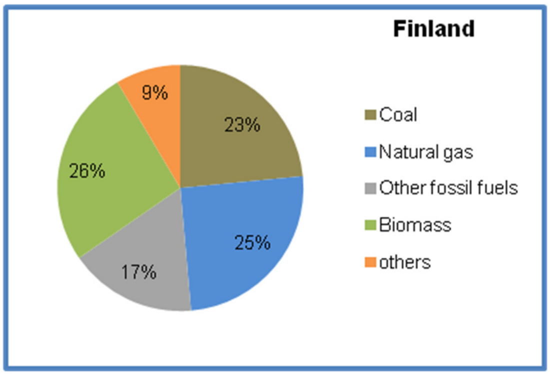
*Coal, natural gas and biomass are the fuels used most to generate district heat in Denmark



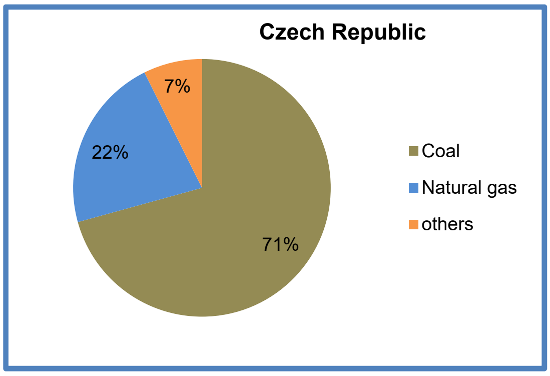
*Natural gas, biomass and fuel oil make up most of the district heat generation in Estonia



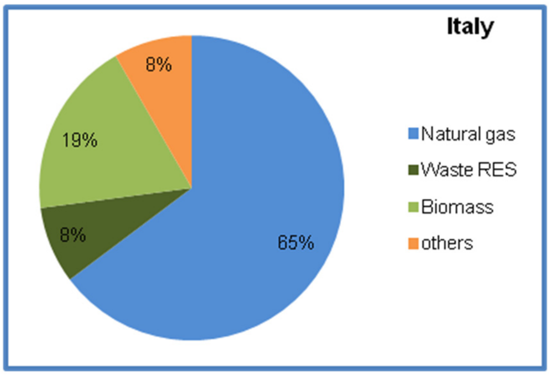
* The main source for district heat generation in Croatia is natural gas



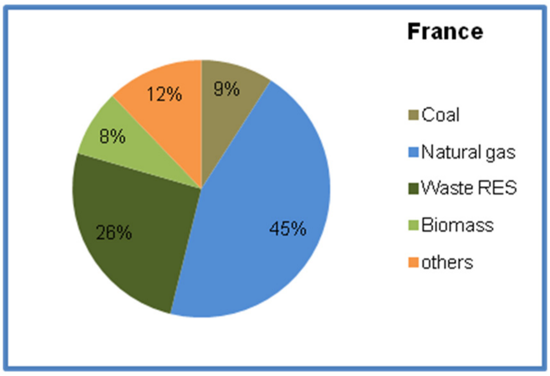
*Biomass, coal, natural gas and fossil fuels are the main fuels used for district heat generation in Finland



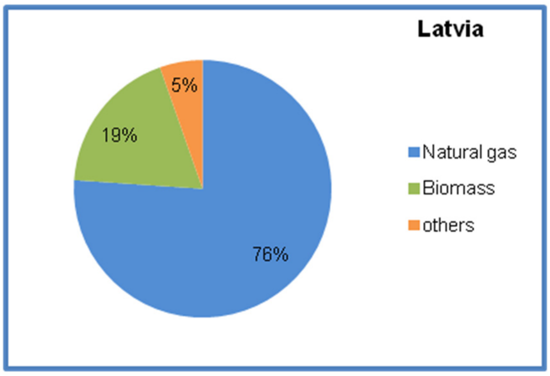
*Coal is largely used for district heat generation in Czech Republic



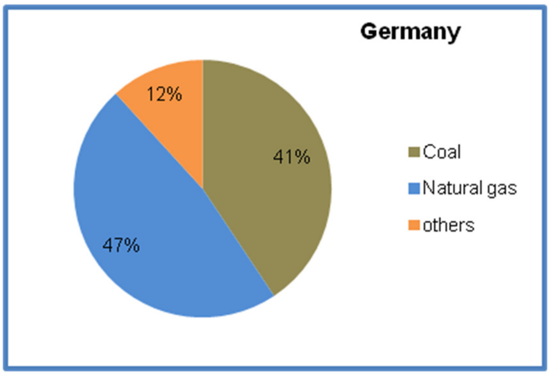
*Natural gas is the main fuel used for district generation in Italy. Biomass plays an important role as well



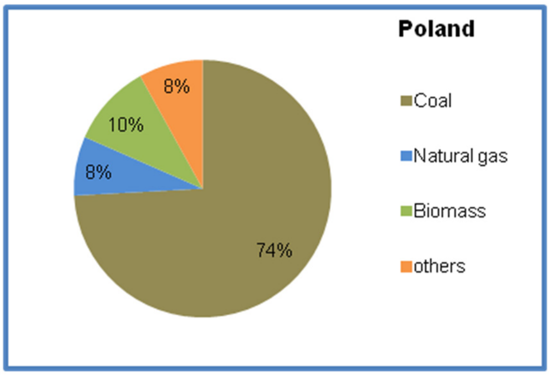
*Natural gas and waste from renewable sources are mainly used for district heat generation in France



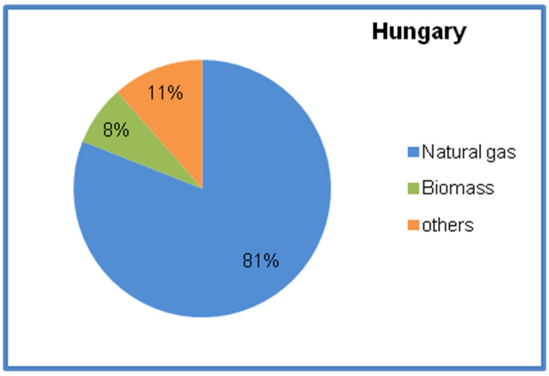
*Natural gas is the main fuel used for district heat generation in Latvia

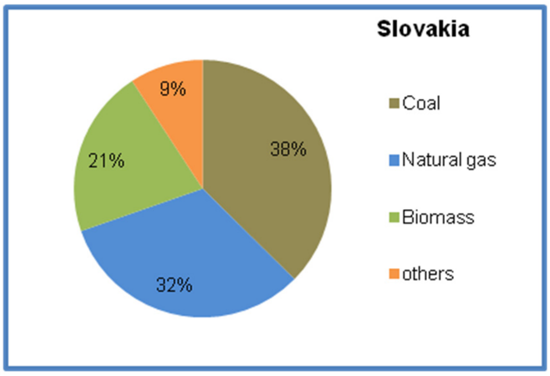


*Coal and natural gas are the main fuels used to generate district heat in Germany



