2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

Baseline scenario of the heating and cooling demand in buildings and industry in the 14 MSs until 2050

WP3: D3.3 and D3.4

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1 Introduction and objective

In Europe, there is a clear objective to decarbonise the energy system, but it is currently unclear how to achieve this in the heating and cooling (H&C) sector. The Heat Roadmap Europe 4 (HRE4) project enables new policies and prepares the ground for new investments by creating more certainty regarding the changes that are required to achieve a proper H&C transition. By increasing H&C lead-users' capacities at local to EU levels via the development of key tools and methodologies, the impact of efficient measures on both the demand and supply sides of the H&C sector can be quantified and eventually realised.

In the frame of the Heat Roadmap Europe 4 project, two scenarios are developed. These are:

- **Baseline Scenario:** The baseline scenario shows the possible future evolution of heating and cooling demand under the assumption that currently implemented policies are continued but not tightened. The c*urrent policy scenario* considers targets and measures concerning RES-H&C and energy efficiency which have been agreed or already implemented at the latest by the end of 2016. Within this scenario, all implemented instruments are assumed to be in place by 2030, including current financial support programs, without significant changes throughout the years.
- **Heat Roadmap Europe 4 Scenario**: Least cost path towards a decarbonization of the European H&C system by 2050 taking into account linkages to the entire energy system.

This document summarizes the assumptions and definitions taken to construct the baseline scenario. The focus of this document will be on the delivered heat (e.g. "the heat that the boiler needs to provide to heat the building", not to be confound with useful energy that is the heat required in the rooms to maintain the desired indoor temperature, see deliverable D3.1 for definitions). Thus, the choice of heat/cold supply technologies is excluded from this document.

The baseline scenario serves the following **main purposes** in the project:

- It is the reference for the HRE4 scenario to calculate the impact of a decarbonisation strategy for the H&C sector. More specifically,
- the delivered heat baseline will be input to the TIMES model, which optimizes the fuel supply mix to meet the delivered heat/cold demand until 2050 (WP5).
- The delivered heat baseline is the counterfactual for the heat/cold saving cost curves (WP4), which show the potential and costs for additional savings beyond the baseline

Main results:

- **Delivered heat and cold** by sector, country, end-use for 2015 (model result, not fully calibrated to Eurostat statistics which reports final energy but not delivered energy and was not yet available at times), 2030 and 2050. The level of detail will be similar to the 2015 profiles (D3.1)
- Including additional scenario variant "**frozen efficiency**", which only depicts changes from activity and economic framework, but assumes constant energy efficiency.
- **Saving potentials** realized in the baseline compared to frozen efficiency scenario variant by same investment categories.

2 Scenario definition and main assumptions

The current levels of heat and cold delivered and their future developments depend on various drivers. The delivered baseline is calculated using the bottom-up model FORECAST (see annex and http://www.forecast-model.eu for a detailed model description). In this model, a quantitative structure (such as industrial production, heated and cooled floor area derived from population and employment) is concatenated with specific indicators of heat and cold delivered (with in turn depend on various drivers. Assumptions about the implementation of policies such as building codes and standards, the socio-economic development until 2050, energy and CO_2 prices, technology development and implementation and climate data (HDD and CDD) are required. All these factors influence the resulting demand of delivered heat and cold until 2050.

Space cooling is modeled seperately in a bottom-up stock model developed by Armines and described in detail in D3.2. However, space cooling results for tertiary and residential sectors are still included in this report to provide the full view on delivered H&C demand.

In order to allow distinguishing the effect of the individual factors, a variation of the baseline scenario will be calculated assuming no change in technology performance and structure, but allowing for changes in the socio-economic drivers (value added, production, population). This variation is called **frozen efficiency scenario**. By comparing it with the final baseline, the impacts of socio economic drivers (frozen efficiency scenario of year t compared to base year 2015) on the one side and policies as well as technology change (baseline of year t compared to frozen efficiency scenario of year t) on the other side can be distinguished (see annex Table 18).

Framework parameters: Socio-economic development and energy prices

Table 1 provides an overview of framework parameters, the data source used and the main assumptions adopted for the projection until 2050. Note that all framework parameters are identical in the baseline scenario and the frozen efficiency scenario.

Table 1: Summary of data sources and assumptions for projection of framework data

Model parameter	Source	Assumption for projection
Economic drivers (GDP, value added industry and tertiary)	EU Ref 2016 (see Capros et al. 2016)	As EU Ref 2016
Energy prices (wholesale)	EU Ref 2016	As EU Ref 2016
CO_2 prices	EU Ref 2016	As EU Ref 2016
Population	EU Ref 2016	As EU Ref 2016
Number of households	EU Ref 2016	As EU Ref 2016
Industrial production	FORECAST benchmarked with EU Ref 2016	Continous development, no radical changes
HDDs and CDDs	Eurostat	Projection of past long term trend
End-user energy prices	2015 priced from Eurostat	Todays taxes and levies to remain

		fixed;projection of wholesale prices
Discount rates		Reflecting end-consumer
Number of Employees	As EU Ref 2016	Regression analysis based on population forecast

As far as available, framework parameters will be aligned to the EU Reference Scenario 2016 (Capros et al. 2016) referenced as EU Ref 2016 to allow comparability of studies and to build on broadly accepted economic framework. These are provided by country and include:

- Gross domestic product in billion Euro'13
- Value added industry by sub-sector in billion Euro'13
- Value added tertiary sector by sub-sector in billion Euro'13
- Population in million persons
- Number of households in million households
- Wholesale energy prices for oil, coal, gas and electricity in Euro'13/MWh
- CO_2 allowance prices in Euro'13/t CO_2

Other more specific drivers such as the production of basic materials products (e.g. steel or cement), are compared between both models, but the assumptions in FORECAST are allowed to deviate from the EU Reference Scenario 2016. For many specific drivers, also no data was available from the EU Reference Scenario. In this case, FORECAST assumptions had to be taken anyway.

The amount of energy savings adopted in the baseline scenario as compared to the frozen efficiency baseline are determined by cost-effectiveness calculations which depend either on discount rates or payback times, underlying various techno-economic assumptions such as specific CAPEX and OPEX, efficiencies, lifetime, etc.

Technology development and new technologies

In terms of technology development and availability of new technologies the following assumptions are underlined to the baseline scenario:

- Availability of new technologies: no, only current technologies
- Continuous/incremental technology learning: yes, moderate (as falling CAPEX or improvement of techno-economic parameters)

Policy assumptions

The baseline scenario considers a continuation of today's policies. More precisely, the scenario includes the 2016 state of implementation of individual policy instruments such as the Energy Performance of Buildings Directive (EPBD). It assumes that this policy remains as it is in 2016 until 2050. No tightening or other changes of the policy are assumed. Even more, we model EU directives based on how they are implemented in national building standards. In a similar way, the most important national and EU policies are considered as shown in the overview in Table 2.

Targets as e.g. the EU's 2030 targets are not included as input parameters to the model. On the one side, they cannot be properly evaluated with a focus on H&C delivered heat only and on the other side, the explorative simulation approach focuses on assessing policy instruments and their impact on meeting targets, but does not assume that targets are automatically met.

Table 2: Overview of policies supporting efficient and renewable heating and cooling in buildings and industry in the baseline scenario

	EU leg.	Interpretation for baseline scenario
Regulations / Information		
Energy efficiency standards for renovation	EPBD	National building code requirements 2015 or planned tightening as far as data is available. Compliance below 100 %. If no codes are effective: standards similar to new buildings with a certain time lag.
Energy efficiency standards new buildings	EPBD	National building code requirements 2015 or planned tightening as far as data is available. Compliance below 100 %.
Renovation rate	EED (indirectly)	Where applicable: continuation of past and current renovation rates by country
Financial policies and economic instruments		
Energy saving obligation	EED	Energy saving obligations of about 1-1.5 % per year, but national differences in exceptions and alternative systems
Energy and CO_2 taxation	ETD	Taxes varying by fuel and sector. Constant tax as relative share of energy price assumed
EU Emission allowances	ETD	CO_2 price: increase to 90 EUR/tCO_2-equ in 2050 Scope of EU ETS to remain as in phase 3
Subsidies for building renovation	National	Continuation of national subsidy programs

Abbreviations: EPBD: Energy Performance of Buildings Directive, EED: Energy Efficiency Directive, ETD: Emissions Trading Directive, National: National measures

3 Input data and assumptions by sector

3.1 Industry sector

3.1.1 Framework data

Figure 1 provides the industrial value added per country assumed in the baseline. Data is taken from the EU reference scenario 2016 (Capros et al., 2016). The share of the four biggest countries (Germany, Italy, France and UK) decreases from 63 % in 2015 to 58 % in 2050, which is explained by lower growth figures in these countries (see Table 1). In Figure 2, the added value data is split by industrial subsector. Machinery and transport is the biggest industrial sector in terms of added value, whereas energy intensive industries like Iron & steel only modestly contribute to the total industrial added value.

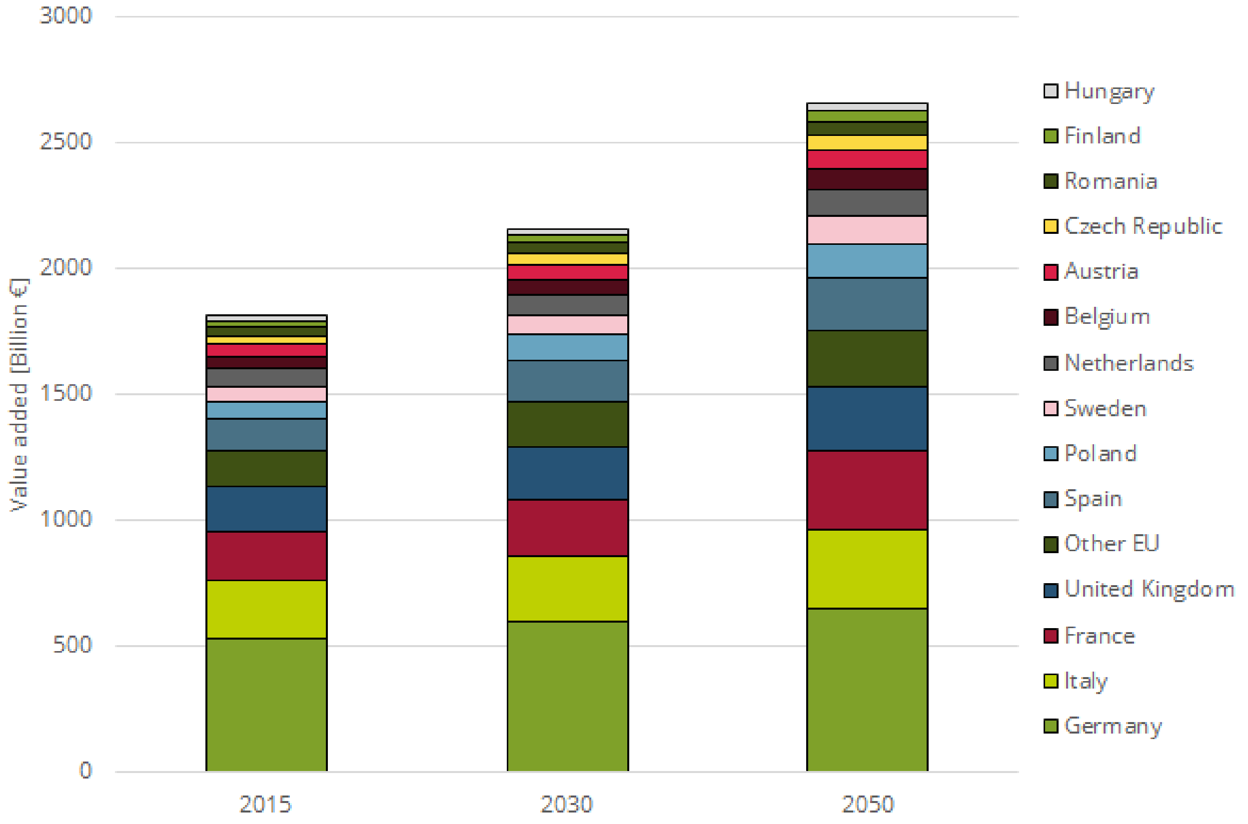


Figure 1: Industrial value added by country (HRE4 core countries + rest of EU28)

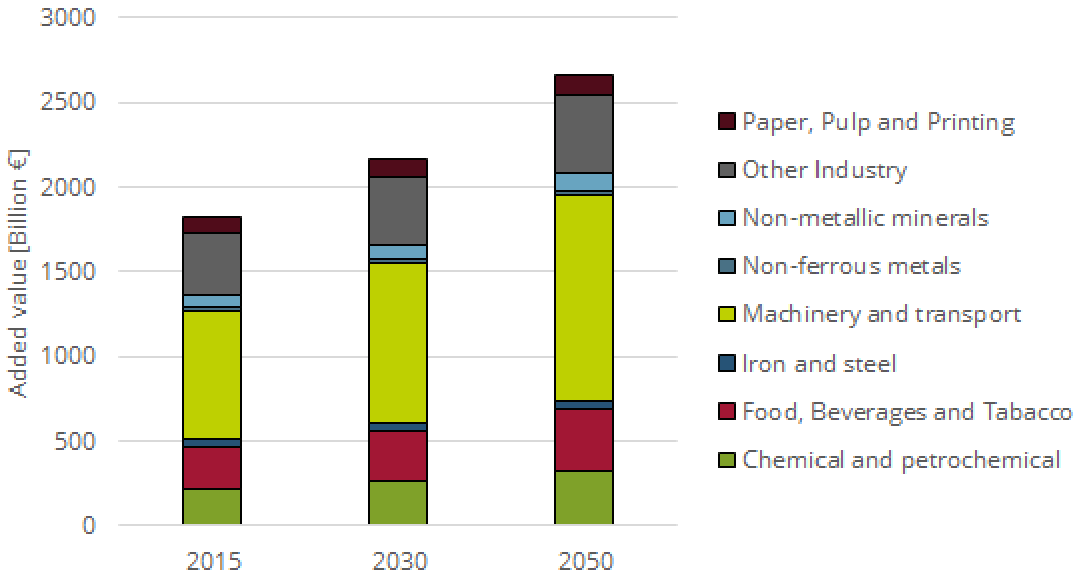


Figure 2: Industrial value added EU28 by subsector

Table 3: Industrial value added by country [billion euros and growth rates]

Country	2015	2030	%2015-2030	2050	%2030-2050
Austria	52,0	62,6	20,3 %	77,8	24,4 %
Belgium	45,8	55,1	20,1 %	78,0	41,7 %
Czech Republic	33,6	43,2	28,6 %	59,1	37,0 %
Finland	28,1	31,9	13,6 %	41,6	30,3 %
France	193,9	230,2	18,7 %	309,8	34,6 %
Germany	534,8	602,1	12,6 %	652,8	8,4 %
Hungary	18,8	25,1	33,7 %	31,4	25,2 %
Italy	227,4	254,3	11,9 %	312,5	22,9 %
Netherlands	70,0	83,2	18,8 %	103,7	24,6 %
Poland	66,5	102,1	53,6 %	135,0	32,3 %
Spain	129,7	164,5	26,9 %	207,5	26,1 %
Sweden	60,6	78,5	29,6 %	111,9	42,6 %
United Kingdom	179,6	202,9	13,0 %	255,9	26,1 %
Romania	31,8	43,9	38,1 %	54,2	23,3 %
Other EU	145,6	184,2	26,5 %	233,8	26,9 %

In terms of physical production, blast furnace steel, electric arc steel, paper and cement are among the most important industrial products. Figure 3 shows the production development in the baseline period. Only cement shows a clear increase (mainly in the period 2015-2030). Although electric arc steel production in 2050 is almost equal to 2015 production level, it becomes more important than blast furnace steel, which shows a clear decrease in production. Production and growth rates for these and industrial products are provided in

Table 4.

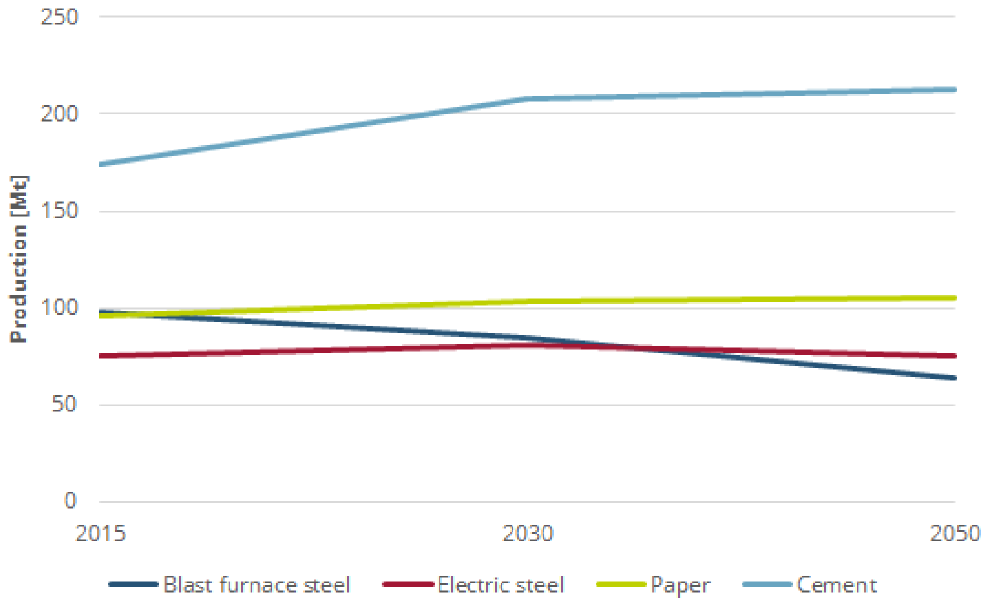


Figure 3: Development of production data of important industrial processes

Table 4: Production data of industrial processes [Mt and growth rates]

	2015	2030	% 2015-2030	2050	% 2030-2050
Chemical industry					
Carbon black	17,1	19,5	13,7 %	20,4	4,8 %
Ethylene	16,3	17,7	8,5 %	19,1	7,9 %
Poly sulfones	15,8	21,1	32,9 %	21,0	-0,2 %
Methanol	23,0	27,8	21,1 %	29,7	6,7 %
Ammonia	18,0	18,7	4,2 %	19,6	4,8 %
Soda ash	13,6	14,2	4,4 %	14,0	-1,3 %
TDI	3,8	5,1	35,3 %	5,4	5,1 %
Oxygen	32,7	33,0	0,8 %	32,9	-0,2 %
Iron and steel					
Blast furnace	97,5	84,9	-13,0 %	64,3	-24,3 %
Rolled steel	159,9	154,0	-3,7 %	131,3	-14,7 %
Sinter	109,5	99,2	-9,4 %	76,9	-22,5 %
Electric arc furnace	75,1	81,2	8,2 %	75,3	-7,3 %
Coke oven	41,7	38,3	-8,1 %	31,8	-17,2 %
Food					
Meat processing	64,5	67,4	4,5 %	68,0	0,8 %
Sugar	30,3	32,1	6,0 %	32,8	2,4 %
Dairy	72,5	74,7	3,1 %	76,0	1,7 %
Bread & bakery	26,8	27,8	3,7 %	27,8	0,0 %
Brewing	47,0	50,7	7,9 %	51,9	2,4 %
Non-ferrous metals					
Aluminum, primary	4,1	4,3	4,0 %	4,3	0,3 %

Non-metallic minerals					
Clinker calcination-dry	123,0	146,1	18,8 %	148,2	1,4 %
Lime burning	40,6	49,8	22,6 %	55,6	11,6 %
Flat glass	13,1	14,6	11,8 %	15,2	4,0 %
Container glass	22,9	23,5	2,9 %	21,0	-10,7 %
Bricks	80,7	82,7	2,4 %	83,2	0,6 %
Gypsum	117,3	119,7	2,0 %	120,4	0,6 %
Pulp and paper					
Paper	95,6	103,1	7,7 %	105,6	2,5 %
Chemical pulp	27,1	28,6	5,7 %	29,5	3,0 %

3.1.2 Technology data

Table 5 provides the base year assumptions for selected technologies regarding the specific fuel and specific electricity consumption. To serve the purpose of this study, the table also provides information which share of the fuels and electricity is used for heating and cooling. In Table 6 more detailed information is provided for these selected technologies regarding the shares of temperature levels for process heating and/or cooling. More background information can be found in Fraunhofer ISI et al. 2017, Fleiter et al. 2013 and Rehfeldt et al. 2016.

Table 5: Technology assumptions of selected technologies

		Specific energy consumption		Share for heating		Share for cooling	
		Fuels	**Electricity**	**Fuels**	**Electricity**	**Fuels**	**Electricity**
Chemical industry	Carbon black	64,8	1,8	100 %	0 %	0 %	6 %
	Ethylene	35,9	0,0	100 %	0 %	0 %	0 %
	Poly sulfones	24,5	3,1	100 %	0 %	0 %	4 %
	Methanol	15,0	0,5	100 %	0 %	0 %	4 %
	Ammonia	11,3	0,5	100 %	0 %	0 %	6 %
	Soda ash	11,3	0,3	100 %	0 %	0 %	0 %
	TDI	26,7	2,8	100 %	5 %	0 %	2 %
	Oxygen	0,0	2,5	100 %	0 %	0 %	96 %
Iron and steel	Blast furnace	11,6	0,6	100 %	0 %	0 %	0 %
	Rolled steel	2,4	0,6	100 %	10 %	0 %	0 %
	Sinter	2,2	0,1	100 %	0 %	0 %	0 %
	Electric arc furnace	1,0	2,3	100 %	95 %	0 %	0 %
	Coke oven	3,2	0,1	100 %	0 %	0 %	0 %
Food, drink and tobacco	Meat processing	2,0	1,5	100 %	5 %	0 %	61 %
	Sugar	4,5	0,7	100 %	0 %	0 %	42 %
	Dairy	1,6	0,5	100 %	5 %	0 %	57 %
	Bread & bakery	2,4	1,4	100 %	45 %	0 %	44 %
	Brewing	1,0	0,4	100 %	5 %	0 %	41 %
Non-ferrous metals	Aluminum, primary	27,0	57,5	100 %	5 %	0 %	0 %

		Specific energy consumption		Share for heating		Share for cooling	
Non-metallic minerals	Clinker calcination-dry	3,5	0,1	100 %	0 %	0 %	0 %
	Lime burning	3,7	0,1	100 %	0 %	0 %	0 %
	Flat glass	10,9	3,3	100 %	0 %	0 %	6 %
	Container glass	5,8	1,4	100 %	4 %	0 %	6 %
	Bricks	1,4	0,2	100 %	0 %	0 %	0 %
	Gypsum	1,0	0,2	100 %	0 %	0 %	0 %
Pulp, paper and printing	Paper	5,5	1,9	100 %	1 %	0 %	1 %
	Chemical pulp	12,7	2,3	100 %	1 %	0 %	0 %

Table 6: technology assumptions regarding the shares of different temperature levels for process cooling and heating

		Cooling			Heating			
		<-30 °C	-30-0 °C	0-15 °C	<100 °C	100-200 °C	200-500 °C	>500 °C
Chemical industry	Carbon black	20 %	30 %	50 %	0 %	-	-	100 %
	Ethylene	15 %	50 %	35 %	0 %	-	-	100 %
	Poly sulfones	0 %	40 %	60 %	0 %	100 %	-	-
	Methanol	0 %	40 %	60 %	0 %	-	-	100 %
	Ammonia	20 %	30 %	50 %	0 %	-	-	100 %
	Soda ash	5 %	45 %	50 %	30 %	40 %	-	30 %
	TDI	0 %	30 %	70 %	0 %	100 %	-	-
	Oxygen	80 %	10 %	10 %	-	-	-	-
Iron and steel	Blast furnace	-	-	-	1 %	1 %	1 %	97 %
	Rolled steel	-	-	-	0 %	-	-	100 %
	Sinter	-	-	-	0 %	0 %	20 %	80 %
	Electric arc furnace	-	-	-	1 %	0 %	0 %	99 %
	Coke oven	-	-	-	0 %	-	-	100 %
Food, drink and tobacco	Meat processing	0 %	30 %	70 %	40 %	60 %	-	-
	Sugar	0 %	20 %	80 %	10 %	60 %	-	30 %
	Dairy	0 %	30 %	70 %	90 %	10 %	-	-
	Bread & bakery	0 %	10 %	90 %	20 %	33 %	47 %	-
	Brewing	0 %	35 %	65 %	55 %	45 %	-	-
Non-ferrous metals	Aluminum, primary	-	-	-	0 %	-	-	100 %
Non-metallic minerals	Clinker calcination-dry	-	-	-	0 %	-	10 %	90 %
	Lime burning	-	-	-	0 %	-	-	100 %
	Flat glass	-	-	100 %	2 %	21 %	43 %	34 %
	Container glass	-	-	100 %	2 %	19 %	19 %	60 %
	Bricks	-	-	-	20 %	-	-	80 %
	Gypsum	-	-	-	0 %	50 %	30 %	20 %
Pulp, paper and printing	Paper	-	-	1 %	5 %	88 %	5 %	2 %
	Chemical pulp	-	-	-	0 %	100 %	-	-

3.1.3 Policy assumptions

The main assumptions in terms of policies are the CO2 certificate prices form the EU ETS prices and the energy taxes. The former is aligned with the EU Reference Scenario 2016 and shown in Figure 4. Accordingly, an increase until about 90 euros per tons of CO_2 in 2050 is assumed. Energy taxes are assumed to remain constant in the future based on the 2015 level as reported by Eurostat.