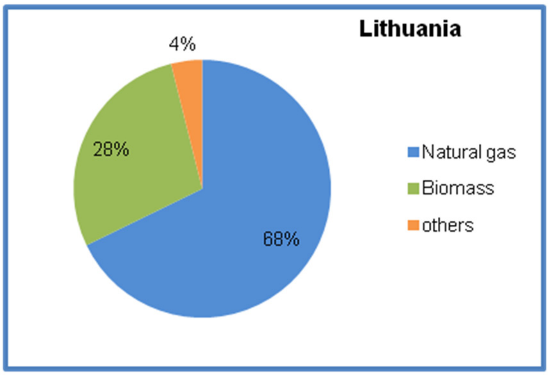
*Coal is the main fuel used for district heat generation in Poland

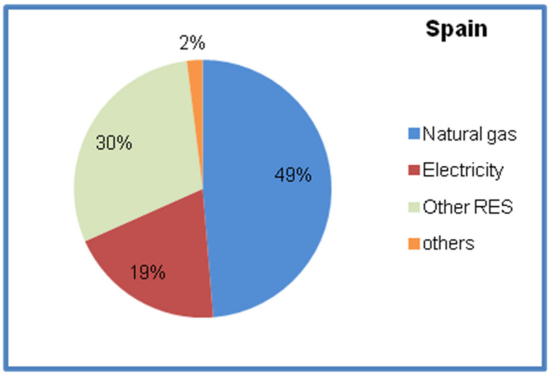




*Natural gas is the main fuel used for district heat generation in Hungary

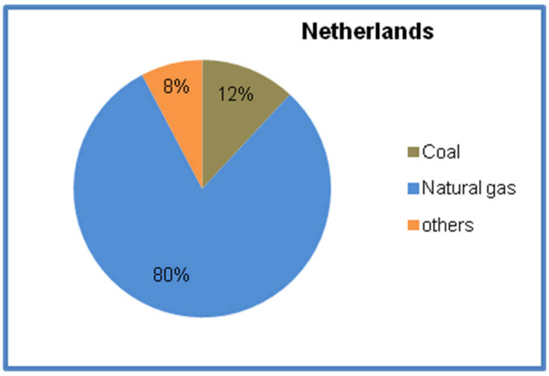
*Coal, natural gas and biomass are the main fuels used to generate district heat in Slovakia

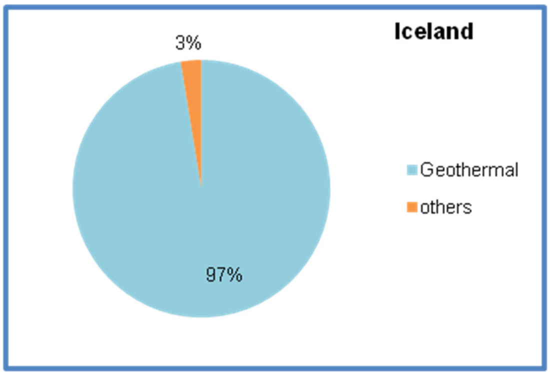




*Natural gas and biomass are the main fuels used to generate district heat in Lithuania

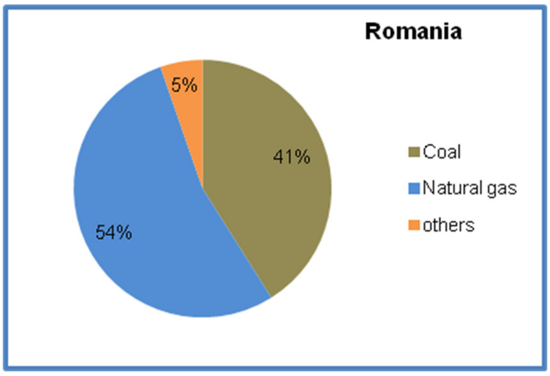
*Besides natural gas and renewable sources, electricity is also used for district heat generation in Spain



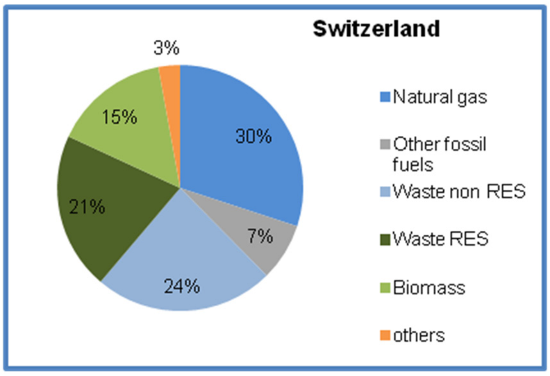


*Natural gas is the main fuel used to generate district heat in the Netherlands.

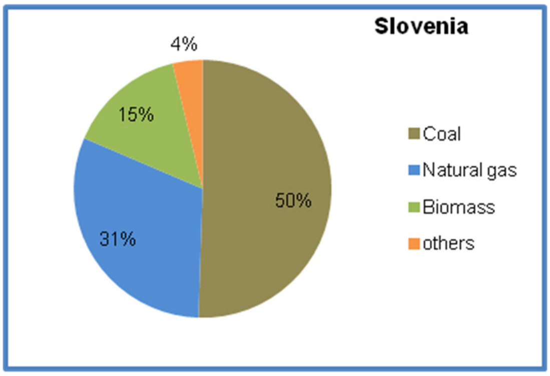
*Almost all the generation of district heat depends on geothermal sources in Iceland



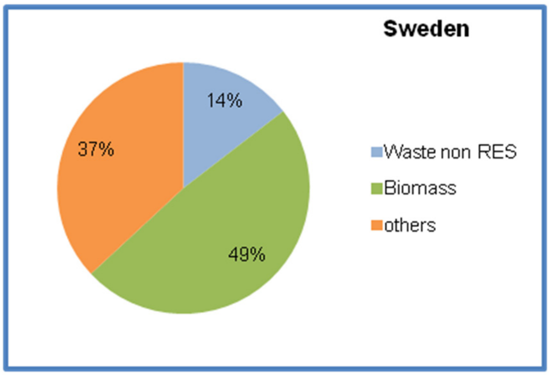
*Natural gas and coal are the main fuels for district heat generation in Romania



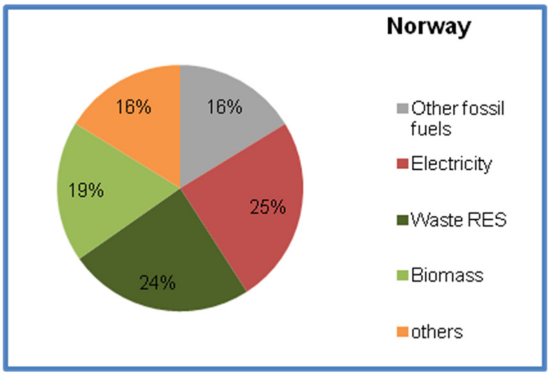
*Natural gas, waste and biomass are the main fuels for district heat generation in Switzerland



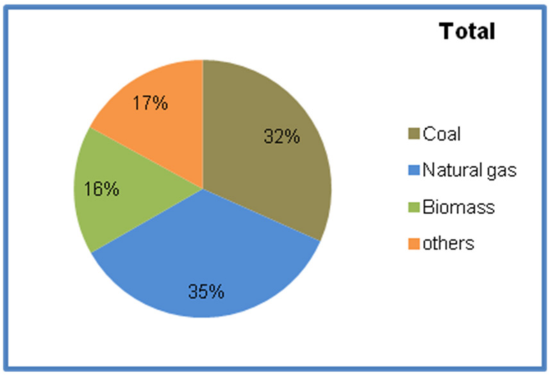
*80% of the energy needed for district heat generation in Slovenia is met by coal and natural gas



*Biomass is the main fuel used in Sweden to generate district heat



*Biomass, waste (renewable), electricity &fossil fuels are used for district heat generation in Norway.



*Coal and natural gas together cover almost 70% of the share of fuels used for district heating generation in the countries represented above

6 Summary, conclusions and recommendations

6.1 Summary

The Eurostat energy balances and similar statistics provide only an incomplete picture of the EU heating and cooling (H/C) sector (see Table 2). Data is scattered, incomplete – e.g. for non-commercial biomass and ambient heat – or simply not available, such as the disaggregation to individual end-use categories. However, H/C accounts for the major share of the final energy demand in Europe and more empirical evidence is an important basis for an adequate energy and climate mitigation policy. Thus the objective of WP 1 included the following elements:

1. Quantification, description and graphical depiction of the final energy demand related to heating and cooling in the sectors households, industry and services/tertiary, disaggregated in energy carriers and end-use categories such as space heating, water heating as well as process heating and cooling and space cooling.
2. Quantification of Europe's useful and primary energy demand for H/C in the sectors households, industry and services, disaggregated in end-use categories based on the calculated final energy demand.

In order to fulfil the objectives, available national and EU energy statistics and other data collections on heating and cooling are assessed and the current data collection practice in Member States is analysed. Data gaps are closed as much as possible and recommendations on how to improve data collection regarding heating and cooling energy, useful and primary energy and energy use balances are drafted.

By assessing the national and EU energy statistics and other data sources it was found that national energy balances differ widely in their quality regarding the depth of detail and length of comparable time series. They range from datasets which contain only a few energy carriers, such as electricity, to "complete" energy balances including extra balances for renewable energies. Regarding countries, the main data gaps are for Malta and Cyprus. Thus, there is still some potential to improve the coverage and quality of the data collections.

However, the low availability of national end-use balances remains an issue. Most countries of the European Union do not provide these for the industry or tertiary sectors. As for the residential sector, end-use balances are more widely available - 14 out of 31 countries have partial or complete end-use balances for this sector. For these countries final energy is broken down by end-uses such as space heating, hot water, process heating/cooling, and others (e.g. appliances). In about half of the countries these energy use balances are empirically founded, in other cases model or mixed approaches are implemented. Note that reporting end-use balances will be mandatory for households in the 2015 data under Regulation (EU) No 431/2014. With regard to useful energy availability was found to be very low.

Against this background a **methodological framework was developed to close data gaps.** Some of the methods were already applied within this study, others are included in the recommendations as they could not be implemented within the scope of this project. A definition of useful energy was developed, adopting two different approaches. The first one is based on final energy demand and conversion efficiency and the second one is based on characteristics of considered energy services considered. For instance, in the case of space heating useful energy is defined as the balance of thermal losses and gains. As much as possible, definition and approaches are based on existing EN norms.

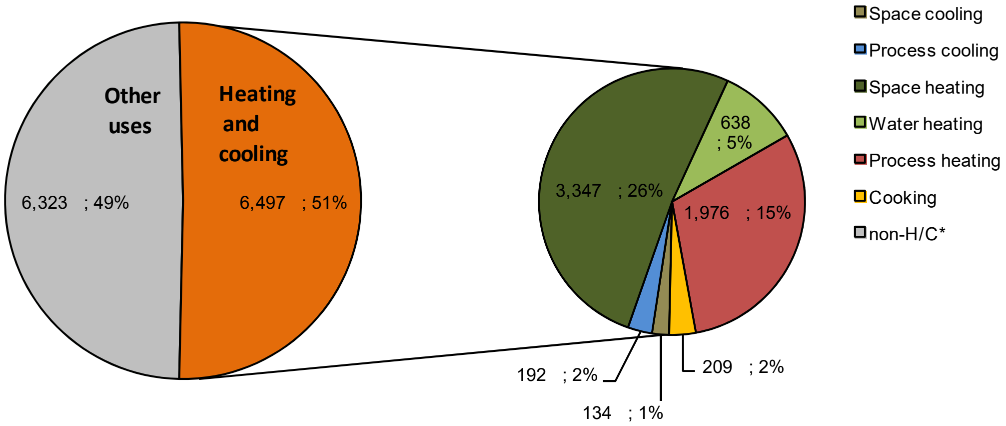
Primary, final and useful energy balances including a break down to end-use categories are calculated. The disaggregation is calculated following a combined top-down and bottom-up approach on the one hand and based on empirically founded data and model results on the other hand:

- Data of conventional energy carrier by demand sector (industry, tertiary, household) such as electricity, gas and fuel oil came from EUROSTAT and were used to "anchor" the consumption of heating and cooling as part of these sector totals.
- Surveys were carried out to close data gaps with regard to renewable energy use and district heating on the final energy level. Partly, previously non-available information regarding the break down into heating and cooling and its different end-use categories could be gathered from statistical offices and energy agencies through these surveys.
- If no or no detailed information could be gathered a coherent approach was developed to impute missing data or to resolve inconsistencies in case of data availability from different sources. Either model results were used to impute missing values or results from models calibrated with data gathered were used to generate results.
- Useful energy demand is derived from final energy consumption figures by applying specific end-use conversion figures (e.g. technical efficiency scores of heating and cooling systems and appliances). With regard to end-use conversion efficiencies technology data from WP 2 were used to amend existing model input.
- Primary energy consumption was calculated from final energy consumption by applying primary energy factors (based on the countries' input mix to the conversion sector, typically the input for generating electricity, district heat, and final energy such as fuel oil and gas in power and district heating plants and refineries).

It becomes apparent from WP 1 results that the **final energy for heating and cooling** was responsible for about 51% of the total final energy consumption that was roughly 12,800 TWh in 2012. Space heating is the most relevant end-use with a share of 52% of the total final energy demand for H/C (~3350 TWh), followed by process heating which makes up 30% (~2000 TWh). Water heating (sanitary hot water) accounts for about 10% (~640 TWh), cooking in the residential sector for about 3% (~200 TWh) and cooling uses 5% with about 130 TWh for space cooling and about 190 for process cooling (see Figure 59 – similar to Figure 18).

With the three demand sectors, industry, residential and tertiary, H/C demand breaks down quite differently into the individual end-uses: The residential sector is dominated by space heating and water heating (share of 76% and 16% respectively) whereas the remaining end-uses such as cooking and space cooling account for only 7% and 1%, respectively. In the industrial sector, process heating makes up for the major share with about 81%, the rest is covered by space heating and process cooling. Also in the tertiary sector, space heating has the major share (61%), but other end-uses such as water heating, (14%), process cooling (10%) and space cooling (9%) also show relevant shares.