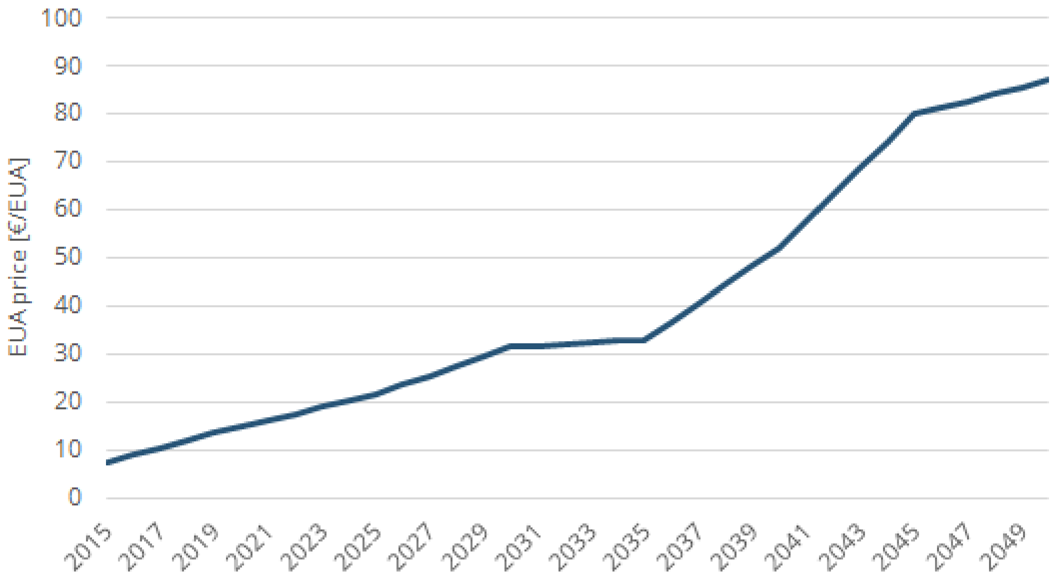


Figure 4: ETS CO_2 price path assumed in baseline scenario (EUAs)

Further policies for the industry sector include minimum standards from the EU Ecodesign Directive for various techniques, of which some are related to H&C including smaller boilers and largescale ventilation and cooling systems. Standards for steam boilers and furnaces are under discussion but not yet decided on. Further policies include energy management schemes, energy audits and often national support programs like the provision of grants or soft loans for energy efficiency measures. All such programmes cannot be modelled in large detail, but are considered in a more aggregated form that still considers the varying intensity in which such programs are implemented in the different countries (see Fraunhofer ISI et al. 2014).

3.2 Residential sector buildings

The current levels of heat and cold delivered and their future developments depend on various drivers which are taken into account in the bottom-up model FORECAST. In this model, a quantitative structure of heated and cooled floor area and related building stock data is concatenated with specific indicators of heat and cold delivered. Both the quantitative structure and specific indicators of heat and cold delivered depend on exogenous drivers such as population, individual space need on the one hand side (in the following depicted as framework data) and construction practice, retrofit activities, retrofit levels, indoor and outdoor temperature, building use, and others on the other hand side. Some of variables in turn depend on policy instruments and economic drivers which are part of the general framework data (see Chapter 1).

Table 16 provides an overview on the most relevant drivers of current and future heat and cold delivered.

Table 7: Most relevant drivers of current and future heat and cold delivered (residential sector).

	Current level of heat and cold delivered	Future development of heat and cold delivered
Quantity structure	Total floor area	Future development of total floor area, depending on • Population development • Household size or floor area per capita
	Share of heated and cooled floor area (depending on socio-economic data and current climate conditions)	Future share of heated and cooled floor area (depending on socio-economic data, changing comfort expectations, and future climate conditions)
	Building typology of existing building stock	Demolition rate and new-built
Specific energy delivered (per m²)	Building geometry of existing building stock	Building geometry of new buildings
	Thermal transmittance, depending on • original construction practice (depending on past building code implementation, i.e. construction period) • **past** retrofit activities and levels (partly depending on past building codes, past energy prices and technology spill-over from the new built sector)	Thermal transmittance, depending on • construction practice (depending on current building codes and potential amendment) • **future** retrofit activities and levels (partly depending on current building codes, energy prices and technology spill-over from the new built sector)
	Ventilation rate (mainly depending on user behaviour and air tightness of buildings of the past)	Ventilation rate (mainly depending on user behaviour and increasingly from the use of ventilation systems)
	Indoor temperature	Indoor temperature
	Current climate conditions	Future climate conditions

Assumptions about these drivers as well as intermediate model results are described in the next sections.

3.2.1 Framework data

The framework data basis of residential sector modelling is essentially based on an in depth literature research of recently published studies addressing the European residential sector. In terms of the framework parametersr the EU Reference Scenario 2016 (Capros et al. 2016) provides a broad set of socio-demograhpic and macroeconomic data including the population and the number of households distinguished by country until 2050. These parameters are directly linked to each other, as the number of households is derived from the development of population by further considering the persons per household. Hence, the number of households is taken from the EU Reference Scenario 2016. Analysing Figure 5 shows that especially in countries like France,Italy and the United Kingdom the number of households are expected to increase by up to 17 % until 2050 compared to 2015. Whereas in Spain or in Germany the number of households stagnates or even is expected to decrease over time (due to a decreasing population).

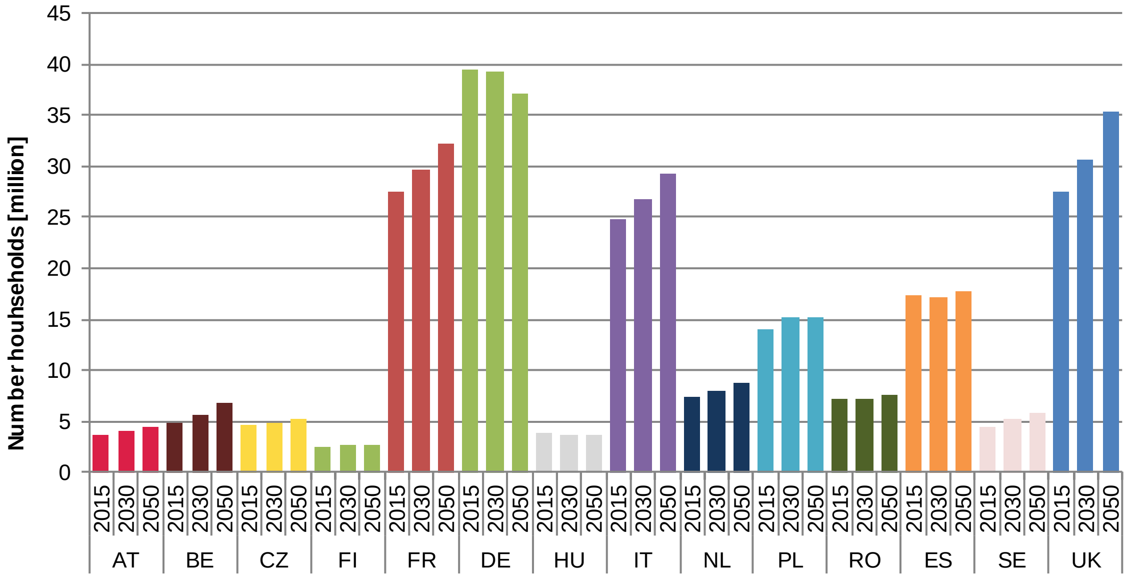


Figure 5: Households per country for the time periods 2015, 2030 and 2050

In a subsequent step the given number of households is used to derive the development of the building stock until 2050 distinguished by Single-family houses (SFH) and Multi-family houses (MFH), which is further broken down by construction period and by thermal efficiency. Within the modelling, the demolition of buildings results from the age distribution of the building stock. The amount of new constructions is endogenously modelled and basically driven by the number of households assumed.

Another crucial driver to model the heating and cooling demand is the living area. The development of living area is presented in Figure 6 for SFH and in Figure 7 for MFH. The analysis reveals that besides Romania the square meter per dwelling for SFH are at least around 80 m² until 2050. The most space per dwelling exists in Spain, which even increases up to 150 m²/dwelling in 2050. In general, similar trends per country can be seen for MFH except the dynamics are different between the 14 HRE4 countries. According to the number of households the trends vary depending on empirical development and assumptions about the future. Furthermore, saturation effects are considered regarding the relation of number of households and the corresponding living area on a country basis.

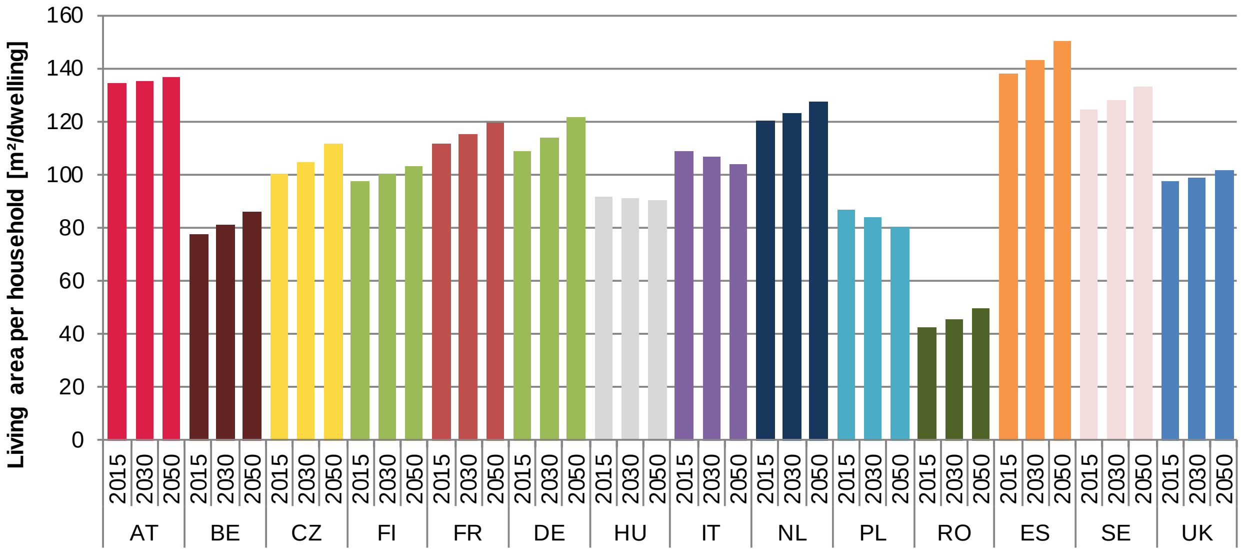


Figure 6: Living area per dwelling in SFH and country for the time periods 2015, 2030 and 2050

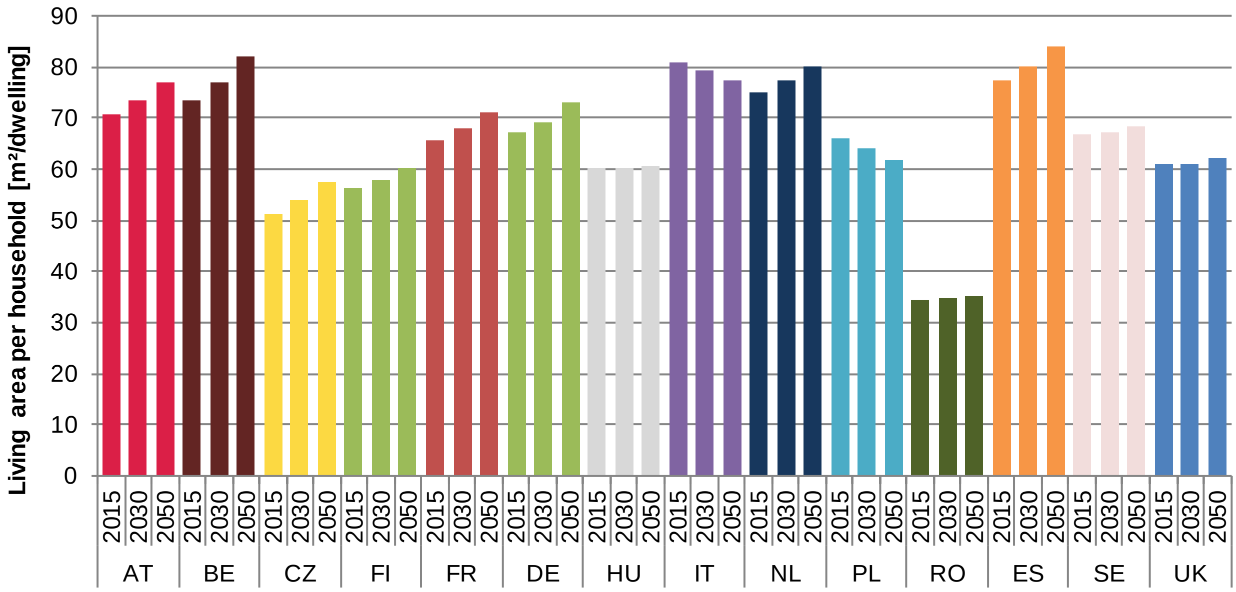


Figure 7: Living area per dwelling in MFH and country for the time periods 2015, 2030 and 2050

3.2.2 Building stock and technology data

Generally, bottom-up models are characterized by their high demand for detailed input data. As a large body of building stock data has been published in recent years, an essential step of the analysis is to obtain a consistent data set. Until a few years ago, the building stock data largely lacked in terms of detailed information about the European building typology. As the thermal improvement of building envelopes has been demonstrated as having the highest energy saving potential, several studies have been conducted in recent years addressing this issue. Some of these studies are: TABULA/Episcope, Entranze (a), Mapping EU heat supply (Fraunhofer ISI et al. 2017), Zebra 2020, IWU (2017) etc.

These studies mainly focus on the residential building stock, which consequently leads to a broad data basis for energy demand analysis, in contrast to delivered energy demand. A comparison of typology data based on these studies shows that the level of detail and differentiation varies. Furthermore, the data comparison revealed that data is either pertained to the number of buildings or to the number of dwellings and therefore the link between buildings and dwellings is sometimes difficult to establish.

Based on this background, the European Commission established the European Building Stock Observatory with the goal to monitor the energy performance of buildings across Europe and to provide comprehensive resources for policy makers, investors, energy utilities, local and national authorities and all of the interested stakeholders. The main focus of the European Building Stock Observatory is the building stock characteristics and its energy needs, including building energy performance and refurbishment, integration of renewable energy technologies and the resulting or attainable energy savings. Initially, the Observatory provided an overview of the data by the projects mentioned above. As differences between the various sources occurred, the EU Building Stock Observatory tried to establish a harmonized dataset considering all collected data.

However, in terms of the harmonisation there is no detailed description of the procedure, what kind of data was used and to which degree the data from the different EU-wide sources was reckoned up. This leads to some challenges in terms of the traceability. Main caveats in terms of plausibility and consistency across different EU-wide source are:

- Building geometry: The envelope to heated floor ratio, i.e. the area of the individual building elements to heated floor ratio for SFH and MFH, are based on TABULA and some specific amendments for selected countries. Indeed, geometry data in TABULA is not plausible for some elements (e.g. almost no windows, total envelope area too high or too low etc.). Adjustments have been made to the following countries: BE, CZ, IT, RO and some non-EU14 countries for MFH and FI, SE and some non-EU14 countries for SFH.
- Thermal transmittance of the building envelope (U-Values): as mentioned above building typology data including U-Values have been published by various projects and initiatives. Both the existing building stock (usually with a break down on construction periods) and standards or typical values for new buildings (and retrofits) are covered. Analysing and comparing these different sources among each other it was found that
    - **Definition:** It is mostly not clear whether U-values represent the building elements of the original state of construction or whether they represent a (weighted) average of the current state, i.e. whether or not the effect of retrofits of the past twenty to thirty years is included. It seems that national sources and contributing authors and agencies did not handle these aspects the same way.
    - **Consistency:** Data across different sources, across different countries (within one source) or across construction periods often are not consistent. Difference between countries cannot be traced back to explanatory factors such as climate, construction practice, or building codes. We assume that such inconsistencies are mainly due to different definitions adopted by contributing authors (see previous bullets) and due different (empirical) data quality.

- **Level:** In general U-Values are rather high, first from a content point of view (considering construction practice and building physics), and second from a modelling point of view. Indeed, the values of aforementioned sources are rather high as compared to the model input of FORECAST which has been calibrated in previous applications, including the EU heating and cooling mapping project (Fleiter et al. 2016). Using the data of the different sources directly as a model input would lead to a distinct overestimation of final energy demand compared to EU and national energy statistics.

Given these findings U-Values were adjusted for most of the countries for selected building types and construction periods.

Regarding the Heat Roadmap 4 project the data harmonization was done by Fraunhofer ISI and TEP Energy, as the harmonized dataset of the EU Building Stock Observatory was finalized after the modelling of the baseline already took place. Nevertheless, we tried to consider the Observatory data whenever possible. In case of non-plausibility, we replaced the data by different assumptions.

This broad data basis allows to calculate the average specific energy demand (SEC) per household for space heating and water heating. Additionally, the numbers of heating and cooling degree days together with the achieved level of comfort within the different countries play an important role (see appendix 7.2 for details on HDD and CDD). Furthermore, the conversion level of heating systems was considered to finally derive the delivered energy demand per country, distinguished by construction period and building type.

The analysis for 2015 depicted in Figure 8 emphasizes very heterogeneous patterns of delivered heat demand in Europe. Whereas Southern and Eastern European countries (e.g. Spain and Romania) generally show a lower level of delivered energy demand, the analysis also shows significant differences between the various countries in similar climate regions like Spain and Italy. In contrast, Nordic countries such as Sweden with colder winter climate already have advanced building standards today and, hence, have a relatively low level of energy demand in relation to their average level of outdoor temperature.

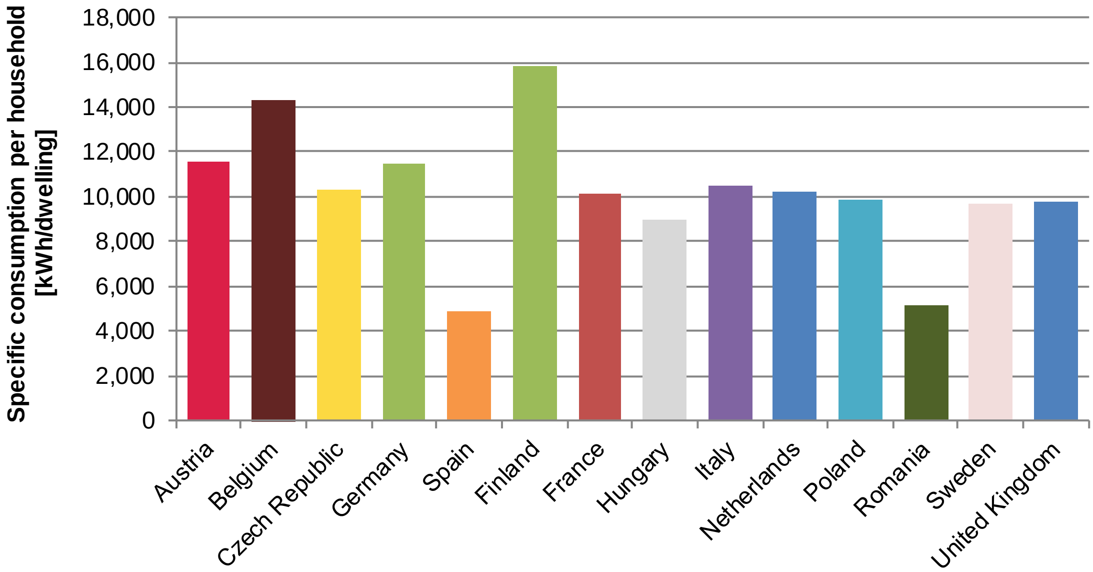


Figure 8: Specific energy demand per dwelling for space heating and water heating for the year 2015

Space cooling

Space cooling is modeled seperately in a bottom-up stock model developed by Armines and described in detail in D3.2.The space cooling model is based on sales data from the 14 EU member states obtained mainly from BSRIA market intelligence and Eurovent Certification Company. It contains the number of units sold of all technologies with significant market share: movable units, split systems, VRF units, rooftop and packaged systems, air and water cooled chillers. It also contains information on the sales repartition over the residential and tertiary sectors which was extrapolated over countries and years, weighted by the tertiary/residential floor area ratio. This data together with a number of assumptions allow to estimate the composition of the current technology stock for each sector in each country from which we derive the total cooling power installed and, with additional assumptions on the installation sizing, the total cooled floor area. Specific (per unit floor area) cooling demand data, shown in sections 2.3.2. and 2.4.2. is then used to obtain the total cooling demand. Projections up to 2050 are made by forcasting sales growth based on pre-2008 growth rates up to a market saturation limit which is estimated based on US market data as a function of the climate and household income.

Rivière et al. (2008) performed dynamic building demand simulations for residential and service sector buildings, determining both the theoretically ideal installation size (W/m²) and the specific demand (kWh/m²) as a function of the climate for a number of European locations. For the residential sector these specific demand figures are re-fitted to updated climate indicators (CDD) for this work. More detail can be found in D3.2.