Figure 59: Final energy demand for EU28 by end-use for H/C in all sectors in 2012 [TWh]



Source: own calculation

The breakdown of final energy into the different energy carriers reveals a significant relevance of natural gas which has a share of 45% (~2660 TWh). The rest of the final energy consumption for heating and cooling is more or less equally distributed among electricity, fuel oil, biomass, coal and district heating: 12% for electricity, 12% for fuel oil, 12% for biomass, 9% for coal, and 8% for district heating. Less relevant are waste, ambient heat, solar energy, and geothermal energy, each of them having a share of about 1% or less.

In total, 66% of the **final energy for H/C** is supplied by fossil fuels and 14% by renewable energy sources[25]. The remaining 20% are from secondary energy carriers – electricity and district heating. However, the proportions of each energy carrier vary across the different end-use categories: While heating is characterized by a diverse mix of energy carriers, cooling is predominantly generated by electricity. Yet cooling end-uses still only account for a small part of the total heating and cooling demand in Europe and most of its member states.

In 2012, about 8000 TWh of **primary energy** were used in the EU28 for H/C purposes. 45% of this was natural gas, which is the most relevant individual energy carrier for the supply of heating and cooling. It is followed by coal with about 15%. Biomass and fuel oil each account for about 11%, nuclear energy for 7% and RES-E (wind, PV and hydro) for 5%. Both Nuclear energy and RES-E are used to generate the electricity used for heating and cooling. Other RES like solar thermal energy, ambient heat and geothermal energy together account for 1.5%. Altogether, the different types of RES account for 18% of the primary energy supply for H/C, whereas fossil fuels account for the major share of 75% in the EU28. This calculation is different to the methodology applied in the SHARES tool used by EUROSTAT which calculates RES-H&C share on the level of final energy. Thereby derived heat

25 RES used for generating district heating and electricity are not account

from renewables (district heating) is considered but RES used to generate electricity is not taken into account.

Useful energy is calculated to complete the energy balances. This is important to derive valuable insights into transformation efficiencies. From the 6500 TWh of final energy demand in 2012, only about 5100 TWh are effectively used and roughly 21% of final energy is dissipated during its conversion to useful energy. The transformation losses are not evenly distributed among the different end-uses. Useful energy demand has been defined as the heat/cold used by the end-user (e.g. at the radiator), which implies that useful energy demand can be further reduced by energy-efficiency measures, e.g. building insulation.

In addition to the results summarized here more insights are found in the report, e.g. regarding temperature levels of industrial process heat – about one third is above 500°C, the split to building categories in the residential sector – H/C demand of single family houses is more than twice as high as the one in multi-family houses.

Country-specific insights are also an important outcome of the WP. For instance, shares of heating and cooling on total final energy demand, shares of different end-uses, energy carrier mixes etc.

6.2 Quality of results

The calculated end-use energy balances for final energy are based on numerous sources from national and EU studies and statistics. By including the data sources in bottom-up models to provide a consistent set of results, the uncertainties could be reduced considerably in the scope of the project. Albeit that, some uncertainties are remaining. **Across the three sectors** the following observations were made with regard to the robustness of the results:

- **Uncertainty** occurs at different levels (total consumption, share H/C, end-uses etc.) and increases with differentiation (e.g. total space heating well defined, but allocation to individual energy carriers less certain).
- **Share of H/C** is well defined for most energy carriers (exception: electricity, which is used for many other non-H/C purposes).
- **H/C in absolute terms** is well defined for fossils, but less accurate for RES. Main reason is the better quality of energy balances for fossil sources, because RES are often not even commercially traded (non-commercial biomass, solar energy).
- **Space cooling** empirical data is scarce and energy estimates are uncertain, because they are mainly based on assumptions for user behavior and (average) performance of appliances.
- **Space heating in industry** is uncertain, because virtually no empirical / statistical information is available and all energy carriers are mainly used for process heating.
- The split of residential demand in **urban/rural** is substantially less robust than the total for each end-use.
- For **RES** and **district heating**, the breakdown to the three demand sectors is relatively uncertain, because most statistics only provide totals.
- Among the **RES**, results are relatively robust for solar thermal, geothermal and renewable waste, while they are more uncertain for biomass (especially

small-scale non-commercial biomass) and ambient heat tapped by heat pumps.

- While the total amount of **district heating** consumed is relatively well known from Eurostat, the allocation to sectors is less certain as well as its supply composition.
- Parameters to estimate **useful energy estimates** have low empirical basis (specific studies for selected countries and years, but not consistently longitudinal and cross-sectoral)**.** Consequently, useful energy balances are less robust than final energy balances.

6.3 Conclusions

The analysis of national end-use energy balances shows that consistent data regarding heating and cooling energy consumption only exist in a minority of countries, mostly focusing on the household sector. Particularly original (i.e. empirical) information on heating and cooling use in the different economic sub-sectors is scarce.

Adopted methodology to establish end-use energy balances vary across countries, ranging from original surveys to establish complete end use balances to model based top-down break downs and bottom-up calculations.

A methodological framework combining bottom-up models with survey methods and empirical data was used to calculate energy demand of various heating and cooling end-uses. The approach allowed establishing a full end-use energy balance for H/C in Europe by member state. The following conclusions can be drawn with regard to the quality of the results:

- Coverage: Data gaps with regard to end-uses could be closed and a complete European end-use energy balance was established.
- Coherence and comparability: The use of models increases the coherence and comparability of results.
- Robustness: With the combined approach, the quality of the data is improved and the robustness of the results increased since better conditions for calibration are achieved.
- Generally: Energy balances that consider end-uses always have a higher uncertainty than traditional energy balances considering sectors and energy carriers, even when being based on surveys.

With regard to the quantitative results the following main conclusions can be drawn.

- From the quantitative results it can be concluded that half of the EU's final energy consumption is for H/C purposes, which makes it the largest sector in terms of energy demand. Further, final energy demand for thermal purposes is still largely dominated by heating. However cooling gains more relevance when assessing useful energy or primary consumption.
- In the conversion process from final to useful energy on average 24% losses occur – with substantial variation across the energy carriers and end-uses. As we have used a very "narrow" definition of useful energy as the heat being delivered to the final user (e.g. at the radiator), further losses and saving potentials to reduce the calculated demand for useful energy exist – without reducing the utility for the final consumer. The detailed data provided allows identifying the fields with the lowest conversion efficiency from primary to final and to useful energy, i.e. the areas with the highest efficiency potentials.

6.4 Recommendations

Existing data gaps could substantially be filled with the methodology adopted and new important and policy relevant insights are gained. Quantitative results created by the analysis of WP 1 are valid for the year 2012 and provide a so-called point-estimate of heating and cooling energy use. However data and methodology developed and implemented aimed not at monitoring the past effect of policy measures.

Thus it is recommended to establish a methodological framework that allows a coherent monitoring and ex-post analysis of policy measures targeting heating and cooling services. Ideally such a framework combines empirical and modelling approaches to overcome weaknesses and emphasize strengths. Empirics is important for models and models are able to separate stochastic effects (e.g. from weather influence) from deterministic effects as a result of technological development, policy instruments etc.

District heating statistics preparation could significantly be improved defining a methodology in order to harmonize the data on European level. The supply composition of district heating and cooling comprises several improvement possibilities. These are mainly:

- Accounting of supply composition for district heat at the system boundary: to date, the supply composition is in some cases accounted at the supply side of the heating plant (input to plant) and in some cases at the connection of the plant with the district heating system (output of plant).
- So far, not all fuels used for district heating are accounted and can be distinguished in the statistics. This is mainly true for renewable energy sources and heat from auto-producers. Furthermore, recovered heat from e.g. the industry is not accounted.

A major difficulty with European statistics is the unclear definition of 'derived heat'. Currently it is not possible to directly distinguish between heat for industrial processes and district heating. Another critical point in current statistics is that peak boilers installed together with a CHP plant are usually accounted as CHP plants. Statistics on a unit basis rather than on a plant basis would improve the data quality.

For many countries and end-uses the empirical data foundation is weak. More empirical assessments via broad surveys could substantially increase the robustness of the end-use balances. Even when balances are calculated by the use of models, more robust empirical input data will improve the results. Across Europe, the main data gaps currently exist with regard to space cooling across all sectors; space heating in the industrial sector; the current use of RES in industry and tertiary (besides biomass); the use of non-commercial biomass in the residential sector; derived heating regarding the split between district heating and industrial auto-generation and regarding the break down into the main demand sectors; the split between urban and rural and the use of ambient heat. Additional surveys are needed to fill these data gaps.

Comparing results on a country level reveals huge differences across the individual countries as well as in comparison to the EU average values. Policies addressing H/C will therefore need to take country-specific situation and the heterogeneity across Europe into account.

7 Literature

ADHAC (2014): Asociación de Empresas de Redes de Calor y Frío. Censo de Redes.

ADHAC (2015): R. González, Asociación de Empresas de Redes de Calor y Frío. Personal communication. 23 July 2015.

Adnot, J., Orphelin, M., Carretero, C., Marchio, D., Waide, P., Carre, M., Lopes, C., Cediel Galan, A., Santamouris, M., Klitsikas, N., Mebane, B., Presutto, M., Rusconi, E., Ritter, H., Becirspahic, S., Giraud, D., Bossoken, E., Meli, L., Casandrini, S., Auffret, P. (1999): Energy Efficiency of Room Air Conditioners (EERAC) - Final report. Armines.

Adnot, J., Waide, P., Rivier, P., Marcho, D., Holmstrom, M., Naeslund, J., Saba, J., Becirspahic, S., Lopes, C., Blanco, I., Perez-Lombard, L., Ortiz, J., Papakonstantinou, N., Doukas, P., Joppolo, C.M., Casale, C., Benke, G., Giraud, D., Houdant, N., Colomines, F., Gavriliuc, R., Popescu, R., Burchu, S., Georges, B., Hitchin, R. (2003): Energy Efficiency and Certification of Central Air Conditioners (EECCAC) - Final report - Voume 1. Armines, Paris.

AGFW (2013): AGFW. Hauptbericht 2012.

AIRU (2013): Associazione Italiana Riscaldamento Urbano. Il riscaldamento urbano 2013.

Arnemann, M., Schwarz, J.: Kältetechnologien in Deutschland: Emissionen, Projektionen, Potenziale - Industrie, GHD, sonstige Anwendungen - Nahrungsmittelindustrie - Lebensmittelhandel - Wärmepumpen - Stationäre Klimatechnik; Hochschule Karlsruhe - Technik und Wirtschaft, noch unveröffentlicht

BASREC (2014): District Heating and Cooling, Combined Heat and Power and Renewable Energy Sources, 143 pp.

BFE (2014): Bundesamt für Energie. Analyse des schweizerischen Energieverbrauchs 2000 - 2013 nach Verwendungszwecken.

C (2013) 1082: "Guidelines for Member States on calculating renewable energy from heat pumps". European Commission. Bruxelles.

CODE2 (2013): Cogeneration Observatory and Dissemination Europe. Final CHP roadmap. Ireland.

CODE2 (2014): Cogeneration Observatory and Dissemination Europe. D5.1 - Final Cogeneration Roadmap. Member State: Cyprus.

Cullen, Jonathan M.; Allwood, Julian M. (2010): Theoretical efficiency limits for energy conversion devices. In: Energy 35 (5), S. 2059–2069. DOI: 10.1016/j.energy.2010.01.024.

Danish Energy Agency (2015): Annual energy statistics 2012. http://www.ens.dk/en/info/facts-figures/energy-statistics-indicators-energy-efficiency/annual-energy-statistics.

Dansk Fjernvarme (2015): A. Jespersen. Personal communication. 8 July 2015.

DECC (2013): Department of Energy & Climate Change UK. Summary evidence on District Heating Networks in the UK.

DECC Department of Energy & Climate Change (2015): Energy Consumption in the UK – Overall data tables.

DECC, Department of Energy & Climate Change, 2015: Energy consumption in the UK, Chapter 4: Industrial factsheet and tables, crown copyright 2015.

Dengler, J., Fette, M., Henning, H.-M., Idrissova, F., Jochem, E., Kost, C. , Reitze, F., Schicktanz, M., Schnabel, L., Schulz, W., Steinbach, J. & Toro, F. (2011): Erarbeitung einer Integrierten Wärme- und Kältestrategie - Arbeitspaket 1 - Bestandsaufnahme und Strukturierung des Wärme- und Kältebereichs. Freiburg: 2011.

DIN EN 15603:2008-07 Energy performance of buildings - Overall energy use and definition of energy ratings; German version EN 15603:2008

DIN EN ISO 13790:2008-09 Energy performance of buildings - Calculation of energy use for space heating and cooling (ISO 13790:2008); German version EN ISO 13790:2008

Dumortier, R., Lang, T., Schmutz, B. (2012): Elektrizitätsbedarf fürs Kühlen in der Schweiz; Schweizerischer Verein für Kältetechnik (SVK)

EIHP (2015): B. Vuk, Energy Institute Hrvoje Pozar. Personal communication. 17 July 2015.

eJarn, 2014: World compressors study 2014, www.ejarn.com.

ERA Technology Limited, Bio Intelligence Service (2012): Lot 4: Industrial and Laboratory Furnaces and Ovens – Tasks 1 – 7 Final Report. Ecodesign Directive Preparatory Study. Hg. v. ERA Technology Limited. Surrey.

EURAC et al. (2014). Database of the project "Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems (INSPIRE). funded from the European Commission's 7th Framework Programme 2007-2013. http://www.inspirefp7.eu/building-stock-statistics/

Euroheat & Power (2014): Detailed comments on the EU heat statistics.

Euroheat & Power (2015): District heating and cooling. Country by country - 2015 survey, 378 pp.