Table 8: Specific space cooling demand per m² in residential sector buildings

RESIDENTIAL SECTOR	Specific cooling demand (kWh/m²)
Austria	18.1
Belgium	10.8
Czech Republic	12.3

Finland	7.4
France	18.6
Germany	12.4
Hungary	19.8
Italy	38.3
Netherlands	8.3
Poland	11.9
Romania	29.3
Spain	36.3
Sweden	7.1
United Kingdom	7.3

3.2.3 Policy assumptions

National Building codes included

The modelling framework of building envelopes' thermal efficiency is set by the status quo of the building stock and current building standards (i.e. Buildup 2016, Kunkel et al. 2015). The standards are essentially defined by the EU building performance directive (EPBD) and by country legislation covering the minimum efficiency requirements for large refurbishments and new constructions. Most countries have adopted performance based requirements for these cases. In view of estimating cost-curves of delivered heat savings (input to HRE4 WP 4) building envelop data is used as a primary model input (see section 3.3.2 for a more detailed reasoning). In some countries building codes set limits on energy-related technical parameters (e.g. U-Values and thermal resistance of existing buildings and retrofit measures) in addition the performance requirements and/or for partial (small) retrofits. In Figure 9 and Figure 10 the current averages of SFH and MFH are presented by country and furthermore distinguished by building component (wall, window, roof basement). In addition, the minimum standards are depicted to emphasize the need for further improvements. While considering the heterogeneity between the countries, the analysis reveals a significant efficiency potential. Moreover, the building code could be tightening significantly in some countries, especially in the case of windows, given the techno-economic progress made in the past years.

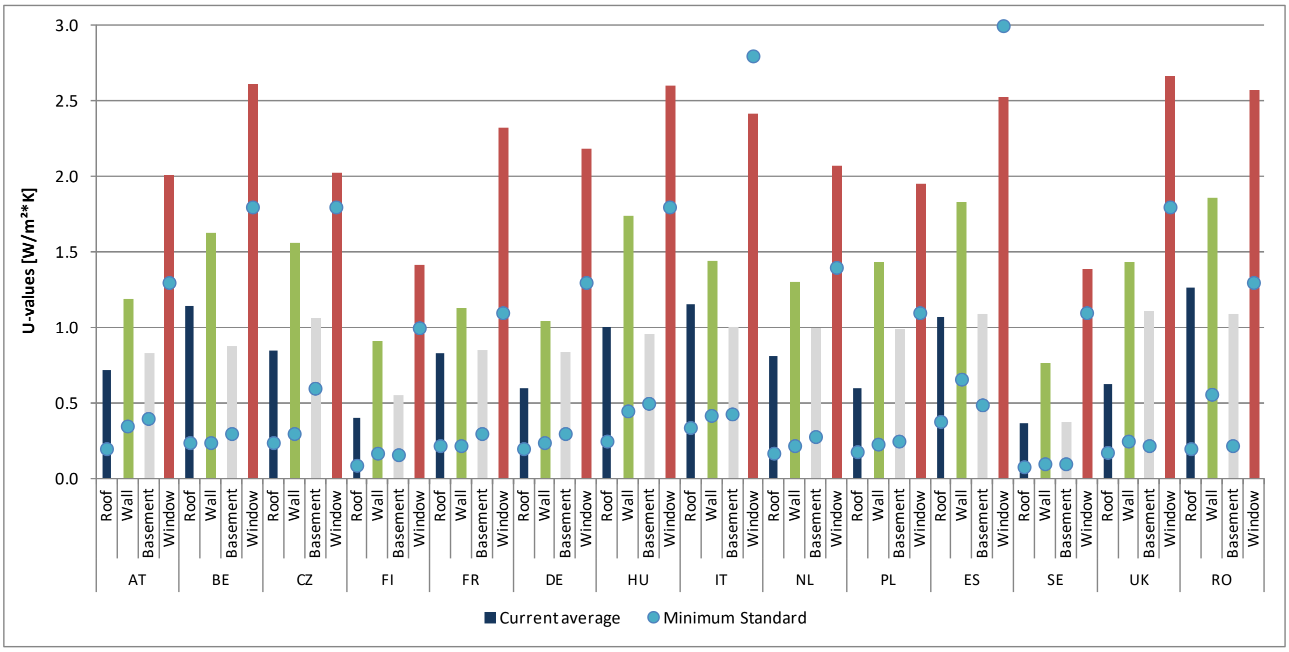


Figure 9: **Current average building status (coloured bars) and future minimum standards (blue bullets, U-values in W/m2*K) for the SFH building parts "wall", "window", "roof" and "basement".**

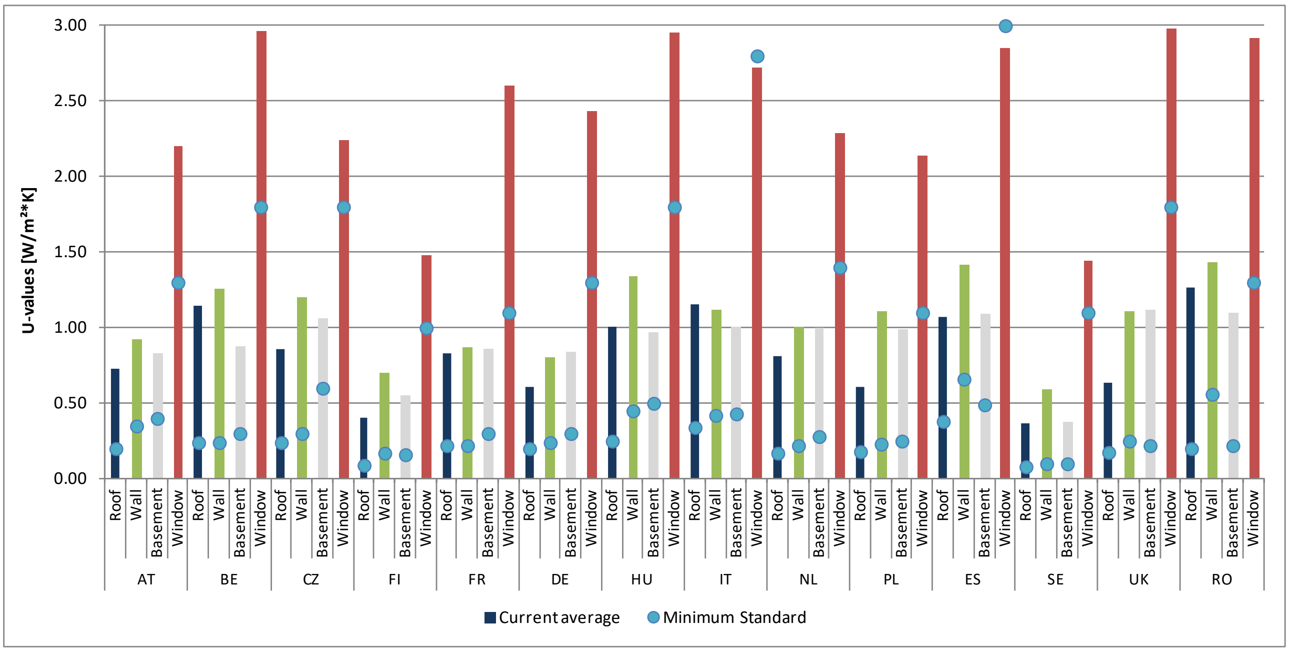


Figure 10: **Current average building status (coloured bars) and future minimum standards (blue bullets, U-values in W/m2*K) for the MFH building parts "wall", "window", "roof" and "basement".**

In Figure 11 and Figure 12 the average building status of new buildings (SFH and MFH) are depicted in relation to the minimum building standards. Depending of the economic framework conditions the algorithm decides the level of efficiency, thus, if overperformance, compliance or even non-compliance occures. For instance, the model chooses an implemented set of building components with a higher degree of efficiency compared to the minimum standard, if this is more benefitial to the residential decision maker (e.g. windows). In contrast, the model rather chooses lower standards (less efficient) compared to the minimum standards, due to a lower economic feasibility for selected components and therefore showing non-compliance in relation to the minimum codes (e.g. roof).

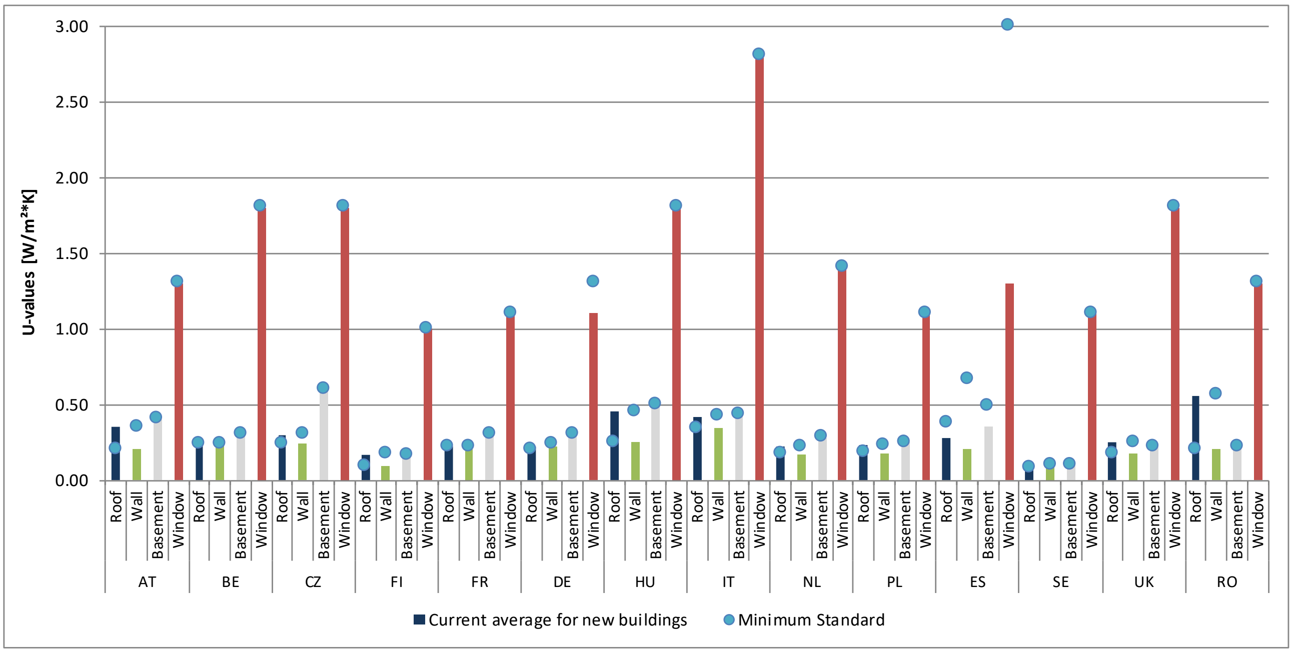


Figure 11: Average building status of SFH new buildings and minimum building standards for the same period.

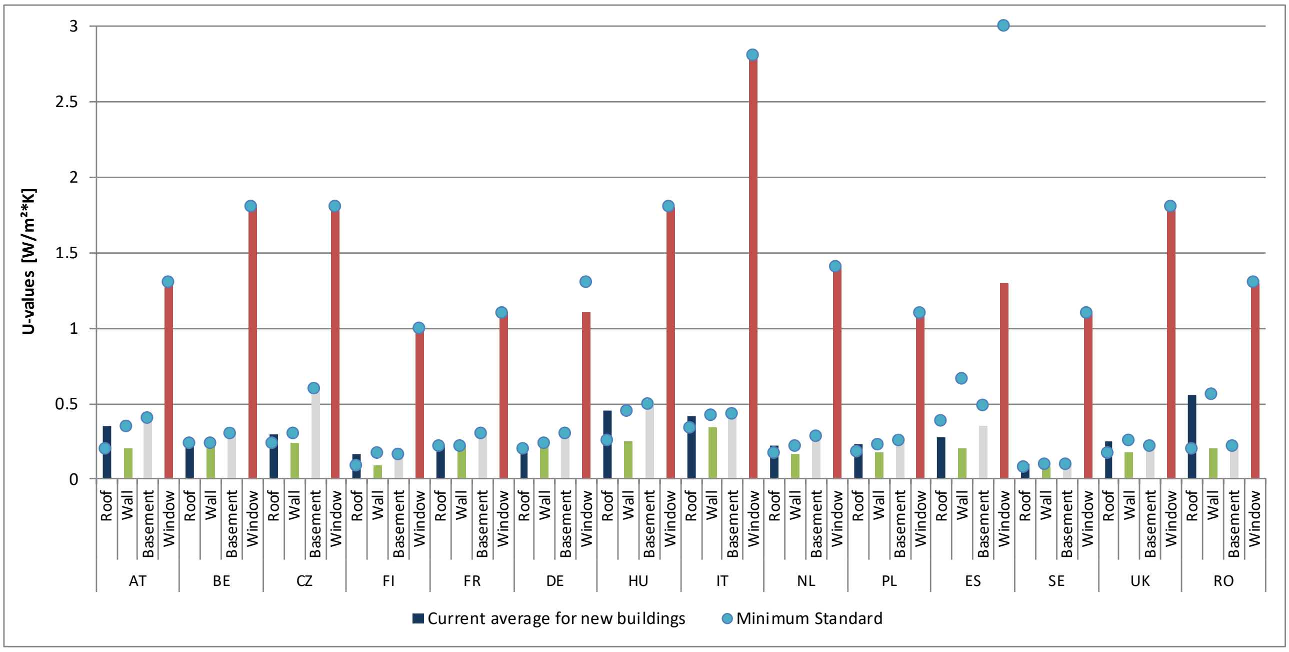


Figure 12: Average building status of MFH new buildings and minimum building standards for the same period.

Renovation rates

The renovation rate (or refurbishment rate) is defined as the number of existing buildings that are partly or fully improved in terms of their thermal performance. As indicated in Figure 13, today's refurbishment rate varies between 0.3 % (Romania) and 1.0 % (e.g. Finland). The presented refurbishment rates can be interpreted as 'full refurbishment equivalents' meaning that the rates are calculated based on the area of each component in combination with the corresponding renewal cycle of the corresponding component. The essential parameters driving the refurbishment rate are the age distribution of each component, the energy carrier price and the level of efficiency of the installed heating system (see Annex 7.3 and EEPotential. 2009).

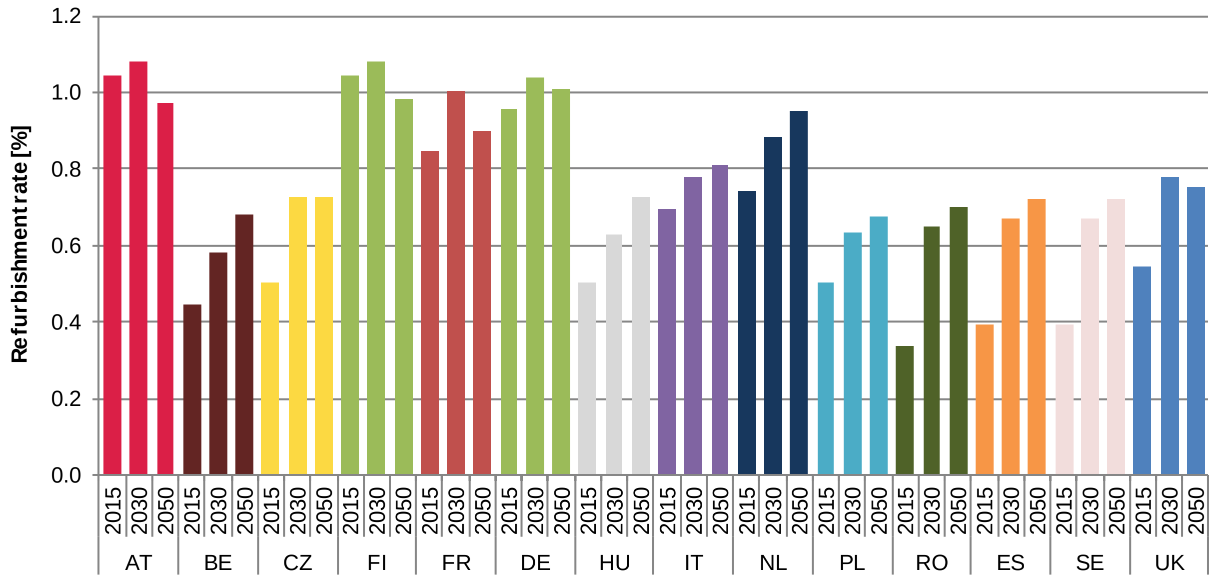


Figure 13: Renovation rates for the time periods 2015, 2030 and 2050

Compliance rates

The refurbishment rate defines the frequency in which buildings are thermally improved over time. Furthermore, the national building standards, respectively the requirements defined by the EPBD, set the threshold for the depth of refurbishment and the conditions to which new buildings need to be built. However, in reality there is a difference the values defined by the regulations and the actually achieved energy-efficiency level. This difference is expressed by a certain level of compliance or non-compliance resulting from, for instance, wrongly applied minimum standards or inaccurate planning. As depicted in the previous figures it is essential to consider this parameter as it brings the modelling results much closer to the actual development.

3.3 Tertiary sector buildings

As in the case of the residential sector the current levels of heat and cold delivered of the tertiary sector and their future development depend on various drivers which are taken into account in the bottom-up model FORECAST (see appendix 7.3 for further details and data references). With the exception of some sector specificities the most relevant drivers of current and future heat and cold delivered is similar to the residential sector (see Table 16). The quantitative structure and specific indicators of heat and cold delivered depend on exogenous drivers such employment, space need per employee on the one hand side and construction practice, retrofit activities, retrofit levels, indoor and outdoor temperature, building types and use, and others on the other hand side. Some of the variables in turn depend on policy instruments and economic drivers which are part of the general framework data (see Chapter 1). Assumptions about these drivers as well as intermediate model results are described in the next sections.

3.3.1 Framework data

Number of employees

Based on macroeconomic data, the number of employees per sub sector and country is calculated as input for the FORECAST Tertiary analysis. It is expected, that the overall employment in the 14 HRE4 countries described will decrease slightly by 2050 (- 1 %), compared to 2015 values (see Figure 14). However, there is an increase expected for these countries until 2030 (+9 % compared to 2015) and a decline afterwards.

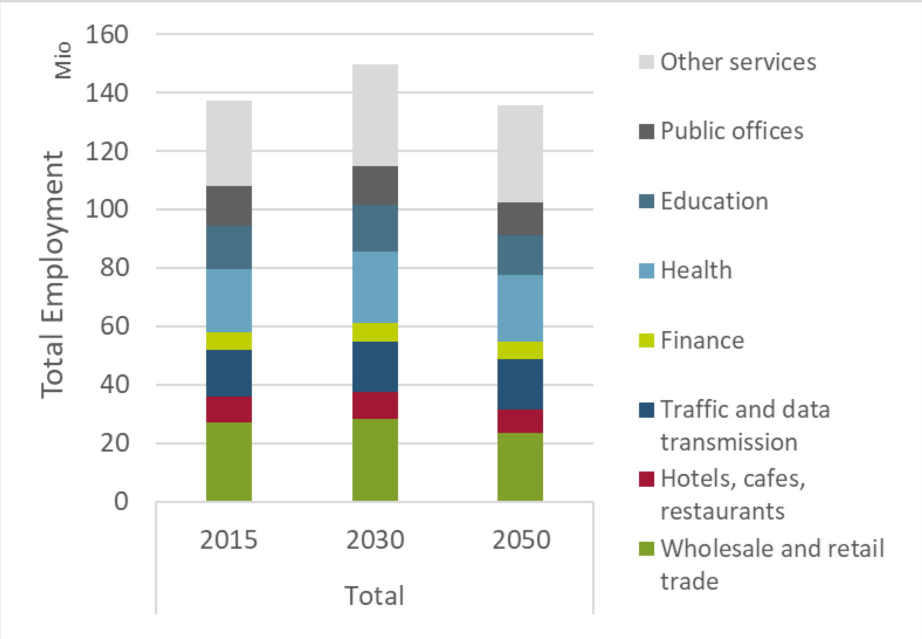


Figure 14: Total employment for the 14 HRE4 countries per sub-sector

Additionally, sub-sector specific data (see Figure 15) can differ from this overall trend (e.g. overall growth in sub-sectors such as ICT (+7 %), health (+5 %) or finances (+4 %) until 2050 as compared to 2015 values but decline of employment in sub-sectors such as wholesale and retail trade (-13 %); education (-8 %) or public administration (-17 %) for the same time period).

The employment data is used as one of the drivers for heat and cold energy demand as the number of employees is closely related to the heated and cooled floor area, although the specific floor area per employee develops differently across sub-sectors.

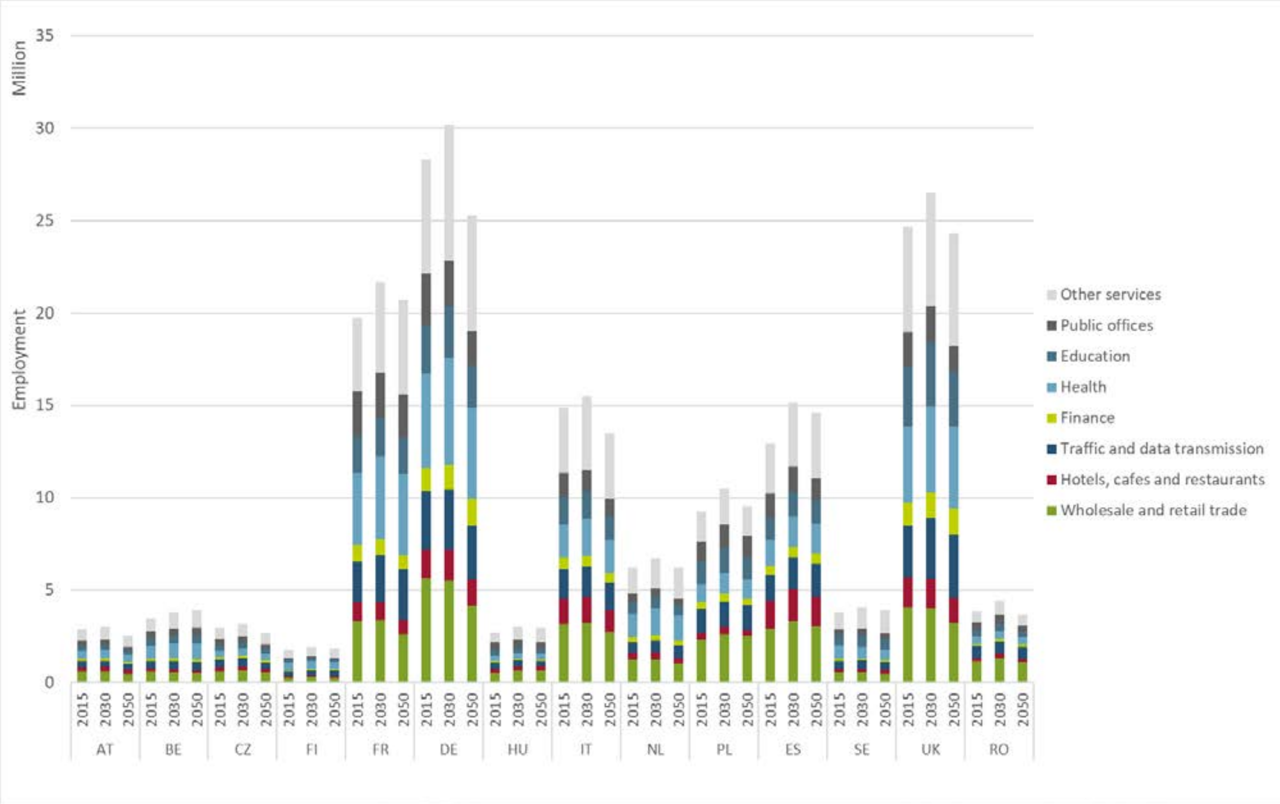


Figure 15: Employment data per sub sector and country for the time periods 2015, 2030 and 2050

Heated floor area

The total heated floor area is expected to increase by +21 % within the 14 HRE4 countries from 2015 to 2050 (see Figure 16). It is noteworthy, that the overall growth trend until 2030 is more substantial as compared to the period from 2030 to 2050. This can be explained by the country specific growth expectations. Additionally, the growth trend varies for the different sub-sectors based on economic assumptions.