Euroheat & Power (2006): The European Cold Market. Work package 2 of th ECOHEATCOOL project supported by Intelligent Energy Europe. http://www.euroheat.org/files/filer/ecoheatcool/project_2.htm

European Commission (2014): Quality report of European Union energy statistics, 2014. http://ec.europa.eu/eurostat/documents/38154/4956233/ESR-Quality-report-2014.pdf (access 2015/11/15)

Eurostat (1978): Useful energy balance sheets – 1975. Statistical office of the European Communities. Luxembourg.

Eurostat (2007): Panorama of Energy - Energy statistics to support EU policies and solutions, European Communities, Luxembourg

Eurostat (2014): ESS guideline on the implementation of the ESS quality and performance indicators (QPI), 2014. http://ec.europa.eu/eurostat/documents/64157/4373903/02-ESS-Quality-and-performance-Indicators-2014.pdf

EUROSTAT (2014b): SHARES Tool Manual. European Commission, Eurostat Unit E.5 – Energy. http://ec.europa.eu/eurostat/de/web/energy/data/shares

EUROSTAT (2015a): Questionnaire for statistics on energy consumption in households.http://ec.europa.eu/eurostat/documents/38154/4956229/Energy+Statistics+in+Households/f0bdaddb-294e-49a8-8ac1-555230d8d256

EUROSTAT (2015b):Urba-rural typology. http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology#cite_note-1

EUROSTAT (2015bc):Statistics exlplained – Urban Clusters. http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Urban_cluster

Expert Interviews 2015: with Dr. Marscheider-Weidemann, Dr. Preuß, VDMA, Prof. Dr. Arnemann, 2015.

Finnish Energy Industries (2015): A. Kohopaa. Personal communication. July 2015.

Finnish Energy Industries (FE). District cooling. http://energia.fi/en/statistics-and-publications/district-heating-statistics/district-cooling.

Fraunhofer ISI (2014): Anwendungsbilanzen für die Endenergiesektoren in Deutschland in den Jahren 2011 und 2012 mit Zeitreihen von 2008 bis 2012. Bundesministerium für Wirtschaft und Technologie, Berlin

Häfele, W. (1977): On Energy Demand. Scientific afternoon lecture at the 21st general conference of the International Atomic Energy Agency, Vienne, September 1977.

Heinrich, C., Wittig, S., Albring, P., Richter, L., Safarik, M., Böhm, U., Hantsch, A. (2014): Nachhaltige Kälteversorgung in Deutschland an den Beispielen Gebäudeklimatisierung und Industrie; Institut für Luft- und Kältetechnik Dresden gGmbH, Dresden

Hitchin, R., Pout, C., Riviere, P. (2013): Assessing the market for air conditioning systems in European buildings. Energy Build. 58, 355–362. doi:10.1016/j.enbuild.2012.10.007

IEA (2014): International Energy Agency. Energy Statistics of OECD Countries. 2014 Edition, 431 pp.

IEA (2014b): International Energy Agency. Energy Efficiency Indicators: Fundamentals on Statistics, 191 pp.

Instituto Nacional de Estatística. Inquérito ao Consumo de Energia no Sector Doméstico 2010. Lisbon, Portugal: 2011

Jakob, M.; Fleiter, T.; Catenazzi, G.; Hirzel, S.; Reitze, F.; Toro, F. (2012): The impact of policy measures on the electricity demand of the tertiary sector of the European Union: An analysis with the bottom-up model FORECAST, conference proceedings IEECB 18-19.04.2012, Frankfurt.

Kranzl, L., Müller, A., Toleikyte, A., Hummel, M., Steinbach, J., Kockat, J., Rohde, C., Sebi, C., Keramidas, K., Lapillone, B. (2014): Entranze Projekt . Policy pathways for reducing energy demand and carbon emissions of the EU building stock until 2030, Deliverable 4.4 of WP4

LDHA (2013): Lithuanian District Heating Association. ŠILUMOS TIEKIMO BENDROVIŲ. 2012 METŲ - ŪKINĖS VEIKLOS APŽVALGA.

Marscheider-Weidemann, et. al., 2008: ESTIMATION OF CARBON COSTS IN THE CHEMICAL SECTOR, Cambridge and Fraunhofer ISI

Müller, A. (2015): Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock. Dissertation. TU Wien. March 2015

Pardo, N., Vatopoulos, K., Krook-Riekkola, A., Moya, J.A., Perez, A. (2012): Heat and cooling demand and market perspective (JRC scientific and policy reports No. Report EUR 25381 EN).

Pardo, Nicolas; Vatopoulos, Kostantinos; Krook-Riekkola, Anna; Perez, Alicia (2013): Methodology to estimate the energy flows of the European Union heating and cooling market. In: Energy.

Persson, Urban (2015): District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions. Thesis for the degree of Doctor of Philosophy, Gothenburg, Sweden, 109 pp.

PrEN 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. June 2010.

Preuß, G. (2011): Energiebedarf für Kältetechnik in Deutschland - Eine Abschätzung des Energiebedarfs von Kältetechnik in Deutschland nach Einsatzgebieten; Verband Deutscher Maschinen- und Anlagenbau (VDMA)

Prognos AG, Infras AG, TEP Energy GmbH (2014): Analyse des schweizerischen Energieverbrauchs 2000 – 2013 nach Verwendungszwecken. Bundesamt für Energie BFE, Bern

Reitze, F. (2012): Endenergiebedarf zur Prozesskälteerzeugung, Effizienzpotentiale, sowie hemmende Faktoren für den Einsatz von effizienter Kältetechnologie im GHD-Sektor und bei milchproduzierenden Betrieben in Deutschland in der Periode 2008-2020

RESCUE (2012/2013): Rescue Renewable Smart Cooling for Urban Europe. Work Package 2 EU District Cooling Market and Trends.

Riviere, P., Grignon-Masse, L., Legendre, S., Marchio, D., Nermond, G., Rahim, S., Andre, P., Detroux, L., Lebrun, J., L'Hoest, J., Teodorose, V., Alexandre, J.L., Sa, E., Benke, G., Bogner, T., Conroy, A., Hitchin, R., Pout, C., Thorpe, W., Karatasou, S. (2008): Ecodesign Preparatory Studies: Lot 10 Residential Room Conditioning Appliances - Task 2 - final report. Armines.

SNCU (2014): Syndicat national du chauffage urbain et de la climatisation urbaine. Enquete Nationale sur les Reseaux de Chaleur et de Froid. Restitution des statistiques portant sur l´annee 2012.

Sebi C, Lapillonne B, Routin G. Guideline on the databases and web- tool. Energy Economics Group, Natitonal Consumer Research Centre, Fraunhofer ISI, CENER, Politecnico di Milano, Öko-Institut e.V., Sofena,BPIE, Enerdata,SEVEn; 2013.

Sousa J. Background of portuguese domestic energy consumption at european level. CEUR Workshop Proc 2012;923:49–56

Statistics Norway. Balance of district heating. Accessed 1 July 2015: https://www.ssb.no/en/energi-og-industri/statistikker/fjernvarme/aar/2014-10-14?fane=tabell&sort=nummer&tabell=200984.

Statistics Norway. District cooling consumption. Accessed 28 August 2015: https://www.ssb.no/statistikkbanken/SelectVarVal/Define.asp?MainTable=FjernKjoling&KortNavnWeb=fjernvarme&PLanguage=1&checked=true.

Statistics Sweden. Electricity supply, district heating and supply of natural and gasworks gas 2012.

Statistik Austria (2014): Nutzenergieanalyse für Österreich

Statistik Austria, Bundesanstalt Statistik. Nutzenergieanalyse für Österreich (1993 – 2013): http://www.statistik.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/energie/nutzenergieanalyse/index.html.

SURS, Statistical Office of the Republic of Slovenia. Balance of Heat. http://pxweb.stat.si/pxweb/Database/Environment/18_energy/05_18177_heat/05_18177_heat.asp.

Werner, S. (2006): The new European heating index. 10th International Symposium on District Heating and Cooling September.

Werner, S. (2015): European space cooling demands. In: Energy. DOI: 10.1016/j.energy.2015.11.028.

8 Annex

8.1 Structure of energy balances by Eurostat

Gross inland consumption	=	+	Primary production
		+	From other sources
		+	Recycled products
		+	Imports
		+	Stock changes
		-	Exports
		-	Bunkers
		+	Primary product receipts
		-	Direct use
Transformation input	=	+	Transformation input - Conventional Thermal Power Stations
		+	Transformation input - Nuclear Power Stations
		+	Transformation input in Coke Ovens
		+	Transformation input in Blast Furnaces
		+	Transformation input in Gas Works
		+	Transformation input in Refineries
		+	Transformation input - District Heating Plants
		+	Transformation input in Patent Fuel Plants
		+	Transformation input in BKB / PB Plants
		+	Transformation input in Coal Liquefaction Plants
		+	Transformation input - For Blended Natural Gas
		+	Transformation input in Charcoal production plants (transformation)
		+	Transformation input in Gas-to-Liquids (GTL) Plants (Transformation)
		+	Transformation input - Used for electricity generation
		+	Non-specified Transformation input
Transformation output	=	+	Transformation output - Conventional Thermal Power Stations
		+	Transformation output - Nuclear Power Stations
		+	Transformation output - District Heating Plants
		+	Transformation output from Coke Ovens
		+	Transformation output from Blast Furnaces
		+	Transformation output from Gas Works
		+	Transformation output from Refineries
		+	Transformation output from Patent Fuel Plants

Gross inland consumption	=	+	**Primary production**
		+	Transformation output from BKB / PB Plants
		+	Transformation output from Charcoal production Plants
Exchanges, Transfers, Returns	=	+	Interproduct Transfers
		+	Products Transferred
		+	Returns from Petrochemical Industry
Consumption in Energy Sector	=	+	Own Use in Electricity, CHP and Heat Plants
		+	Pumped storage power stations balance
		+	Consumption in Oil and gas extraction
		+	Consumption in Petroleum Refineries
		+	Consumption in Nuclear industry
		+	Consumption in Coal Mines
		+	Consumption in Patent Fuel Plants
		+	Consumption in Coke Ovens
		+	Consumption in BKB / PB Plants
		+	Consumption in Gas Works
		+	Consumption in Blast Furnaces
		+	Consumption in Coal Liquefaction Plants
		+	Consumption in Liquefaction (LNG) / regasification plants
		+	Consumption in Gasification plants for biogas
		+	Consumption in Gas-to-liquids (GTL) plants (energy)
		+	Consumption in Non-specified (Energy)
		+	Consumption in Charcoal production plants (Energy)
Energy Available for Final Consumption	=	+	Gross inland consumption
		-	Transformation input
		+	Transformation output
		+	Exchanges, Transfers, Returns
		-	Consumption in Energy Sector
		-	Distribution losses
Final Energy Consumption - Industry	=	+	Iron and Steel
		+	Chemical and Petrochemical
		+	Non-Ferrous Metals
		+	Non-Metallic Minerals
		+	Transport Equipment
		+	Machinery
		+	Mining and Quarrying

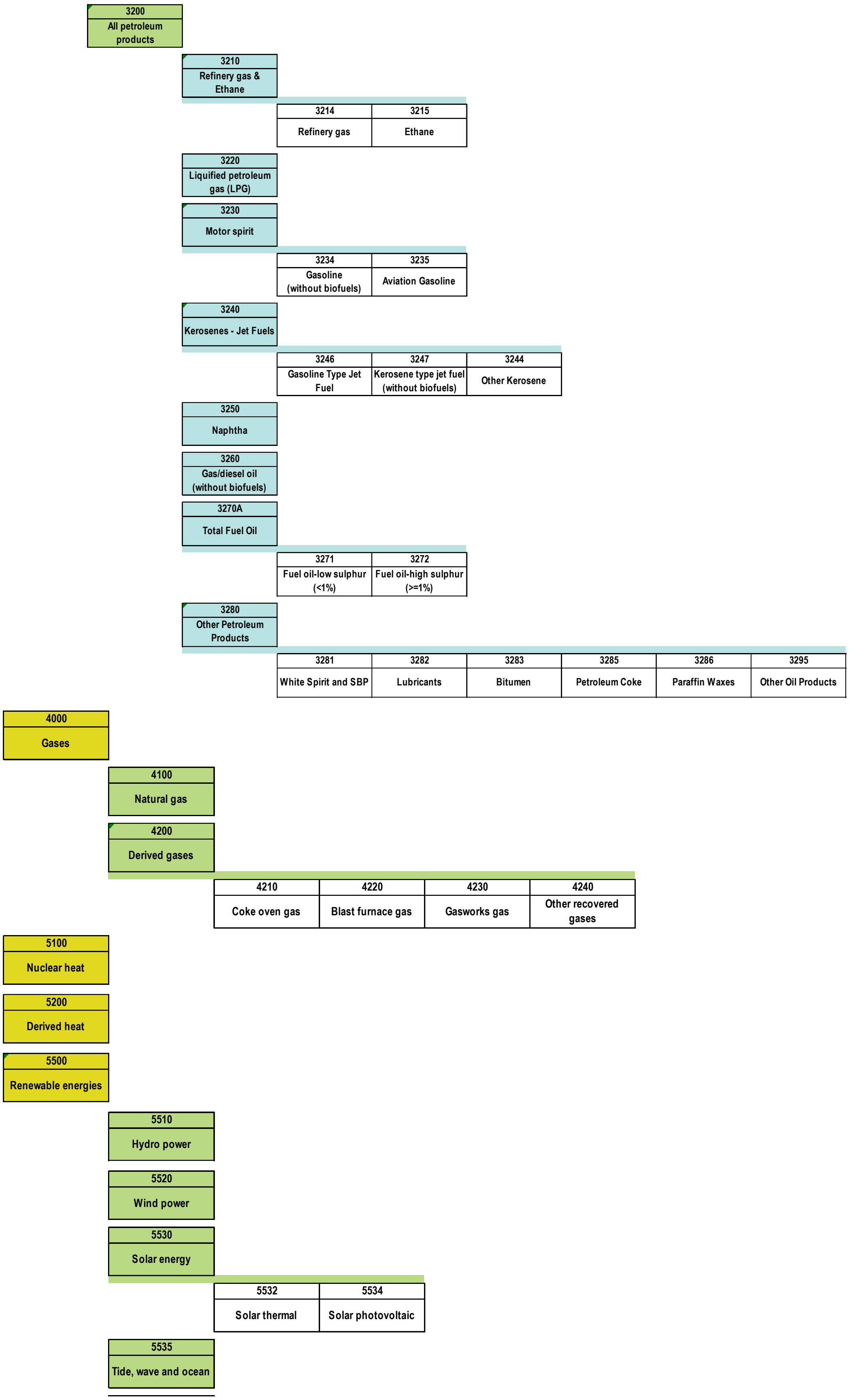
Gross inland consumption	=	+	**Primary production**
		+	Food and Tobacco
		+	Paper, Pulp and Print
		+	Wood and Wood Products
		+	Construction
		+	Textile and Leather
		+	Non-specified (Industry)
Final Energy Consumption - Transport	=	+	Rail
		+	Road
		+	International aviation
		+	Domestic aviation
		+	Domestic Navigation
		+	Pipeline transport
		+	Non-specified (Transport)
Final Energy Consumption - Other Sectors	=	+	Services
		+	Residential
		+	Agriculture/Forestry
		+	Fishing
		+	Non-specified (Other)
Final Energy Consumption	=	+	Final Energy Consumption - Industry
		+	Final Energy Consumption - Transport
		+	Final Energy Consumption - Other Sectors
Final Non-energy Consumption	=	+	Non-energy use in Transformation sector
		+	Non-energy use in Energy sector
		+	Non-energy use in Industry sector
		+	Non-energy use in Transport Sector
		+	Non-energy use in Other Sectors
		+	Non-energy use in Industry, Transformation & Energy Sectors
Statistical Difference	=	+	Energy Available for Final Consumption
		-	Final Non-energy Consumption
		-	Final Energy Consumption