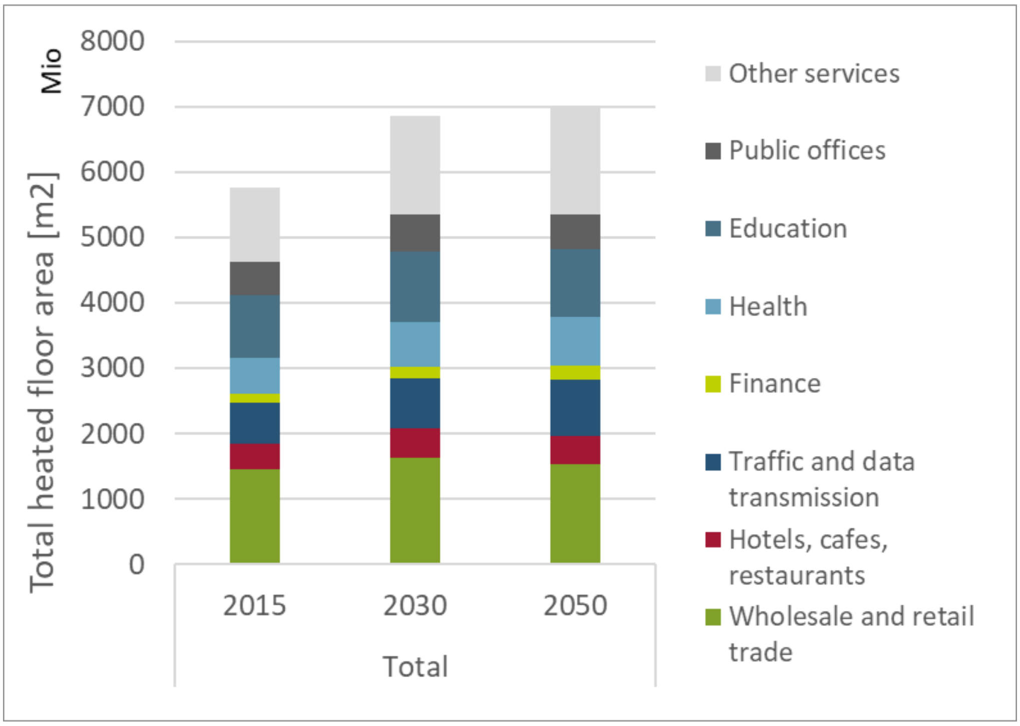


Figure 16: Total heated floor area for 14 HRE4 countries per sub-sector

While for the majority of the countries an increasing trend until 2050 is expected, for some countries such as Germany or Austria a declining heated floor area is expected after 2030 (see Figure 17), slowing the overall growth of the heated floor area. Within sub-sectors, the trends for the considered countries vary as well. While in France the total surface is expected to grow by 23 % from 2015 to 2050, the heated area within the sub-sector “wholesale and retail trade” is expected to decrease (-6 %), whereas the “traffic and data transmission” and “other services” surfaces are expected to increase by more than 60 %. Depending on the specific heat energy demand per sub-sector and country, this change in heated floor area is a major driver for changes in total heat and cold energy demand.

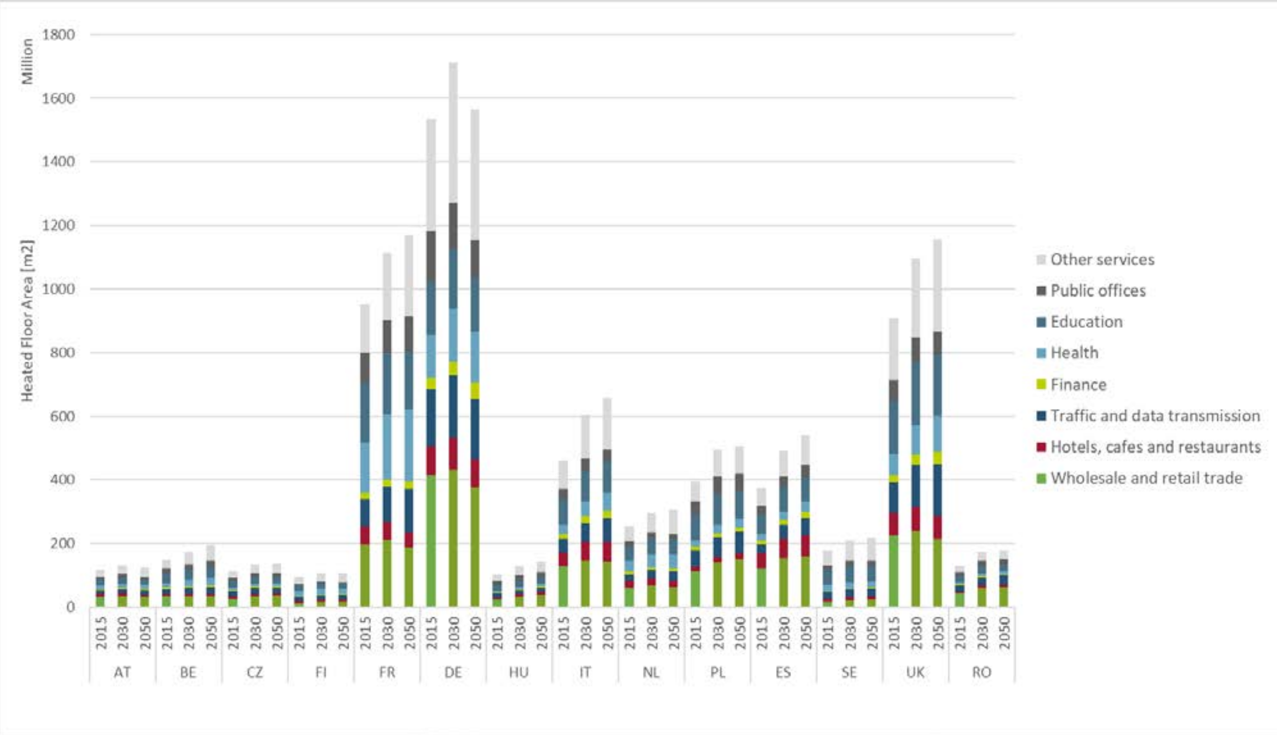


Figure 17: Heated floor area per sub sector and country for the time periods 2015, 2030 and 2050

3.3.2 Building and technology data

Energy related building codes have a long tradition in some countries also for non-residential buildings, i.e. including buildings of the tertiary sector (office buildings, education and health facilities, buildings of the retails sectors, and others). However, the type and the timing of the code implementation, and the requirement levels vary quite substantially across countries, especially for non-residential buildings.

As in the residential sector there are basically two types of energy related building codes that are distinguished (see also ENTRANZE (b))

- Performance based requirements
- Prescriptive/element-based criteria in building codes

Performance based requirements are referring to the energy-efficiency performance or the specific energy consumption (e.g. by m^2) related to defined boundary conditions (e.g. types of energy services (heating, hot water etc.) and which level of energy in the conversion chain (e.g. useful, final, primary) included) and to a defined calculation standard (e.g. EN ISO ISO 13792:2012, ISO 52016-1:2017 and respective national adaptions). These calculation standards are based on annual (historically), monthly or hourly energy balances at various levels, without or with buildings physics related dynamics. Performance based requirements set mandatory limits to one or several of these energy balances (e.g. useful space heating, overall primary energy). In many countries only a part of these calculation standards is included into the mandatory code requirements.

In contrast, prescriptive based criteria building codes are focussing on different elements and technical components of the building envelop and of building technologies, typically:

- Thermal insulation
- Air permeability
- Ventilation requirements
- Boiler and other energy system efficiency
- Lighting Efficiency
- Other requirements (e.g. prevent overheating)

In view of estimating cost-curves of delivered heat savings (input to HRE4 WP 4) the subsequent considerations are focussing on building elements (envelop) rather than on performance (systemic) based approaches. In such cost-curves, costs and energy-efficiency gains are calculated based on energy-related technical parameters (e.g. U-Values).

It is emphasized that separation between building envelope elements on the one hand side and building technologies (in particular heating systems, hot water generation devices, and ventilation systems) might overlook potentials of systemic approaches.

U-values for building envelope: new insights

For the estimation of the current and future heating and cooling demand in the tertiary sector, the accurate description of the existing building stock by means of thermal losses through the building envelope (described by U-values) and solar gains (SHGC) is of high relevance. Therefore, extra efforts were undertaken to analyse the existing information base of the tertiary sector building stock by additional data research, plausibility checks, data harmonisation and model calibration. It has to be noted, that the data availability on existing and past U-values for tertiary buildings on sub-sector level is scarce. Additionally, available data on aggregate level is often derived from residential building data (see e.g. Inspire 2014). However, there is ongoing work to improve and structure data availability on existing buildings (European Building Stock Observatory) also for the tertiary sector. Regarding new buildings (tertiary sector), data availability on heat energy requirements (BPIE 2012) is good, however, specific U-Values for all sub-sector building types are not always available and need to be derived from specific heat energy requirements.

Within this modelling exercise for the tertiary buildings, the description of the current building stock was updated, using available sources (e.g. Inspire 2014, ENTRANZE) and additional information from the residential sector on specific building parts (European Building Stock Observatory) to adapt those values to tertiary sector building statuses (see also section 3.2.2).

The adaptation of tertiary building standards from residential sector buildings is sometimes goal-oriented, since building codes and definitions are in many countries not as accurate for the tertiary sector or building types as for the residential sector. This is due to the fact that often tertiary sector buildings are more complex and less uniform and often of minor relevance from the viewpoint of policy makers and code designers. Moreover, buildings of the tertiary sector include different purposes within one building or fulfil very specific requirements.

Future building standards were updated to the most recent available country data based on sources such as BuildUp 2016 or EURIMA.

2015 building stock efficiency (average SEC by category)

Based on the model input data regarding the existing building stock, namely the age distribution of the building stock and building standards, the average specific energy demand (SEC) for space heating and water heating is calculated. It has to be considered, the number of heating and cooling degree days together with the achieved level of comfort within the different countries play an important role for the SEC calculation.

For central European countries such as Germany, Austria or the Netherlands, the average SEC is at the level of 140-160 kWh /m^2 and year (see Figure 18).

Nordic countries with a per se colder climate follow a longer tradition of advanced building standards (e.g. SE or DK) and reach levels of 120-130 kWh/m^2 and therefore lead the path towards lower energy demand for heating in buildings. Other country groups such as southern countries (e.g. IT, ES or RO) with warmer climates or eastern countries (e.g. PL, CZ or HU) show a heterogeneous pattern of specific energy demand. In Italy, with colder temperatures in the northern part of the country, a higher building density per hectare and lower buildings standards, seem to be the dominating parameters affecting the specific heating demand (between 160-180 kWh/m^2). In Belgium, the age distribution of the building stock with a higher share of old buildings with lower energy standards is driving the higher specific energy demand. At the other end of the scale (e.g. for Poland or Romania with SEC between 100 and 110 kWh/m^2), the driving factors seem to be rather lower indoor temperatures, lower shares of heated surfaces and partially lacking statistical information on all energy carriers leading apparently to reduced specific energy consumption figures. Due to these uncertainties in data accuracy (e.g. on monitoring fuel uses, effective floor area or shares of heated surfaces) and the applied methodology of calibrating model output to statistical values, the SEC for some countries (e.g. Poland, Romania) might be underestimated.

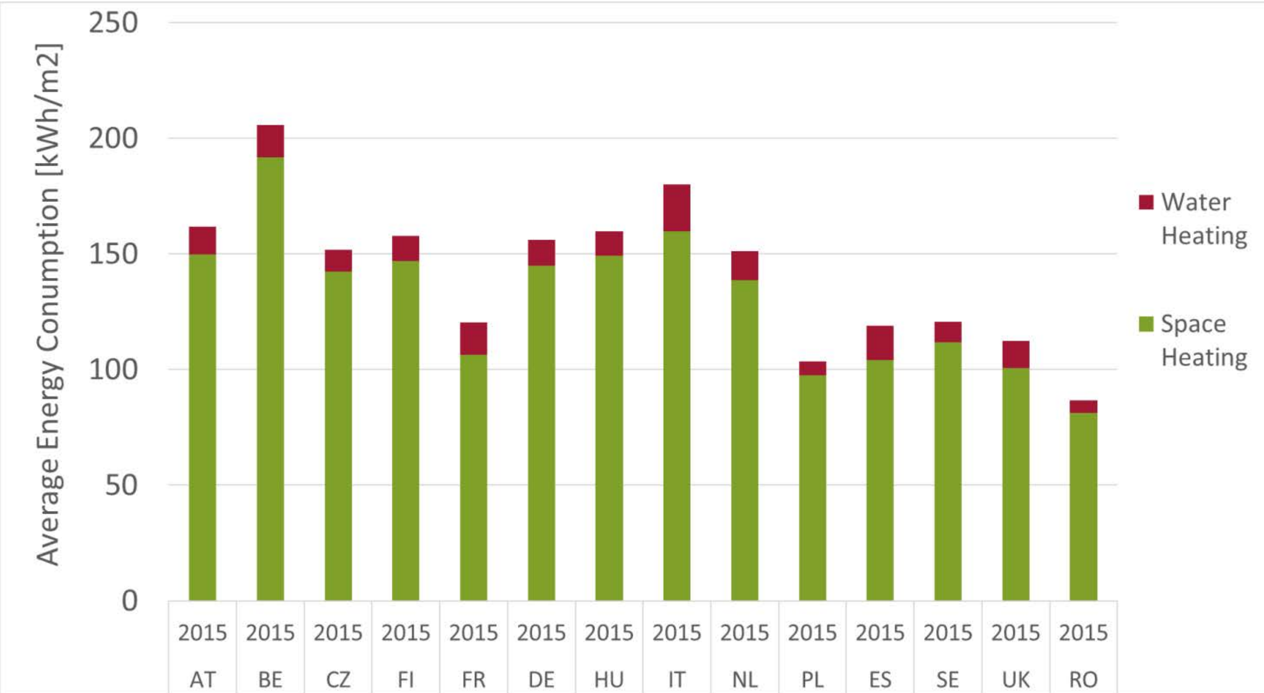


Figure 18: Specific energy demand per m^2 for space heating and water heating for the year 2015

Further parameters

As described in Table 8, additional parameters play a role in the estimation of future heating and cooling demand. In the tertiary sector model, the **demolition rate** is defined by an uppder and lower limit for the share of buildings replaced in each age class. The model then decides for each building on its current status and the economic parameters if a replacement of the building is applicable. What is not considered in the model is the possibiliy of conversion of tertiary floor area into residential floor area and vice versa.

After a refurbishment improving the energy standard of buildings, one can often observe, that **indoor temperatures** are increased, offering the user a better room climate. However, this temperature increase can be considered as efficiency gap since more heat energy is needed to achive the higher indoor temperature level. This energy efficiency gap is considered in the tertiary model following (Burman et al. 2014) and assumptions in the residential sector (Loga et al. 2003) by an increased indoor temperature of +2 °C after a full refurbishment of the building .

The **diffusion of cooled and /or ventilated floor area** can also be influenced by energy ralted refurbishment measures. By reducing the thermal transmittance of the building envelope, the air exchange is also reduced. Therefore, in some cases, additional ventilations and air-conditioning systems are installed, increasing the share of ventilated or cooled floor areas. Heat demand is influenced, since ventialtion systems are not fully equipped with heat recovery systems and the related efficiency losses. However, such diffusion changes and heat losses are not fully reflected in the tertiary model, potentially understimating the heating and cooling demand in the baseline scenario.

Specific energy demand for cooling: Werner (2016) obtained measured average cooling supply to a mix of service sector buildings from a number of European district cooling networks in different climates. These are re-fitted to our climate indicator (CDD) and evolve with it for projections.

Table 9: Specific space cooling demand for tertiary sector buildings by country

SERVICE SECTOR	Specific cooling demand (kWh/m^2)
Austria	72.2
Belgium	52.7
Czech Republic	56.7
Finland	43.5
France	73.6
Germany	56.9
Hungary	76.9
Italy	126.3
Netherlands	46.1
Poland	55.6
Romania	102.2
Spain	120.9
Sweden	42.7
United Kingdom	43.4

3.3.3 Policy assumptions

National Building codes included

One of the important drivers for future heat energy demand are the achieved codes and standards for building insulation and windows with respect to heat losses through the building envelope. Based on country legislation and EU building performance directive (EPBD), new buildings and in part large refurbishments need to achieve minimum building standards in the future. These building standards are implemented for the tertiary sector (see Figure 19, blue bullets). To understand the necessary change in the building stock, the current average statuses are of relevance to understand the todays heating (and cooling) demand (see Figure 19, coloured bars).

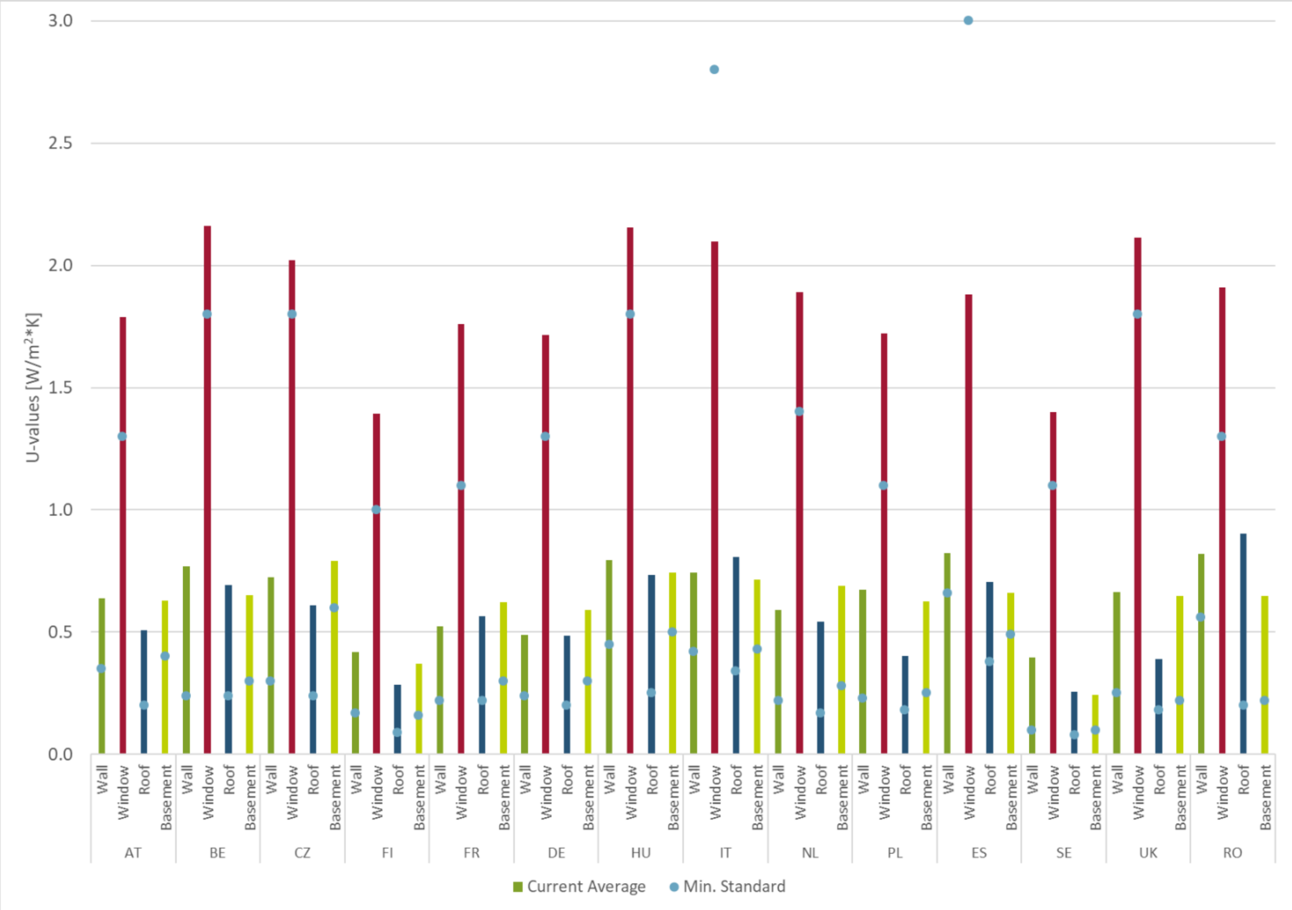


Figure 19: Current average building status of existing buildings (coloured bars) and future minimum standards (blue bullets, U-values in W/m2*K) for the building parts "wall", "window", "roof" and "basement".

While Nordic countries such as Sweden or Finland already today reach better building performances (average status), the difference to the minimum standards is smaller as compared to countries with currently lower building performance such as Belgium or Hungary, among others. However, depending on the available technologies and materials and the existing average status, more stringent targets are not always easily met (e.g. buildings with an already thick insulation of e.g. 15-20 cm have a lower marginal utility by adding additional 5-10 cm of insulation as compared to a building with no insulation as of today, adding 5-10 cm of insulation in the first step).

One shortcoming of our model approach can be shown by looking at the building performance of new buildings which should achieve the minimum standards as of today. However, since in the model code the minimum standards are rather defined as a specific range, than just one value, the model chooses according to economic assumptions which effective building standard is achieved for each modelled building. Therefore, the model can either overperform or choose non-compliance in respect of achieving the minimum building standard for new buildings. The results are shown in Figure 20. In case of "positive" outliers where the implemented standard is higher as compared to the minimum standard of the codes (e.g. Italy or Spain where very low minimum standards are set for windows (U-values between 2.7 and 3 W/m²*K)), the model chooses better windows, reaching levels between 1.5 and 1.8 W/m²*K based on economic calculations.