Source: Eurostat

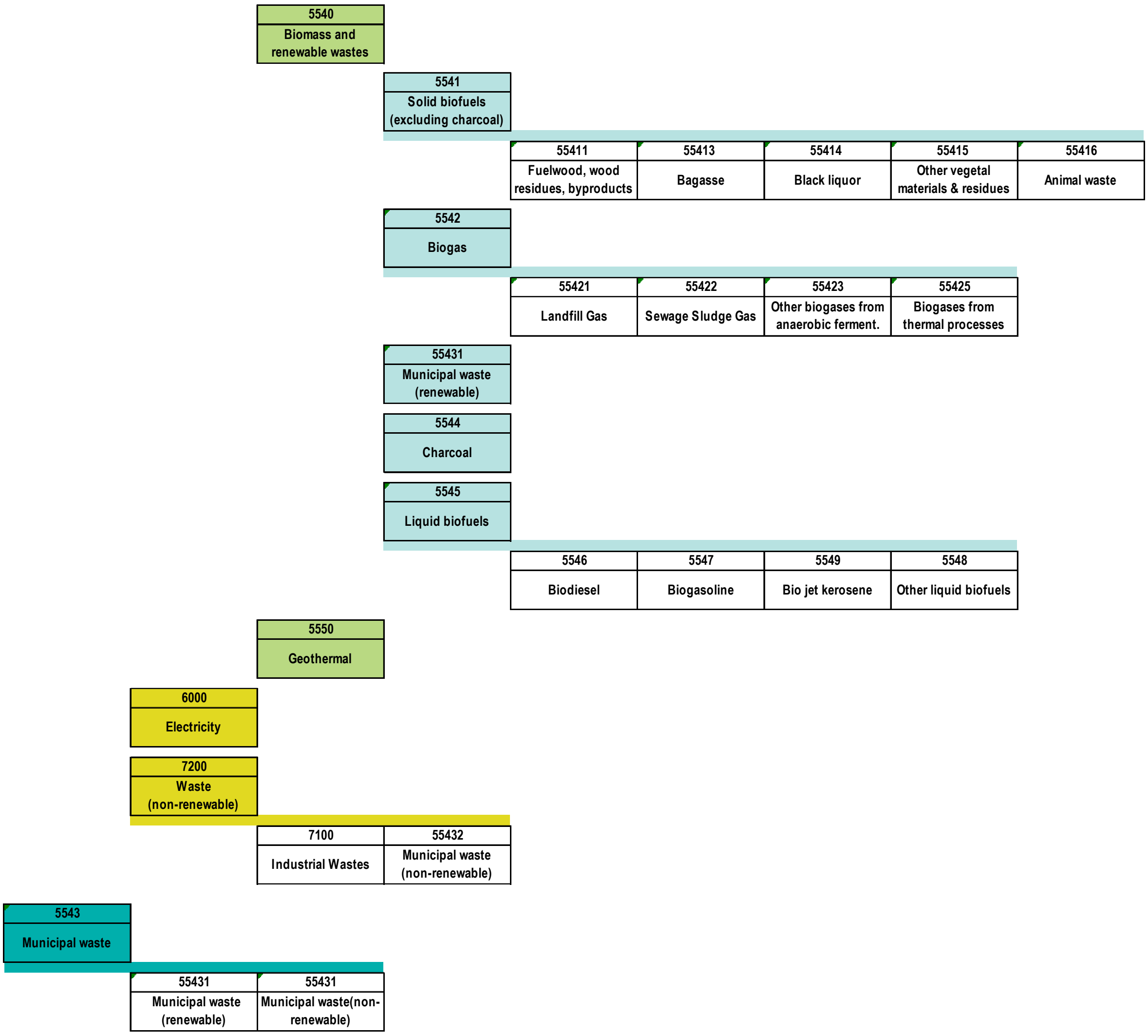
8.2 Structure of products (Eurostat)

- 0000 All products (total)
  - 2000 Solid fuels
    - 2100 Hard coal and derivatives
      - 2111 Hard coal
        - 2115 Anthracite
        - 2116 Coking coal
        - 2117 Other bituminous coal
        - 2118 Sub-bituminous coal
      - 2112 Patent Fuels
      - 2120 Coke
        - 2121 Coke oven coke
        - 2122 Gas coke
      - 2130 Coal tar
    - 2200 Lignite and Derivatives
      - 2210 Lignite/Brown Coal
      - 2230 BKB (brown coal briquettes)
      - 2310 Peat
      - 2330 Peat Products
    - 2410 Oil Shale and Oil Sands
  - 3000 Total petroleum products
    - 3100 Crude oil, feedstocks, other hydrocarbons
      - 3110 Crude oil and NGL
        - 3105 Crude oil (without NGL)
        - 3106 Natural gas liquids (NGL)
      - 3190 Feedstocks & Other hydrocarbons
        - 3191 Refinery Feedstocks
        - 3192 Additives / Oxygenates
        - 3193 Other Hydrocarbons (without biofuels)

Work package 1: Final energy consumption for the year 2012



Work package 1: Final energy consumption for the year 2012



Source: Eurostat