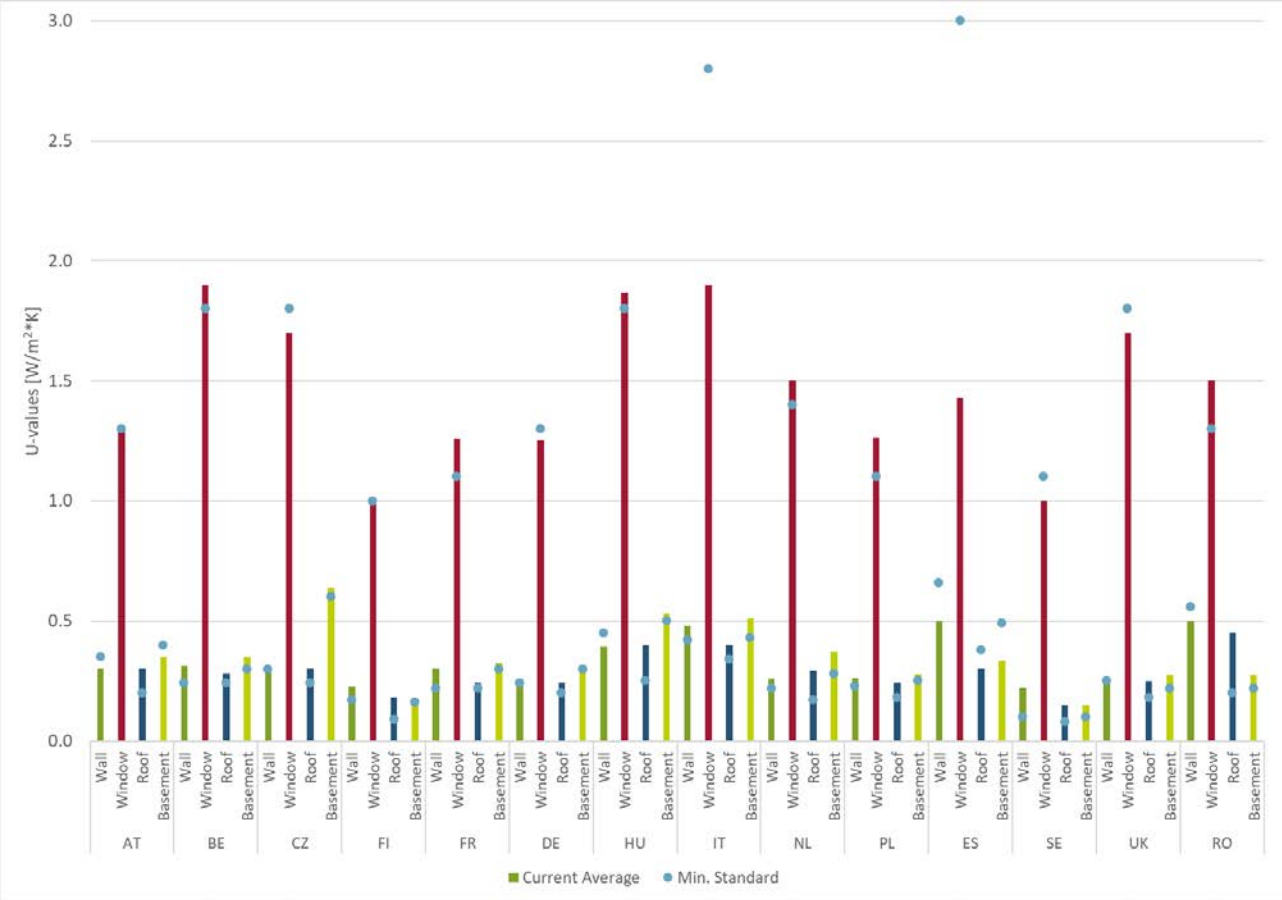


Figure 20: Average building status of new buildings (between 2010 and 2015) and minimum building standards for the same period.

On the other side, for some building parts (e.g. roof or basement), the model rather chooses lower standards for the new building as compared to the minimum standards, due to a calculated lower economic feasibility for such measures and therefore showing non-compliance with the minimum codes.

Renovation rates

The renovation or refurbishment rate indicates how many buildings of the existing building stock are refurbished (partly, if not all building elements are refurbished at the same time or in full, when all 4 building elements undergo energetic refurbishment), to improve the building standard reducing the future heat energy demand (Figure 21). Main drivers of building renovation are the age distribution of the building stock, energy prices and the efficiency of heating systems. Based on the assumption that a building owner evaluates in average every 30 to 50 years on the refurbishment of the window or the façade of a building (e.g. walls), he then decides based on costs and preferences on the refurbishment measures which can reach from superficial renovation (e.g. wall painting), to a complete refurbishment of walls, roof, windows and basement. In countries where the building stock is dominated by a large share of non-refurbished and old buildings with low efficiency standards, it is expected that the refurbishment rate will strongly increase over time (e.g. Belgium, Hungary or Spain), reflecting a backlog demand to catch up with then defining economic investment decisions, quality expectations and energy efficiency codes and regulations.

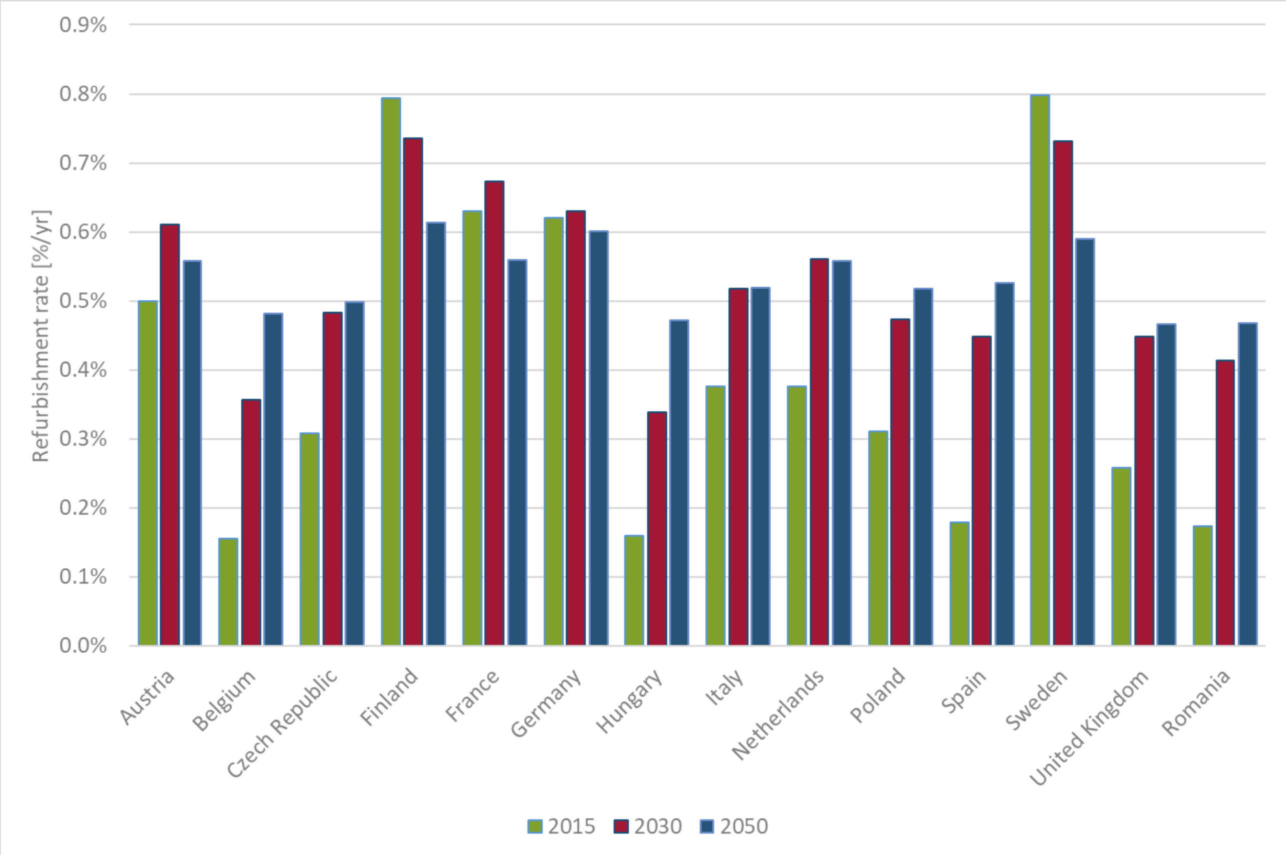


Figure 21: **Renovation rates for the different time steps**

Compliance rates

The compliance rate expresses the difference between and the actually achieved energy-efficiency levels and the minimum standards set by regulations (building codes) which need to be achieved in new construction and in case of specific renovation measures. Differences can occur due to conscious decisions, reluctance, inaccurate planning, incorrect installation of materials (thermal bridges), wrongly applied minimum standards, and other reasons. Especially in the tertiary sector, buildings might have different functions where the appliance of correct minimum standards is not always implemented. As shown in Figure 20, the model approach used for the tertiary sector allows for such deviations. However, due to economic parameters, the model also decides to outperform minimum standards which in reality also occur when building owners decide to achieve higher standards as necessary. Examples for such behaviour exist manifold looking at increasing demand for performance certificates of tertiary buildings (e.g. LEED or BREEAM certified buildings).

4 Results about the baseline scenario

This chapter describes the results for the delivered heat baseline in total and by sector. It is important to underline that delivered heat is not final energy demand but includes one more conversion step (i.e. the boiler). Results for the baseline scenario are compared to a hypothetic frozen efficiency scenario in order to estimate potential energy savings (not induced by activity changes). All results are reported for the 14 core countries of the HRE4 project - if not stated differently. The 14 HRE4 countries are selected based on their importance in terms of energy demand for H&C. In total, they account for more than 90% of EU28 total final energy demand for H&C and about 80% of EU28 final energy demand for space cooling in 2015 (for more details see HRE4 deliverable D3.1).

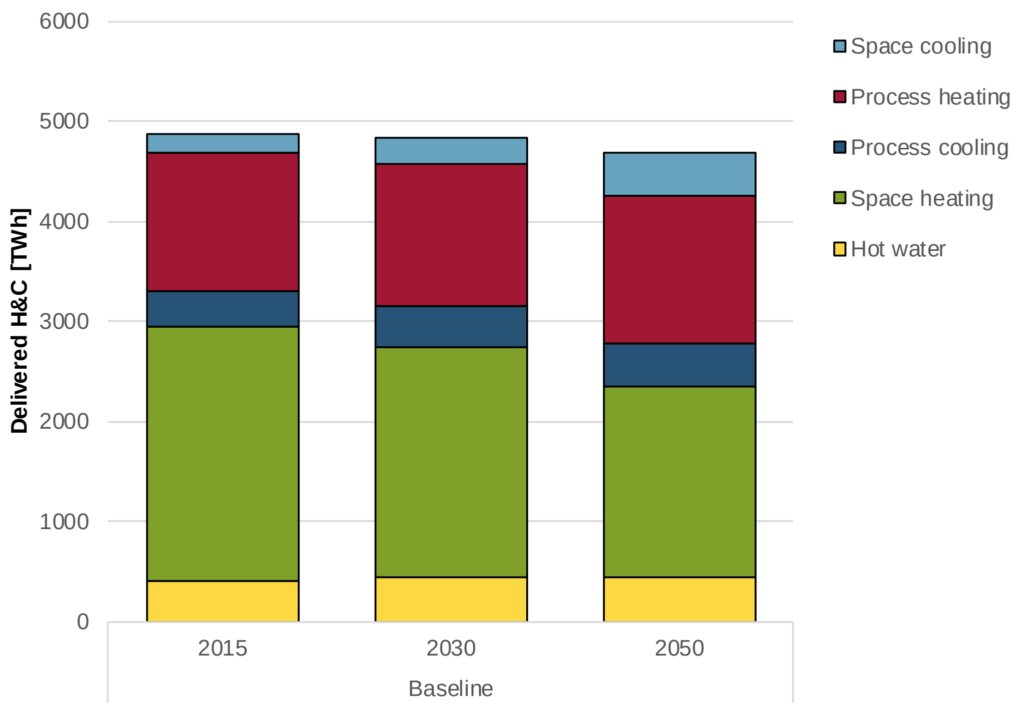
See chapter 2 for a more detailed explanation of assumptions and definitions including "delivered heat" and "frozen efficiency".

4.1 Overall results

4.1.1 Delivered heat and cold

The results of the baseline scenario for the 14 HRE4 countries show that the overall heating and cooling demand (all sectors) is expected to decrease by approx. 4 % until 2050 compared to the 2015 values, which reflects a more or less constant demand (1% decrease until 2030). Together, the 14 HRE4 countries show a delivered H&C demand of 4,870 TWh in 2015, which falls to about 4,690 by 2050. Thus, energy efficiency improvements slightly over-compensate increasing trends from activity drivers such as the value added in tertiary and industry or the living area in residential buildings. However, despite the relatively flat development of overall delivered heat demand, more pronounced developments are observed in the individual sectors, end-uses and countries.

For example, the trends for heating and cooling are developing in different directions. While the space heating demand is expected to decrease by approx. 25 % from 2539 in 2015 to 1910 TWh in 2050, the space cooling demand is expected to increase by approx. 252 TWh (+136 %) from 186 TWh in 2015 to 438 TWh in 2050.



Comparing the delivered H&C development of the individual demand sectors reveals a slight increase in industry from 2015 to 2050 (+5%) and a decrease in the residential (-11%) and the tertiary sectors (-5%) as shown in Figure 22

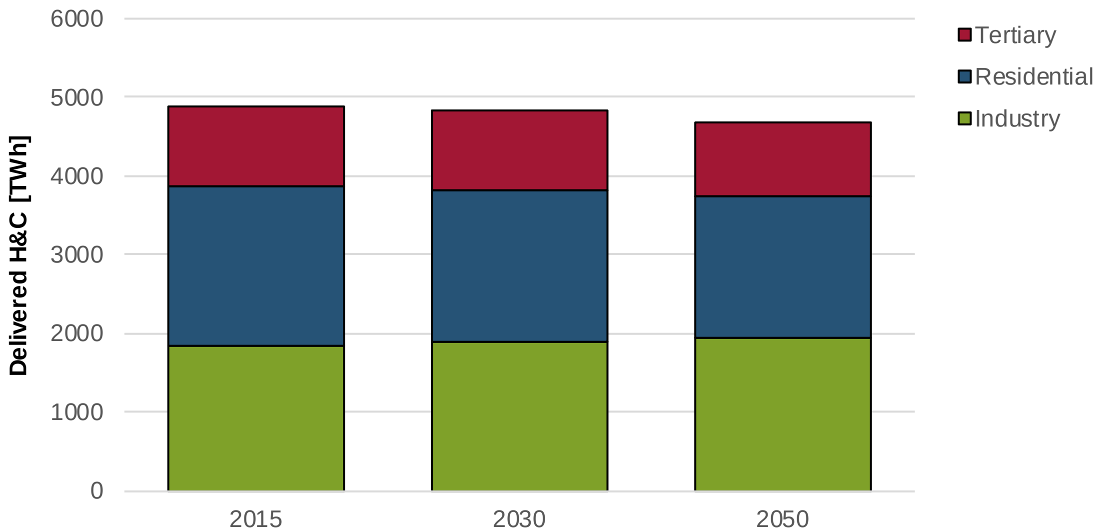


Figure 22: Development delivered H&C demand by sector for the 14 HRE4 countries [TWh]

The allocation of end-uses to demand sectors and their evolution until 2030 and 2050 is depicted in Figure 23. Obviously, industry is dominated by process heating, which tends to grow (driven by production of basic materials products), while the smaller share of space heating in industry is decreasing. Space heating is also substantially decreasing in the tertiary and the residential sectors with -28% and -25%, respectively. This decrease is driven by efficiency gains via building renovation as well as demolition and construction of new buildings.Thus, in the long term, the importance of space heating is decreasing while other end-uses gain shares including most of all space cooling but also water heating and process heating.

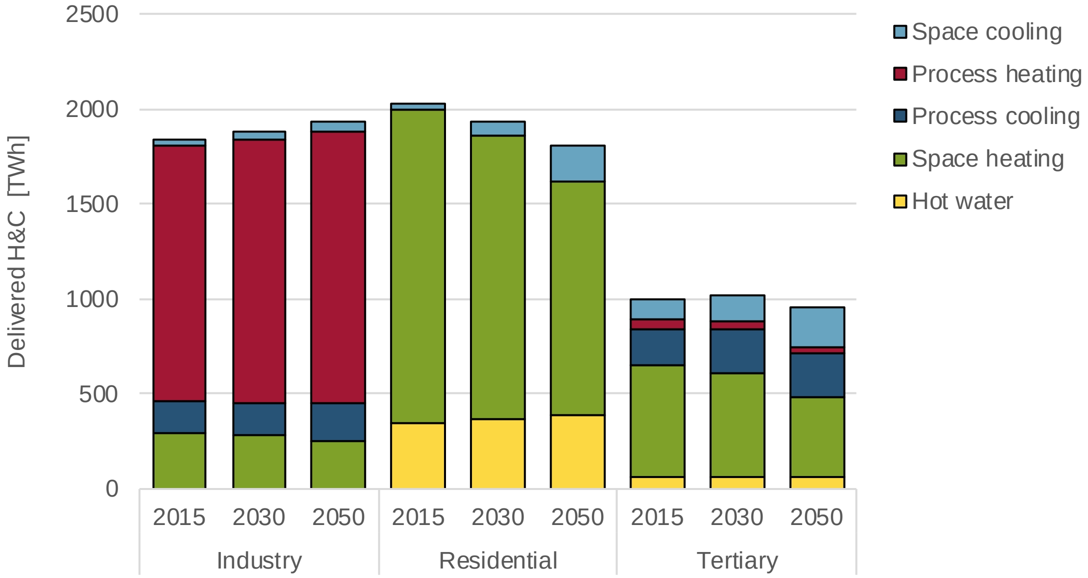


Figure 23: Development delivered H&C demand by sector and end-use for the 14 HRE4 countries [TWh]

The development in the individual countries is shown in Figure 24. Accordingly it can be observed that the status-quo in 2015 is already variyng across the countries as does the development until 2050. Some patterns can, however, be observed. Countries with a high share of space heating in 2015 (e.g. UK) tend to show a decreasing total H&C demand, while countries with high space cooling needs show increasing demands (e.g. Italy and Spain).

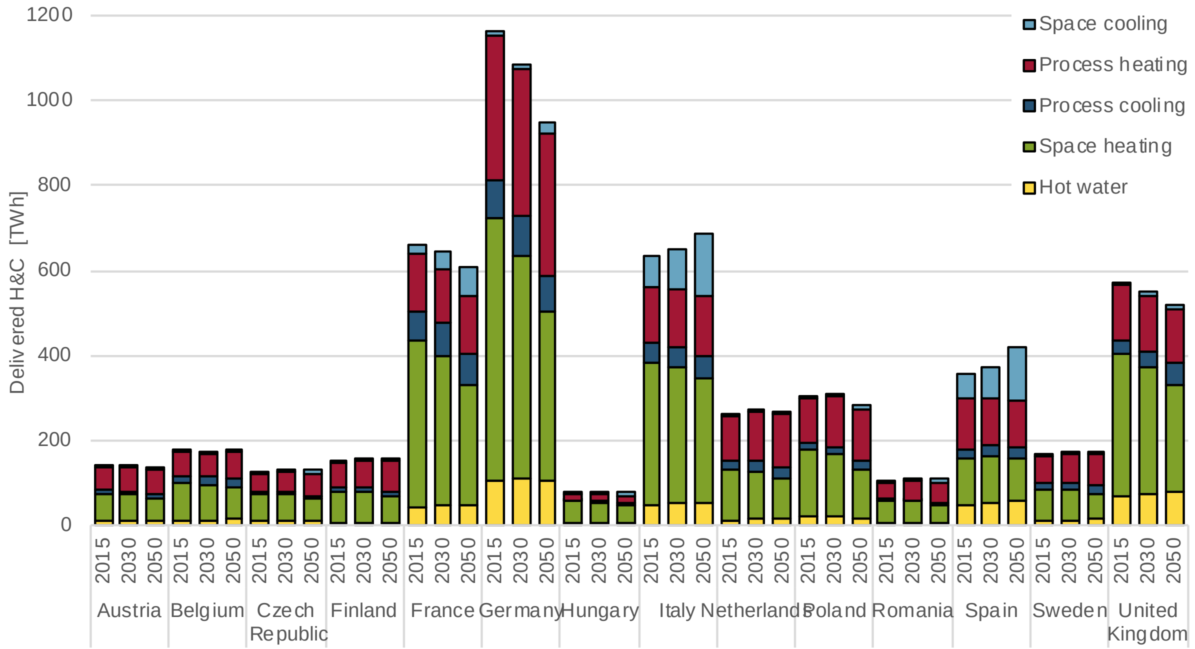


Figure 24: Total delivered H&C demand and change from 2015 to 2050 in the baseline scenario for the 14 HRE4 countries [TWh/a]

The following tables provide a detailed breakdown of delivered H&C by sector, end-use and country.

Table 10: Total delivered H&C demand and change from 2015 to 2050 in the baseline scenario for the 14 HRE4 countries [TWh/a]

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total
Industry						
2015	-	298	165	1,341	37	1,842
2030	-	281	174	1,382	44	1,882
2050	-	256	194	1,435	45	1,930
Change 2030/15		-6%	5%	3%	19%	2%
Change 2050/15		-14%	18%	7%	21%	5%
Residential						
2015	344	1,650	-	-	39	2,033
2030	370	1,488	-	-	76	1,933
2050	386	1,230	-	-	190	1,807
Change 2030/15	7%	-10%			96%	-5%
Change 2050/15	12%	-25%			392%	-11%
Tertiary						
2015	58	591	194	47	109	1,000
2030	65	545	227	45	138	1,020
2050	62	424	227	38	202	952

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total
Change 2030/15	11%	-8%	17%	-4%	26%	2%
Change 2050/15	6%	-28%	17%	-18%	85%	-5%
Total						
2015	402	2,539	359	1,388	186	4,874
2030	435	2,314	401	1,427	258	4,835
2050	448	1,910	421	1,473	438	4,690
Change 2030/15	8%	-9%	12%	3%	39%	-1%
Change 2050/15	11%	-25%	17%	6%	136%	-4%

Table 11: Total delivered H&C demand and change from 2015 to 2050 in the baseline scenario for the 14 HRE4 countries [TWh/a]

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total H&C
Austria						
2015	9	67	8	53	2	138
2030	10	63	9	57	3	141
2050	10	53	9	59	6	136
Belgium						
2015	10	90	16	56	2	174
2030	12	84	17	57	3	173
2050	15	76	20	64	3	177
Czech Republic						
2015	9	65	6	40	1	122
2030	11	63	7	46	2	128
2050	11	53	7	53	6	129
Finland						
2015	4	75	9	61	1	150
2030	5	72	11	65	1	154
2050	5	63	12	73	2	155
France						
2015	41	394	69	133	21	659
2030	46	354	75	127	41	643
2050	49	279	77	132	68	606
Germany						
2015	107	616	90	341	9	1163
2030	111	525	92	344	13	1086
2050	107	396	84	335	28	951
Hungary						
2015	4	53	3	15	2	77
2030	5	50	3	17	3	78
2050	5	42	4	18	11	80

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total H&C
Italy						
2015	48	336	43	133	74	634
2030	52	320	49	134	95	651
2050	54	290	53	141	146	685
Netherlands						
2015	13	116	24	103	2	259
2030	15	110	28	115	3	270
2050	15	94	28	127	4	268
Poland						
2015	19	160	17	101	2	300
2030	19	146	20	118	5	309
2050	17	113	21	122	12	285
Romania						
2015	7	52	4	37	3	104
2030	8	49	4	43	6	110
2050	8	41	4	44	12	109
Spain						
2015	50	106	25	117	59	357
2030	54	109	28	111	72	373
2050	58	99	29	109	125	421
Sweden						
2015	11	73	16	65	1	166
2030	13	69	20	67	2	171
2050	14	59	23	69	2	168
United Kingdom						
2015	69	335	30	132	7	572
2030	75	299	37	127	10	548
2050	80	251	50	126	12	519

4.1.2 Energy savings

Energy savings are calculated by comparing the baseline scenario to the frozen efficiency scenario, which represents a variation of the baseline using similar assumptions but assuming a constant specific energy consumption. The frozen efficiency scenario is a hypothetical variant of the baseline scenario that shows how H&C demand would develop if only changes in the activity drivers are considered (e.g. increasing floor area in buildings). The comparison between both scenarios as shown in Figure 25 reveals that the energy savings are much higher than the 5% decrease of the baseline scenario until 2050 compared to 2015 might indicate. In fact, H&C demand in the frozen efficiency scenario increases substantially by about 18% in the same time period.

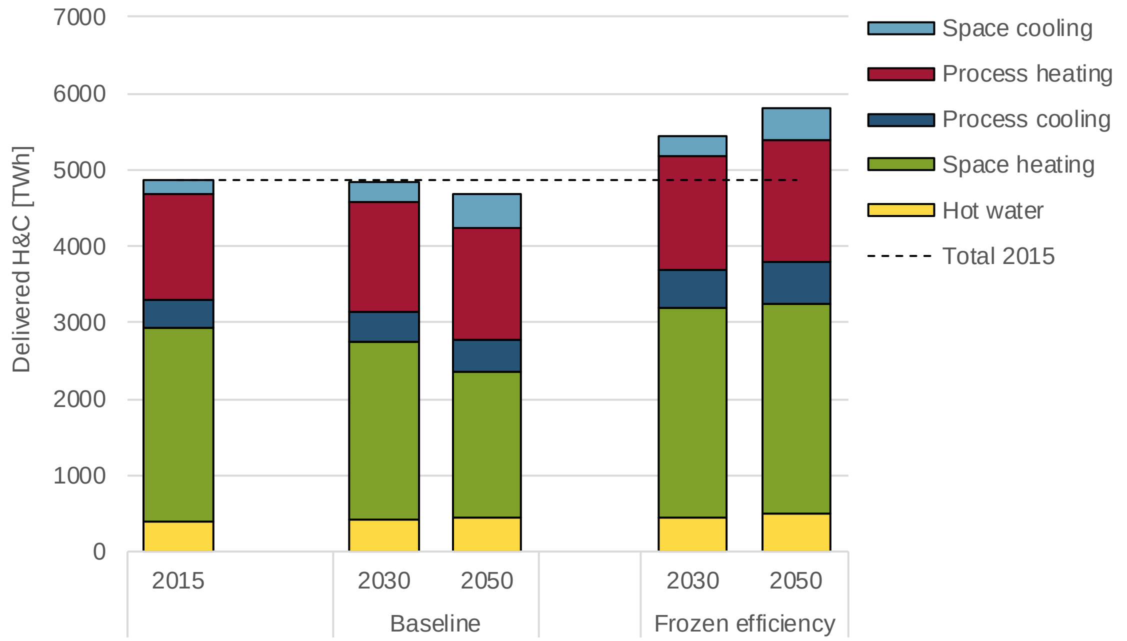


Figure 25: **Development delivered H&C demand by end-use for the 14 HRE4 countries in the baseline scenario compared to the frozen efficiency scenario [TWh]**

An overview of delivered H&C demand in both scenarios including resulting energy savings is given in Table 12. Accordingly, Total energy savings of 24% or 1132 TWh are observed in 2050 (13% in 2030). Most of these savings result from more efficient space heating, which even presents a saving potential of 44% compared to frozen efficiency scenario in 2050 (while only 25% compared to 2015). Process heating shows relatively low saving potential, which can be explained by the fast that many of the very energy intensive basic materials processes (e.g. oxygen steel production, clinker burning, paper and glass production) already show a lower remaining potential by applying available technologies (new innovative technologies were not considered in the baseline scenario).

Table 12: **Energy savings in the baseline scenario compared to the frozen efficiency scenario by end-use for the 14 HRE4 countries [TWh/a]**

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total
Baseline [TWh]						
2015	402	2539	359	1388	186	4874
2030	435	2314	401	1427	258	4835
2050	448	1910	421	1473	438	4690
Frozen efficiency [TWh]						
2015	402	2562	359	1412	186	4921
2030	450	2746	492	1499	258	5444
2050	492	2746	569	1577	438	5821

	Hot water	Space heating	Process cooling	Process heating	Space cooling	Total
Savings [TWh]						
2030	15	432	92	71	0	610
2050	44	836	148	104	0	1132
Savings [% of Baseline]						
2030	3%	19%	23%	5%	0%	13%
2050	10%	44%	35%	7%	0%	24%

4.2 Industry

4.2.1 Delivered heat and cold

Figure 26 provides the development of industrial delivered H&C demand in the period 2015-2050 by subsector in the 14 HRE4 countries analyzed in the project. Demand increases with 2.2 % in the period 2015-2030 and 4.8 % in the period 2015-2050. Without energy savings and structural change in industrial production (frozen efficiency), demand would increase with 11.9 % in the same period. The (petro) chemical industry (+18.2 %), food, beverages & tobacco (+13.8 %), machinery & transport (+25.1 %) and “other” industry (+8.4 %) all contribute to the increase of delivered heat and cooling demand in the period 2015-2050. Iron & steel (-13.9 %), non-ferrous metals (-6.1 %), non-metallic minerals (-5.5 %) and paper, pulp & printing industry (-6.6 %) all show a decrease in delivered heating and cooling demand in this period. For iron & steel (-11.0 %) and non-ferrous metals (-2.7 %) this is explained by a decrease in production whereas for the other sectors with decreasing demand energy savings and structural changes compensate for the increase in industrial output.

The overall energy intensity of the industry (in kWh delivered heat and cooling per euro value added) improves from 1.0 kWh/€ in 2015 to 0.85 kWh/€ in 2030 to 0.69 kWh/€ in 2050, and is mimicking the effect of both structural changes in the activity which is assumed to shift towards higher value added and less energy intensive production processes and the diffusion of energy saving technologies.

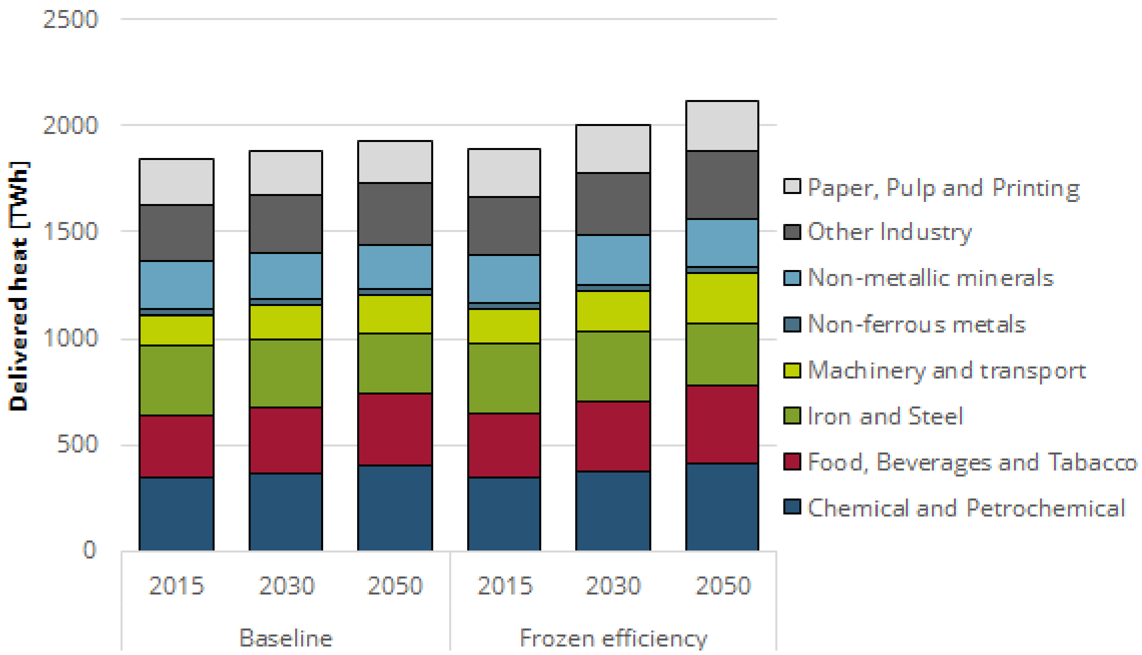


Figure 26: Development delivered heating and cooling demand in industry by subsector for the 14 HRE4 countries

Figure 27 provides the development of industrial delivered heat and cooling demand in the period 2015-2050 by temperature level in the 14 HRE4 countries analyzed in the project. The figure shows that both in base year and target years heat demand is dominant. The share of cooling demand grows from 11 % in 2015 to 13 % in 2050. Process heat demand <100 °C increases with more than 50 % between 2015 and 2050 and explains the net increase of heating and cooling demand in this period since process heat demand >500 °C only marginally grows and process heat demand between 100-500 °C as well as space heating demand decline.

The decrease of process heat demand between 100-200°C is mainly the effect of energy savings whereas the decrease of process heat demand between 200-500°C is the combined effect of savings and reduced activity.

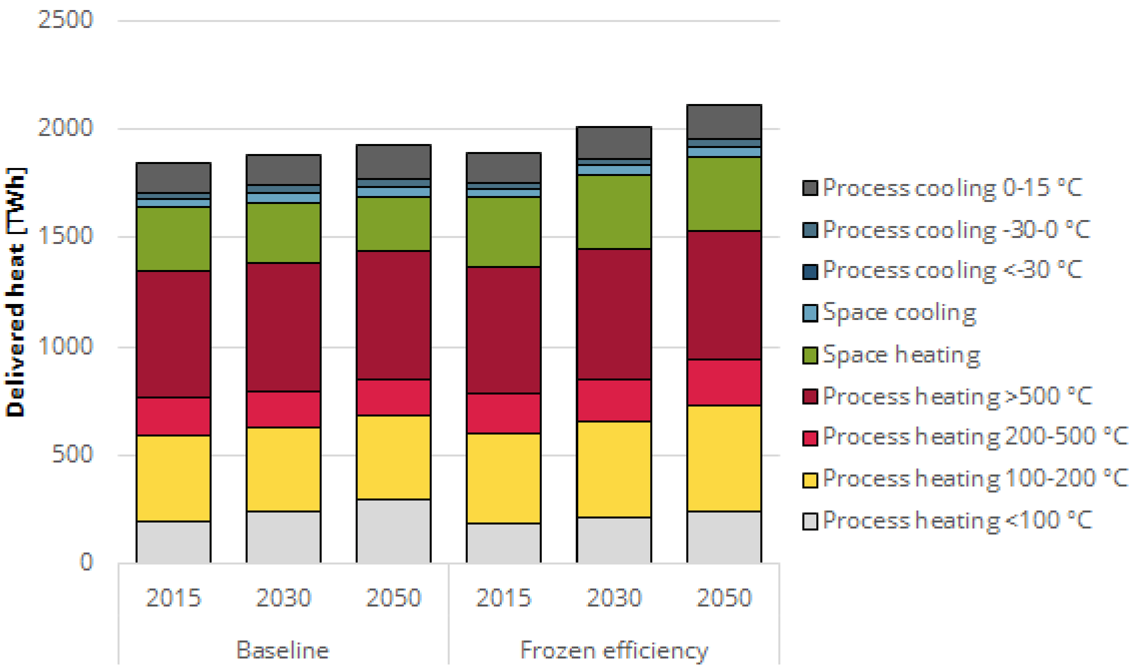


Figure 27: Development delivered heat and cooling demand in industry by temperature level

Figure 28 shows how the heat and cold demand at different temperature levels links to the industrial sectors. Process heating >500°C is the most important category and is mainly found in the non-metallic minerals, iron & steel and petrochemical industry. Most of the cooling demand is found in the food industry.

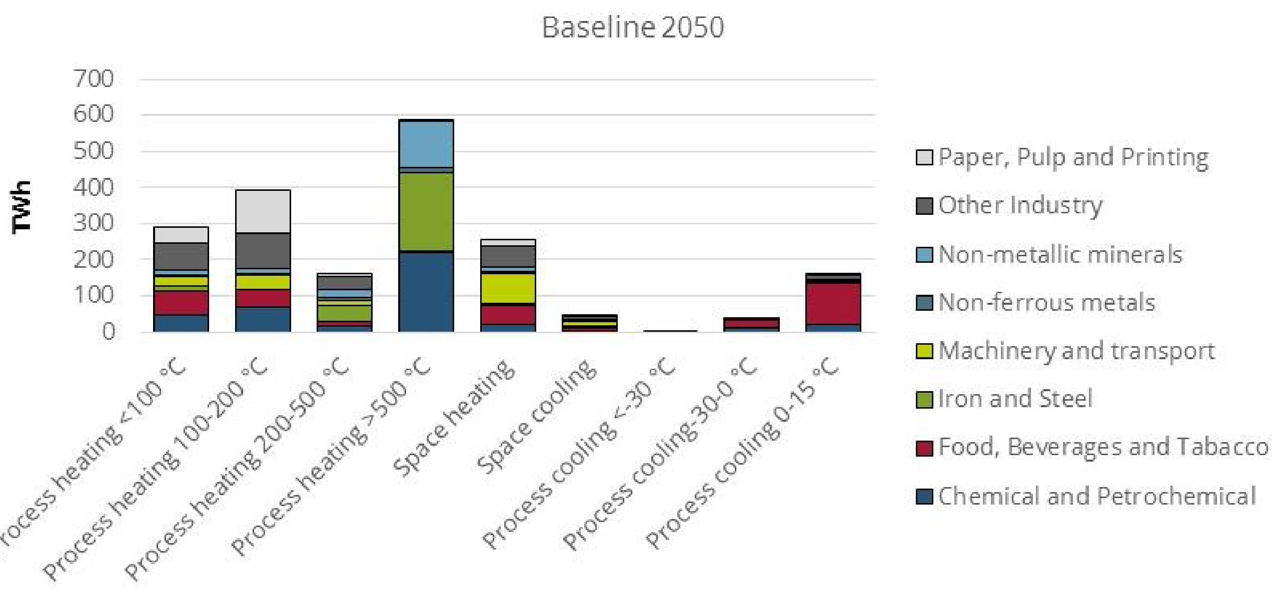


Figure 28: Baseline-2050 heat and cold demand for different temperature levels

Figure 29, Table 13 and Table 14 show the results for the 14 HRE4 core countries. In all countries space heat demand is decreasing and cooling demand increasing. For process heat the picture is more varied with some countries showing an increase above 20% in the period 2015-2050 (Czech

Repuclic, Poland, Netherlands), whereas other countries show a small (Germany, UK) to modest (Spain) decrease of process heat.

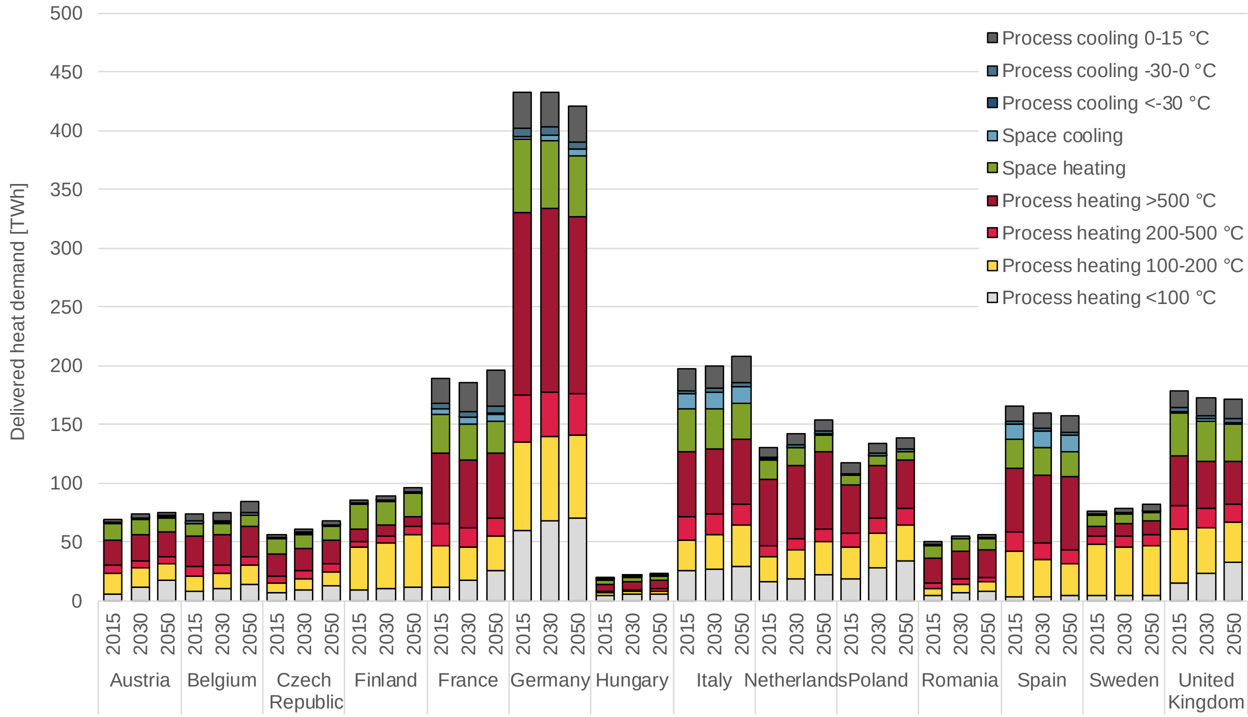


Figure 29: Development delivered heat and cooling demand in industry by end-use and country (HRE4)

Table 13: Delivered H&C demand in industry by end-use in the baseline scenario for the 14 HRE4 countries [TWh/a]

	Process heating			Process cooling			Space cooling			Space heating		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
Austria	52	56	58	3	3	4	1	1	1	14	13	12
Belgium	55	56	63	8	9	11	0	0	1	11	10	9
Czech Republic	40	45	52	3	3	4	1	1	1	13	12	11
Finland	60	64	72	3	3	4	1	1	1	22	21	19
France	126	119	126	26	30	36	5	6	6	33	31	28
Germany	330	334	327	37	37	37	2	4	5	63	58	52
Hungary	14	17	18	2	2	2	0	0	0	4	4	3
Italy	127	129	137	21	22	26	13	14	14	35	34	31
Netherlands	103	115	127	10	11	12	0	0	0	17	16	14
Poland	99	116	120	10	11	12	0	0	0	8	7	7
Romania	36	42	43	3	3	3	0	1	1	10	10	10
Spain	113	107	105	15	15	16	13	14	14	24	23	21
Sweden	64	65	68	4	5	6	0	0	0	9	8	7
United Kingdom	124	119	119	18	19	21	1	1	1	36	34	31
Total 14 HRE4 countries	**1341**	**1382**	**1435**	**165**	**174**	**194**	**37**	**44**	**45**	**298**	**281**	**256**

Table 14: Delivered H&C demand and change from 2015 to 2050 in industry in the baseline scenario for the 14 HRE4 countries [TWh/a]

	Total delivered heat [TWh]			Change 2050/2015				
	2015	2030	2050	Process heating	Process cooling	Space cooling	Space heating	Total
Austria	69	73	75	13%	30%	94%	-15%	9%
Belgium	74	76	84	15%	42%	79%	-17%	14%
Czech Republic	56	61	68	31%	16%	26%	-12%	21%
Finland	86	89	96	19%	28%	13%	-10%	12%
France	189	186	196	0%	38%	27%	-16%	3%
Germany	432	433	421	-1%	0%	116%	-17%	-3%
Hungary	20	22	23	27%	9%	27%	-12%	18%
Italy	197	200	208	8%	22%	6%	-13%	5%
Netherlands	131	142	154	23%	19%	41%	-16%	18%
Poland	117	134	139	21%	17%	74%	-11%	19%
Romania	50	56	57	19%	10%	86%	-8%	14%
Spain	165	159	157	-7%	5%	7%	-12%	-5%
Sweden	77	79	82	7%	47%	11%	-15%	6%
United Kingdom	179	173	172	-4%	14%	32%	-14%	-4%
Total 14 HRE4 countries	**1842**	**1882**	**1930**	**7%**	**18%**	**21%**	**-14%**	**5%**

4.2.2 Energy savings

The difference between Figure 30 and Figure 28 provides insight in the energy savings realized in the baseline compared to frozen efficiency. Biggest savings are achieved in process heating <100 °C in the chemical industry (32 TWh savings), space heating in the food, beverages, tabacco and machinery and transport industry (18 and 33 TWh savings), proces heating 100-200 °C in the paper and pulp industry (38 TWh savings), in the machinery and transport industry (19 TWh savings) and "other industry (48 TWh savings) and proces heating 200-500 °C in the non-metallic minerals industry (12 TWh savings) and "other" industry (19 TWh savings). In the baseline the savings in high temperature process heating and cooling are limited.

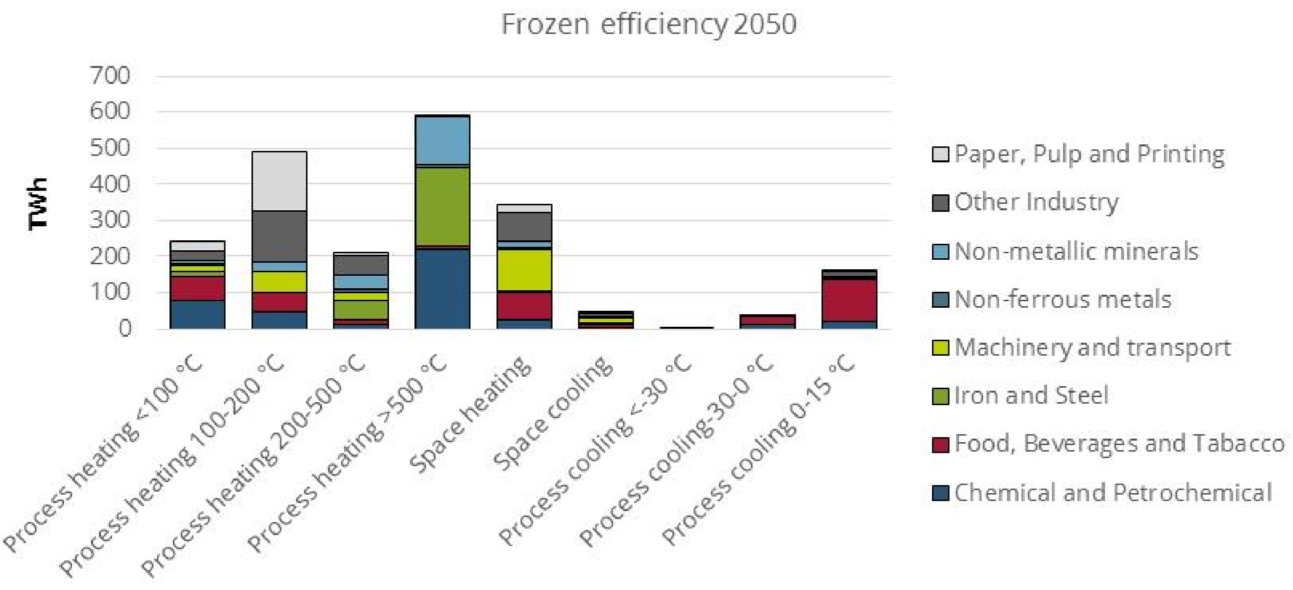


Figure 30: Frozen efficiency-2050 heat and cold demand for different temperature levels

Table 15 shows the delivered heat savings in 2030 and 2050 for selected processes. Most important savings options in the baseline are dry clinker calcination and rolled steel, providing more than 1/3 of the total savings in 2050 of all selected processes, which also reflects the very high energy demand of these processes.

Table 15: Delivered heat savings for selected processes

		Delivered heat savings 2030 [TWh]	Delivered heat savings 2050 [TWh]
Chemical industry	Carbon black	0.9	1.2
	Ethylene	4.5	6.3
	Poly sulfones	0.8	1.6
	Methanol	0.1	0.2
	Ammonia	4.8	9.6
	Soda ash	0.9	1.2
	TDI	0.6	1.9
	Oxygen	0.1	0.1
Iron and steel	Blast furnace	4.6	8.2
	Rolled steel	11.5	16.5
	Sinter	3.3	5.3
	Electric arc furnace	3.0	5.9
	Coke oven	0.2	6.0
Food, drink and tobacco	Meat processing	1.2	4.1
	Sugar	0.5	1.0
	Dairy	0.9	1.1
	Bread & bakery	0.5	0.7
	Brewing	0.7	1.3
Non-ferrous metals	Aluminum, primary	0.0	0.0
Non-metallic minerals	Clinker calcination-dry	20.1	26.5
	Lime burning	-	-
	Flat glass	1.5	3.2
	Container glass	2.9	4.4
	Bricks	1.9	3.4
	Gypsum	0.9	1.5
Pulp, paper and printing	Paper	5.9	9.0
	Chemical pulp	0.0	0.0

4.3 Residential buildings

4.3.1 Delivered heat and cold

The analysis of accumulated deliverd heat demand for the 14 HRE4 countries indicates a total demand of 1994 TWh in 2015, with around 1650 TWh (83 %) being attributed to space heating (Figure 31). The results indicate a continuous drop of space heating demand in the baseline scenario falling by 25 % to a level of 1230 TWh in 2050. In comparison to 2015, the share of hot water in relation to space heating rises up to 24 % in 2050, compared to 17 % in 2015. On the other hand, the frozen efficiency scenario is based on none efficiency improvements, but the living area and the number of buildings does change in an identical manner to the baseline scenario to establish a consistent reference case. In the frozen efficiency scenario delivered heat demand continuously increases up to a level of 2068 TWh in 2050. Shares between the different heating purposes (share of space heating vs. share of hot water) almost remains constant.

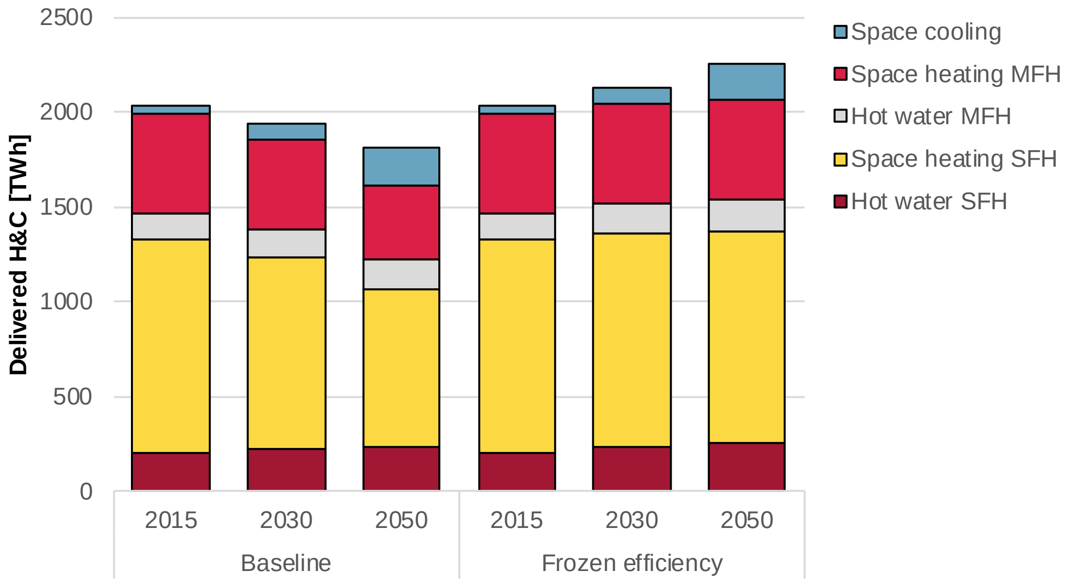


Figure 31: Delivered heating demand for the 14 HRE4 countries (aggregated) in the baseline scenario and the frozen efficiency scenario. Depicted are the three time steps 2015, 2030 and 2050.

A more detailed analysis emphasizes that the individual countries deviate heavily regarding their energy demand reflecting country specific building stock characteristics (Figure 32). For instance, Germany has by far the highest delivered energy demand in 2015 with 470 TWh. When further taking space cooling into account, Italy surpases Germany in 2050 by 3 TWh, becoming the country with highest level of energy demand. This development is attributed to a significantly decreasing space heating demand in Germany and a strong increase of space cooling in Italy. In terms of demand reduction, France and the United Kingdom also reveal significant demand reductions until 2050 of 21 % and 14 %, respectifly. In contrast, Spain shows similar patterns like Italy, with a strong rising share of space cooling demand until 2050, which will then be responsible for 41 % of the total energy demand. When analysing the 14 HRE4 countries as a whole, the share of cooling demand increases from 2 % in 2015 to 12 % in 2050. The detailed future evolution as well as the underlying assumptions for space cooling can be found in the seperate deliverable D3.2.

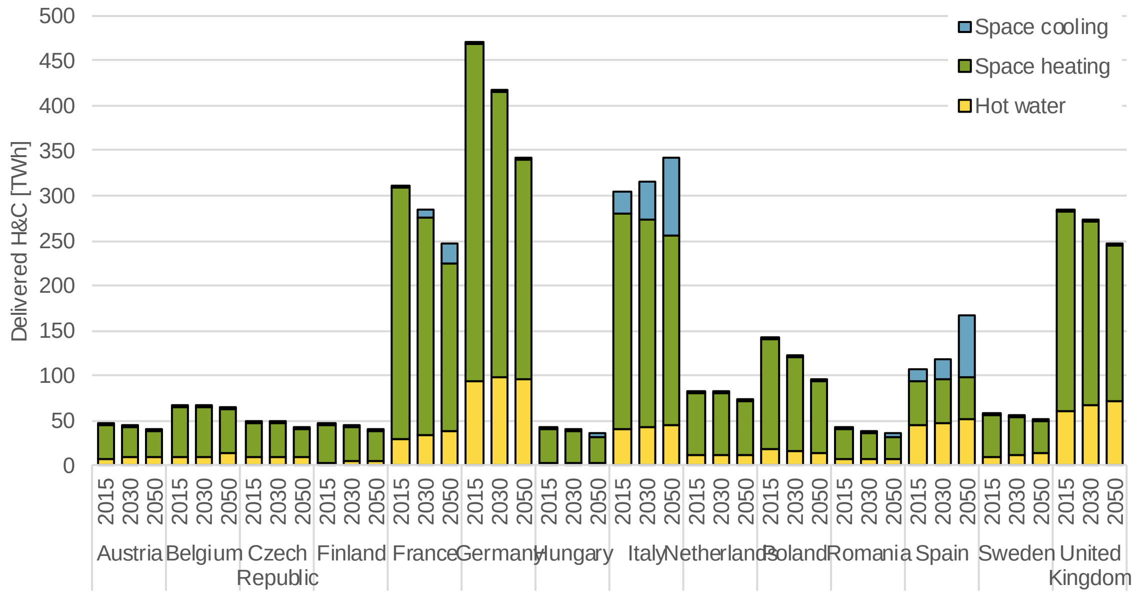


Figure 32: Delivered heating demand for the 14 HRE4 countries (detailled) in the baseline scenario and the frozen efficiency scenario. Depicted are the three time steps 2015, 2030 and 2050.

A further asset of this analysis is the consideration of behavior-related influencing factors in addition to technological parameters and economic framework conditions of residential decision makers. According to the norm-based definition of heat demand modelling, there are three parameters mainly capturing behavioral-based factors like the night setback factor, the space limited heating factor and a parameter called ‘user factor’. These parameters directly determine the value of the effective internal temperature during the heating period. For the first two parameters reference values are provided in literature. However, the user factor is very heterogenous by country and can be seen as a corrective of a pure building-physics based calculations in comparison the the actual energy demand. This difference can be estimated when comparing the energy demand derived from the energy balance in comparison to norm-based calculation results. For unrefurbished old buildings the analysis lead to user factors down to a level of 0.65, meaning that the actual energy demand is around 35 percent lower compared to the calculated demand based on the norm. In contrast, for highly efficient buildings the user factor occurs to be up to a level of 1.45 meaning that the purely norm-based modelling underestimates the actual demand significantly. Besides the thermal efficiency of buildings the analysis showed that the user factor varies according to climate conditions. Hence, in Southern countries the user factor is relatively lower compared to countries with cold climate conditions.

To shed some light on more detailled findings, **Fehler! Verweisquelle konnte nicht gefunden werden.** captures exemplary results of refurbishment measures over time focussing on SFH in Germany and Italy. While doing so the construction periods of the existing building stock are clustered by periods 'before 1960', '1961-1990' as well as '1991-2015' and, furthermore, by four alternative refurbishment packages:

- Current status: share of buildings which are still in the same thermal condition in 2050 compared to the level of 2015
- Refurbishment Package 1: Refurbishment of windows (low degree of efficiency)
- Refurbishment Package 2: Refurbishment of windows and walls (each with a low degree of efficiency)
- Refurbishment Package 3: Refurbishment of windows, walls and roof (each with a medium degree of efficiency)
- Refurbishment Package 4: Refurbishment of windows, walls, roof and basement (each with a high degree of efficiency)

Figure 33 also emphasises the dynamics of varying refurbishment rates between countries.

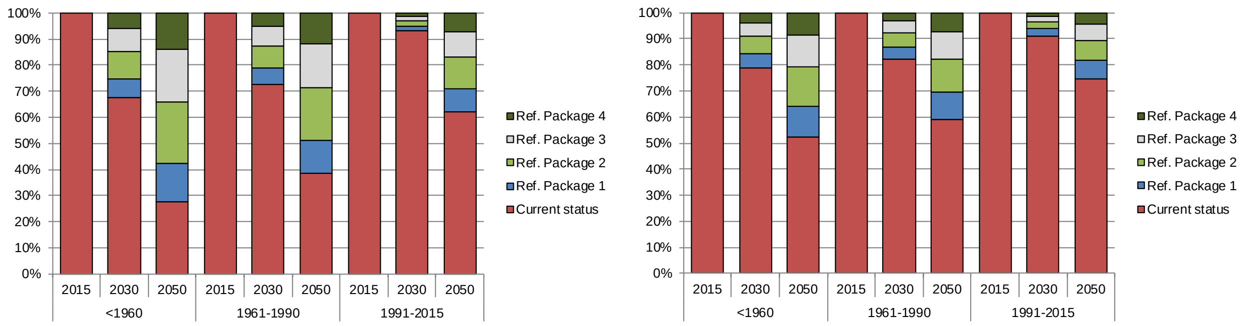


Figure 33: Exemplary share of refurbishment packages for SFH households in Germany (left) and Italy (right) in the baseline scenario. Depicted are the three time steps 2015, 2030 and 2050.

4.3.2 Energy savings

While comparing the delivered heat demand of the baseline scenario with the frozen efficiency scenario on an aggregated level, there are energy savings at around 451 TWh until 2050. As indicated in Figure 34 the savings are achieved for all heating demand purposes. By far the largest improvements are expected for space heating in SFH with around 286 TWh by 2050. In contrast, the energy savings for hot water in SFH and MFH are just around 8 % in 2050 compared to the overall savings (35 TWh).

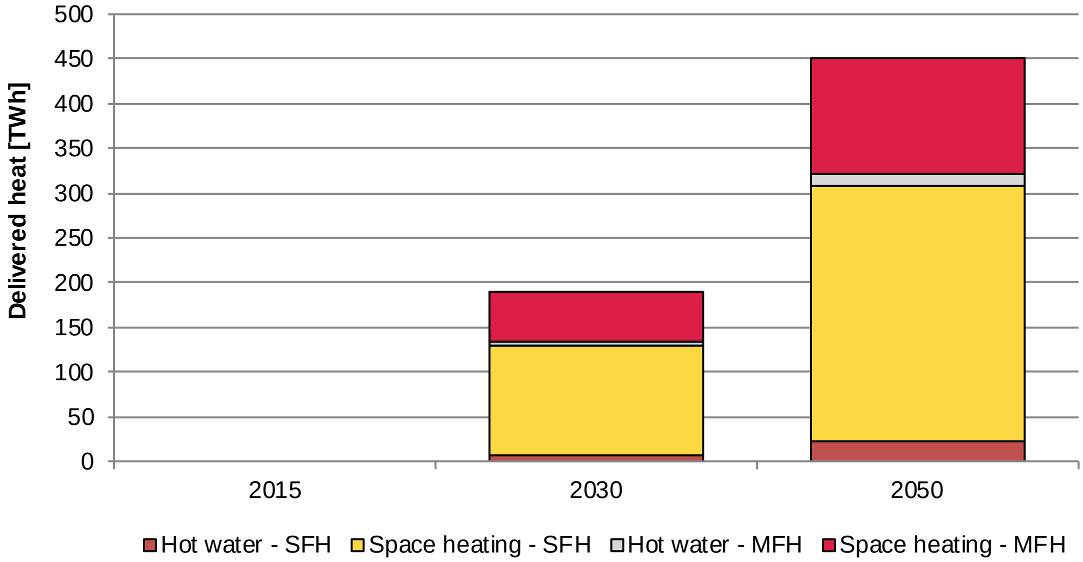


Figure 34: Savings of delivered heat demand in the baseline scenario compared to the frozen efficiency (aggregated). Depicted are the three time steps 2015, 2030 and 2050.

On a country level the highest savings are attributed to Germany, the United Kingdom and France, which is around 52 % of the entire energy savings (236 TWh) achieved by all countries by 2050. Figure 35 emphasizes very heterogenous results depending on the country. Whereas the energy savings in the United Kingdom are essentially driven by the reduction of space heating demand in SFH, the heating demand in Italy declines to a large degree due to improvements accomplished in MFH.

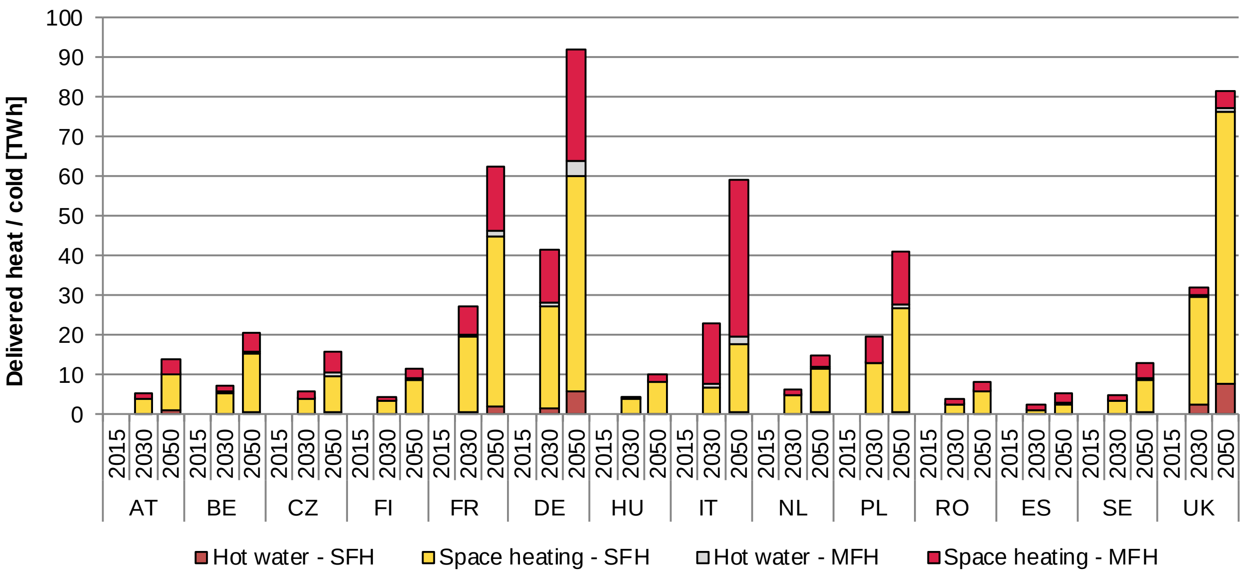


Figure 35: Savings of delivered heat demand in the baseline scenario compared to the frozen efficiency for the 14 HRE4 countries. Depicted are the three time steps 2015, 2030 and 2050.

4.4 Tertiary buildings

4.4.1 Delivered heat and cold

In the baseline scenario, the delivered heat and cold demand from tertiary buildings amounts about to 1000 TWh in 2015 whereas the total delivered heat and cold demand includes the categories space heating, hot water and process heating for delivered heat and space cooling and process cooling for cold demand. Based on the scenario assumptions, it is expected that the total delivered heat and cold demand decreases by approx. 5 % for the 14 HRE4 countries until 2050 (compared to 2015). However, the heat and cold demand develops differently (see Table 16).

Table 16: Total delivered energy demand per demand category in the baseline scenario for the 14 countries

	Space heating	Hot water	Process heating	Space cooling	Process cooling	Total
Baseline	[TWh]	[TWh]	[TWh]	[TWh]	[TWh]	[TWh]
2015	591	58	47	109	194	1000
2030	545	65	45	138	227	1020
2050	424	62	38	202	227	952

Heat demand

The space heating energy demand is expected to decrease (-28 % in 2050 compared to 2015, see also Figure 36), similar to the process heating demand which also decreases by 20 % although on lower levels (-11 TWh in 2050 compared to 2015). The demand from hot water is expected to grow slightly, mainly based on different growth expectations from the related sub-sectors and only smaller expected efficiency gains.

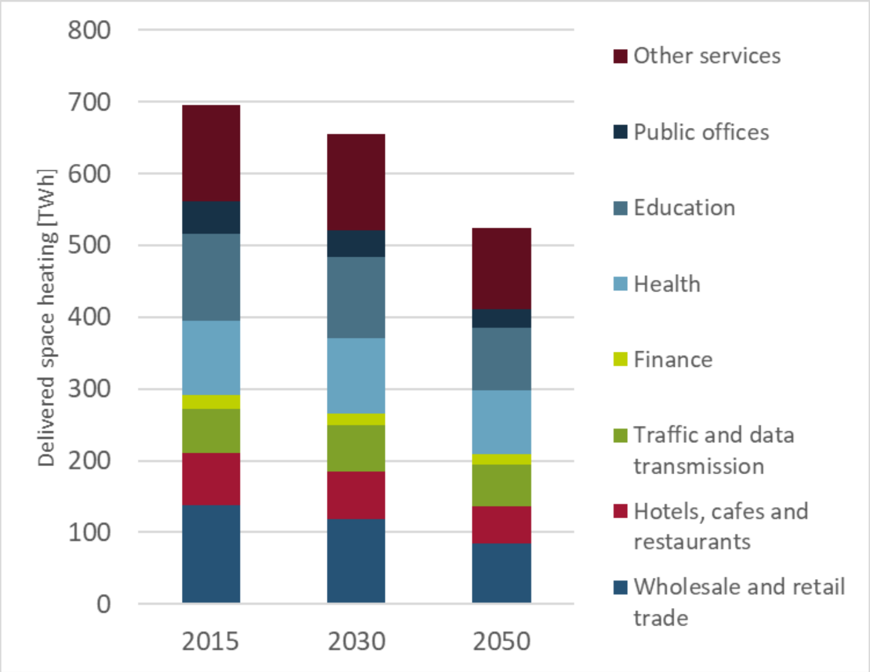


Figure 36: Delivered heat demand in the baseline scenario for the 14 HRE4 countries, differentiated by the tertiary sub-sectors

For the decreasing space heat demand, the driving factors are mainly efficiency gains and reduced specific energy consumption levels due to better insulation standards for new buildings (including replacements) and refurbishment activities. Until 2030, these effects are partially compensated due to increasing heat demand from new buildings. After 2030, the decreasing floor area in some countries is contributing to the further reduction in heat demand. Therefore, it is expected, that the today implemented regulatory measures to reduce heat energy demand become more and more effective.

Heat energy savings are achieved in the tertiary sector throughout all sub-sectors (see Figure 36). Largest efficiency gains are expected in the wholesale and retail trade (-50 TWh), in the public domain (-70 TWh in Health, Education and Public offices) based on the renovation and replacement of building parts with low energy efficiency performance. Therefore, the implementation of stringent building codes is of high relevance also in the tertiary sector to achieve targeted efficiency improvements.

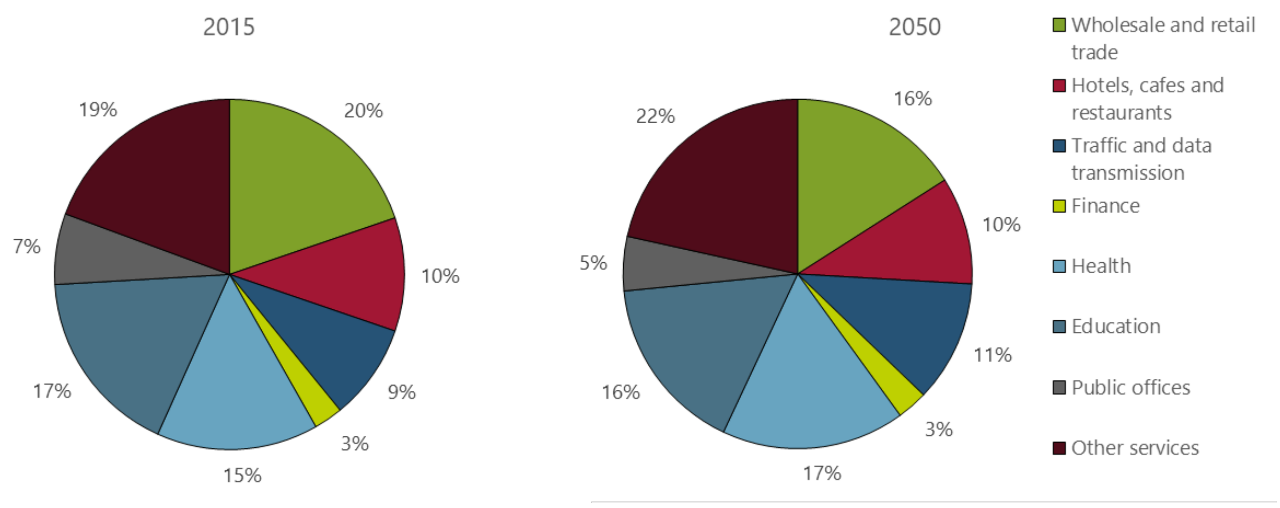


Figure 37: **Relative shares of heating demand per tertiary sub-sector and year. Shift of relative importance of specific sub-sectors between 2015 and 2050.**

In terms of structural change, i.e. the relative importance of the different sub-sectors regarding heat energy demand, the changes are small (see Figure 37). The demand from the Wholesale and retail trade sub-sector decreases stronger and therefore, the relative impact decreases by approx. 4 % until 2050 compared with 2015 values. On average, the public sub-sectors (education, health and public offices) are increasing their contribution by 1 percentage point whereas the Traffic and data transmission as well as the Other services sub-sectors are increasing their relative importance stronger (+2 percentage points and +3 percentage points, resp.) due to a relative increase of heated floor areas.

Cold demand

In the tertiary sector, the demand for total cold (process cooling and space cooling) is expected to increase in the future by +40 % in 2050 compared to 2015 in the 14 HRE4 countries. The cooling demand increase is mainly driven by additional demand from space cooling (+85 % or +90TWh until 2050 in the baseline, see Figure 38) whereas process cooling demand is expected to increase by 17 % (or +33 TWh until 2050 compared to 2015). Main drivers are additionally cooled surfaces based on changes in quality requirements, an increasing number of CDD's (+24 % for total number of CDD in 14 HRE4 countries) and additional process demand based on related services. Additional efficiency gains due to better available cooling technologies driven by more stringent appliance codes, are therefore overcompensated.

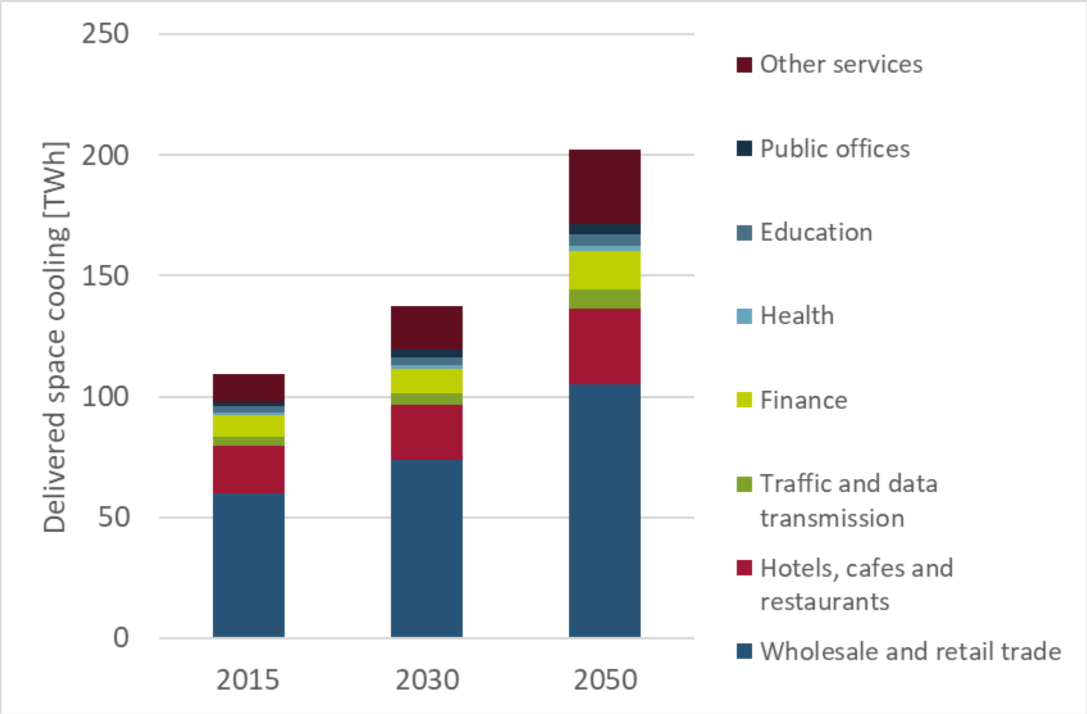


Figure 38: Delivered cold demand in the baseline scenario for the 14 HRE4 countries, differentiated by the tertiary sub-sectors

On country level, the demand development is less uniform as compred to the overall development as country specific differences are visible. Based on the country specific differences in drivers such as employment, floor area or HDD and CDD, the follwing results are expected (see Figure 39).

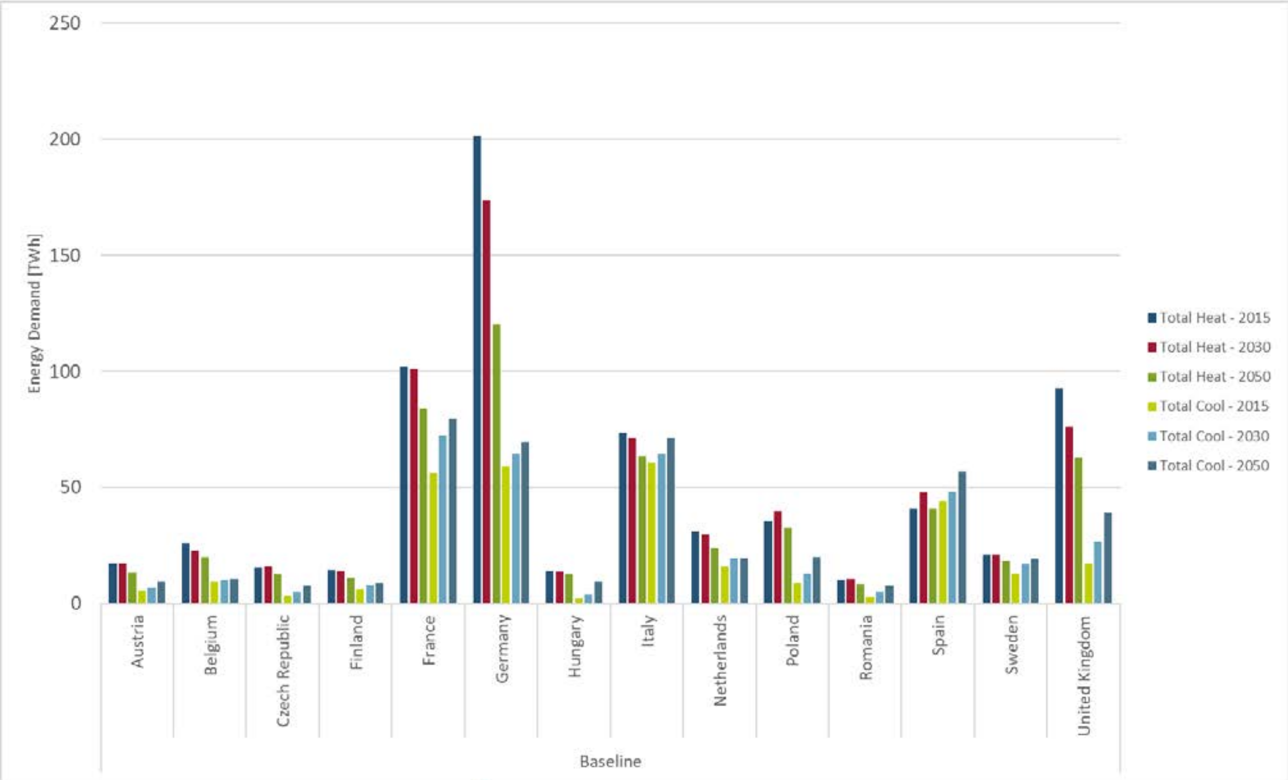


Figure 39: Total heat and cold demand per country in the baseline scenario

4.4.2 Energy savings

For comparison, the frozen efficiency scenario shows increasing demand for heat and cold (see Table 17), driven by increasing floor area until 2030 with lower insulation and efficiency standards (by definition of the scenario set-up, see section 2). Thereafter, the energy demand for heat in the frozen efficiency scenario remains almost constant, reflecting the decline in heated floor area. In 2050, a difference of up to 44 % lower space heating demand in the baseline scenario as compared to this highly hypothetical frozen efficiency scenario could arise (see Figure 40)

Table 17: Total delivered energy demand per demand category in the frozen efficiency scenario for the 14 HRE4 countries

	Space heating	Hot water	Process heating	Space cooling	Process cooling	Total
Frozen efficiency	**TWh**	**TWh**	**TWh**	**TWh**	**TWh**	**TWh**
2015	591	58	47	109	194	1000
2030	733	69	54	138	319	1313
2050	755	71	48	202	374	1450

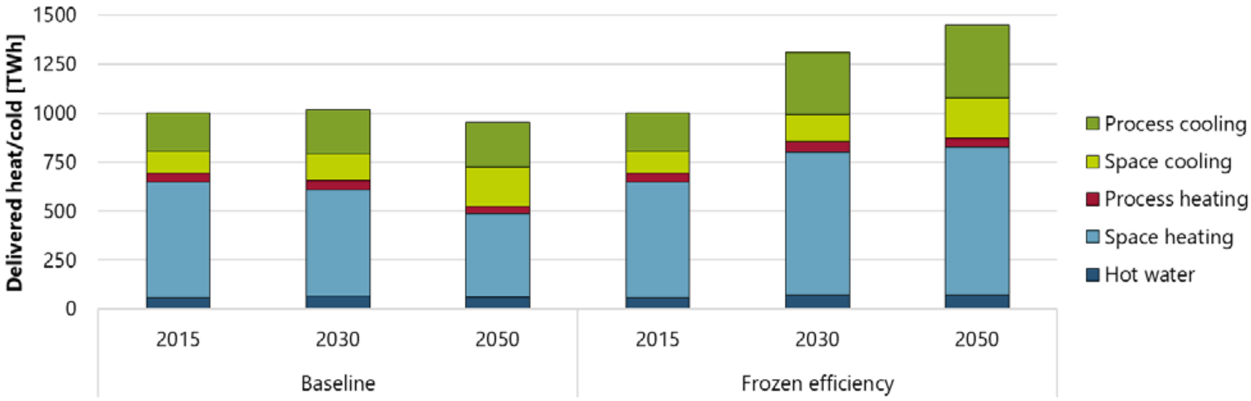


Figure 40: Delivered heating and cooling demand for the 14 HRE4 countries in the baseline scenario and the frozen efficiency scenario. Depicted are the three time steps 2015, 2030 and 2050.

Due to model set-up, the frozen efficiency scenario is only calculated for process cooling in the model FORECAST Tertiary. Therefore, similar to the development in the heat demand sectors, the cold demand from process cooling is expected to increase strongly and is at the level of +65 % in 2050 compared to the baseline figures in 2050 (see Figure 41 for total energy savings achievable per demand category in the specific year).

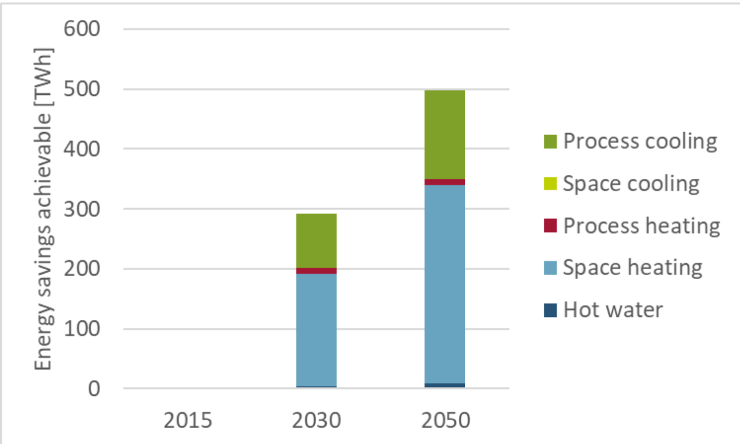


Figure 41: Energy savings achievable (in TWh for 14 HRE4 countries) in the baseline compared to the frozen efficiency scenario

The achievable energy demand savings vary accross countries and demand category (see Figure 42) based on the different saving potentials from increasing building standards and other demand drivers (e.g. employment development, etc.)

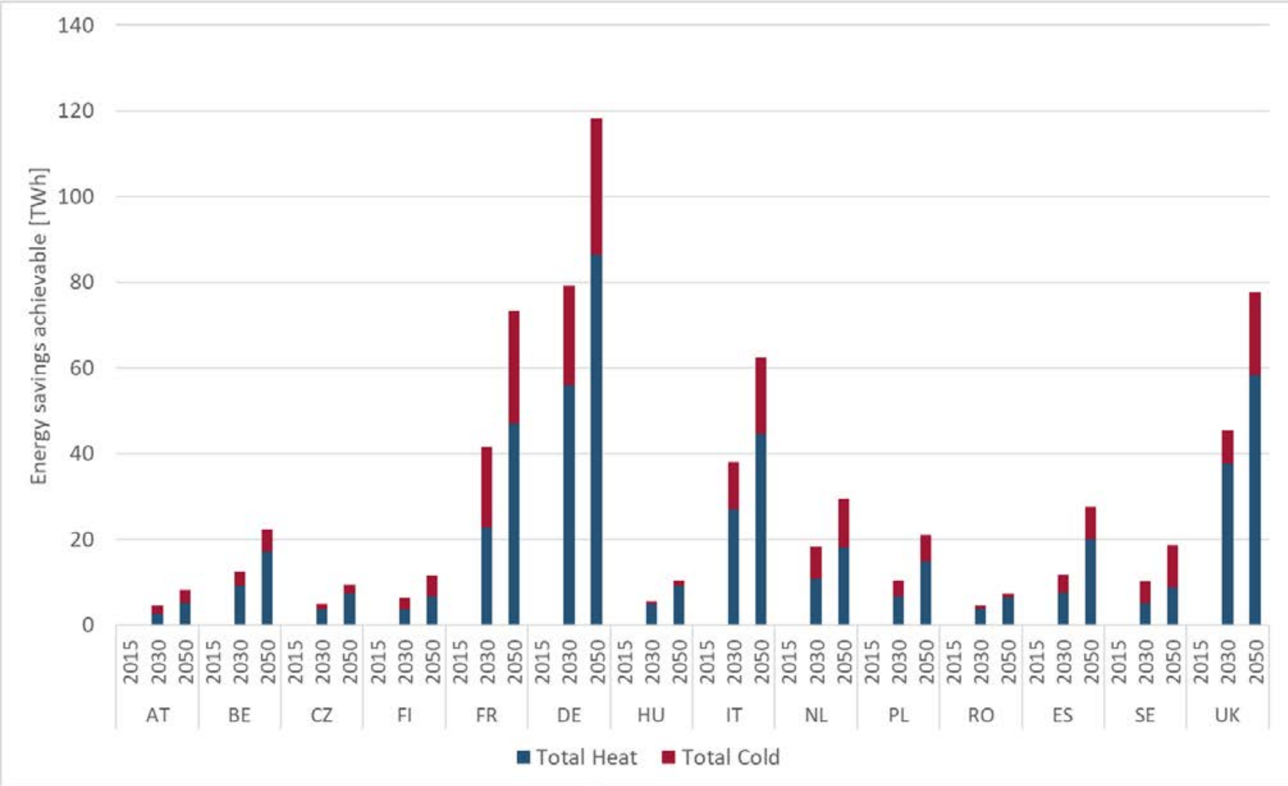


Figure 42: **Energy savings achievable (in TWh) per country in the baseline compared to the frozen efficiency scenario for total heat and cold demand**

5 Summary, discussion and recommendations

Summary of baseline results

The results of the baseline scenario for the 14 HRE4 countries show that the overall delivered H&C demand (all sectors) is expected to decrease by approx. 4 % until 2050 compared to the 2015 values, which reflects a more or less constant demand (1% decrease until 2030). Together, the 14 HRE4 countries show a delivered H&C demand of 4,870 TWh in 2015, which falls to about 4,690 by 2050. Thus, energy efficiency improvements slightly over-compensate increasing trends from activity drivers such as the value added in tertiary and industry or the living area in residential buildings. However, despite the relatively flat development of overall H&C delivered heat demand, more pronounced developments are observed in the individual sectors, end-uses and countries.

For example, the trends for heating and cooling are developing in different directions. While the space heating demand is expected to decrease by approx. 25 % from 2539 in 2015 to 1910 TWh in 2050, the space cooling demand is expected to increase by approx. 252 TWh (+136 %) from 186 TWh in 2015 to 438 TWh in 2050. Comparing the delivered H&C development of the individual demand sectors reveals a slight increase in industry from 2015 to 2050 (+5%) and a decrease in the residential (-11%) and the tertiary sectors (-5%). These average developments vary substantially across the countries.

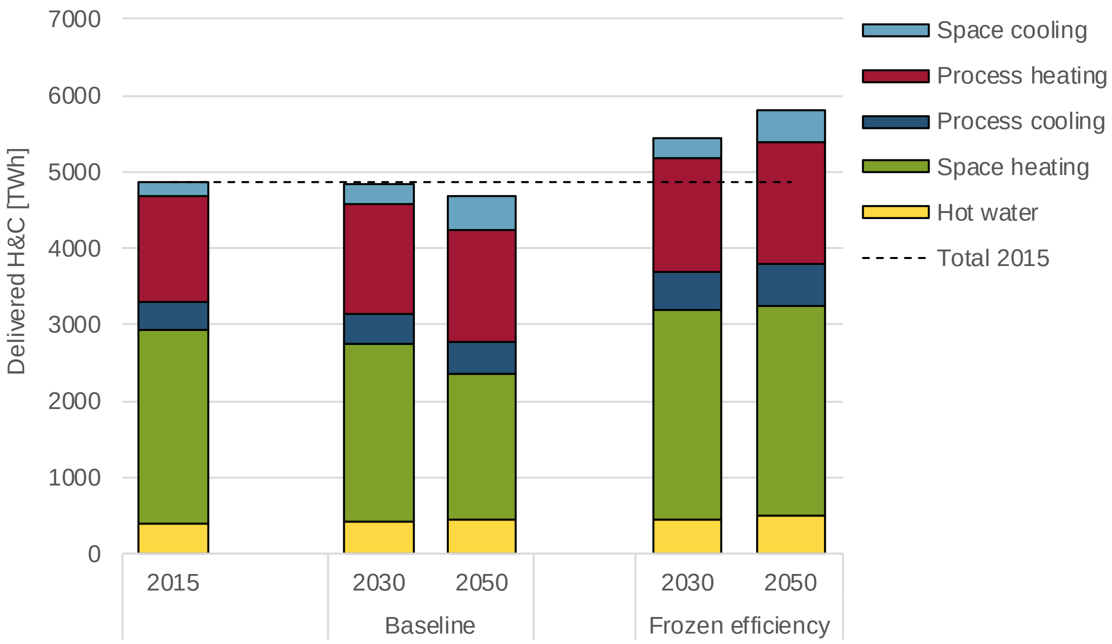


Figure 43: Development delivered H&C demand by end-use for the 14 HRE4 countries in the baseline scenario compared to the frozen efficiency scenario [TWh]

Energy savings are calculated by comparing the baseline scenario to the frozen efficiency scenario, which represents a variation of the baseline using similar assumptions but assuming a constant specific energy consumption. The frozen efficiency scenario is a hypothetical variant of the baseline scenario that shows how H&C demand would develop if only changes in the activity drivers are considered (e.g. increasing floor area in buildings). The comparison between both scenarios as shown in Figure 43 reveals that the energy savings are much higher than the 5% decrease of the baseline scenario until 2050 compared to 2015 might indicate. In fact, H&C demand in the frozen efficiency scenario increases substantially by about 18% in the same time period. Accordingly, total energy savings of 24% or 1132 TWh are observed in 2050 (13% in 2030). Most of these savings result from more efficient space heating, which even presents a saving potential of 44% compared to frozen efficiency scenario in 2050 (while only 25% compared to 2015). Process heating shows relatively low saving potential, which can be explained by the fast that many of the very energy intensive basic materials processes (e.g. oxygen steel production, clinker burning, paper and glass production) already show a lower remaining potential by applying available technologies (new innovative technologies were not considered in the baseline scenario).

The following additional observations can be made for the three individual sectors.

Industrial sector's delivered H&C demand increases by about 5% from 2015 to 2050 driven by increase in value added (mostly less energy-intensive sub-sectors) and to some extent small increases in physical production for many basic materials products. Delivered H&C demand in industry is dominated by process heating, which often already is relatively optimised due to high share in total running costs as discussed above.

In the **residential sector** delivered heat (space heating and hot water reduction is mainly achieved due to improved building codes for new buildings and the refurbishments of old buildings which are implemented as of today. Increasing space cooling demand is driven by additional floor area cooled in the future driven by higher comfort expectations and requirements in buildings and by rising number of cooling degree days as well.

In the **tertiary sector**, the building codes are in many countries less stringent as compared to the residential sector and in some countries no building codes are implemented for (some) tertiary sector buildings. These lower building standards can be explained with the heterogeneity of tertiary building types and their specific functions which led building code designers and policy makers focussing on residential buildings. Additional efficiency potentials can be tapped in the tertiary sector if explicit and more stringent building codes and other measures fostering an energy-efficient operation of the buildings (e.g. building automation and building operation and management) are implemented.

Discussion

First it should be emphasized that the baseline scenario represents a scenario that shows a possible future with certain assumptions on the socio-economic development and with current energy efficiency policies implemented. It includes many simplifications as all models and is not meant to be a forecast. On the contrary, it shows one possible evolution of energy demand in the H&C sector and will be used as the counterfactual for the Heat Roadmap Europe 4 scenario, which represents a low-carbon transition of the energy system until 2050.

The current levels of heat and cold delivered and their future development depend on various drivers. Most of them are characterized with uncertainties arising from incomplete, missing empirical fundamental or inaccuracies. Uncertainties may lead to deviations regarding the level of delivered heat and cold in the base year and/or regarding the slope up to 2050. Both might be relevant from a policy point of view.

Overall the **level of delivered heat and cold of the base year** is quite well represented by the models. The degree of freedom arising from uncertainties are utilized to match model results and statistical data. However individual drivers might be fraught with higher uncertainties. Particularly the modelled level of delivered heat and cold of the base year might include too much or too little energy-efficiency potential which leads to an underestimate or an overestimate of untapped potentials. Baseline results are rather characterized by the latter: the energy-efficiency effects of individual retrofit are overestimated (no performance gap considered) and the retrofit rates are rather underestimated. This is mainly relevant for the HRE4 scenario.

The **slope** might be, for different reasons, both too “optimistic” (from a policy point of view) and too “pessimistic”. For example climate change was considered by a linear trend however, heating demand could be lower than estimated with the model and cold demand higher if climate change progress is faster as reflected.

Recommendations

The approach adopted using a bottom-up model (FORECAST) allowed for calculating delivered heat and cold for a baseline scenario as well as the highlight energy savings achieved as compared to a frozen efficiency scenario. The approach also allowed for relating delivered energy data to underlying explanatory drivers. Data about these drivers are part of the result of this deliverable and will be the basis for estimating cost curves of additional savings.

Despite the successful implementation of the modelling approach and the insights gained from it there is an urgent need to improve the data base of heating and cooling energy demand and of underlying drivers. Particularly, building stock data and data about past and current retrofits activities and their drivers should be surveyed and monitored. Similarly, techno-economic data including costs and efficiencies as well as diffusion of energy-efficient production technologies in industry is very scarce and often outdated. Here, empirical studies that collect original data for selected technologies can provide a large value added for future scenario assessments.

Moreover, we recommend conducting so-called ex-post analysis to explain the past development of energy demand and to identify the effect and the impact of underlying drivers (see for instance Kemmler et al. 2016). Such a monitoring would also reveal the necessity and the usefulness of up-to-date building stock data.

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7 Annex

7.1 Definition of technology diffusion in frozen efficiency and baseline

Table 18: Definition of technology diffusion in frozen efficiency, baseline

	Main question to be answered	Saving options in industry and tertiary	Stock model: Building stock	Diffusion of energy services / behavior	Stock model: Building refurbish-ment	Stock model: Building replace-ment	Heat distribution efficiency
Frozen efficiency scenario	*How would energy demand develop without any energy efficiency gains?*	Constant SEC by process: $EC_t = SEC_t * Prod._t$ $SEC_t = SEC_{t=0}$ (i.e. frozen diffusion of SOs)	Change of number and floor area in buildings allowed Change of building stock structure allowed (e.g. multi vs. single family buildings, office vs. construction buildings, sub-sectors)	Diffusion of energy services as ventilation or space cooling according to scenario assumptions	Constant SEC by building type: No energy-efficiency refurbishment	Constant SEC by building type; New construction with average SEC from building stock in t=0 (base year) by type	Constant for buildings
Baseline scenario	*Depends on scenario definition (e.g. how does energy demand develop with current policies?)*	Diffusion based on policies and prices No new technologies			Energetic refurbishment according to scenario policy mix	New construction SEC according to scenario policy mix	Constant for buildings Increasing for steam systems
Maximum diffusion (for calculation of cost-curves)	How would energy demand develop with maximum diffusion of energy efficient technologies excluding early replacement of capital stock	Exogenous maximum diffusion path (no early replacement) New technologies included			Same refurbishment rate, but very deep renovation	100 % market share of most efficient buildings	

7.2 Overview of heating degree days and cooling degree days

Table 19: Number of heating degree days considered in the modelling analysis.

	2015	2030	2050	Trend 2015-2050
Austria	3318	3209	3009	0.91
Belgium	2633	2397	2138	0.81
Czech	3090	3126	2886	0.93
Finland	5031	5024	4588	0.91
France	2257	2137	1945	0.86
Germany	2908	2818	2589	0.89
Hungary	2597	2540	2340	0.90
Italy	1810	1609	1407	0.78
Netherlands	2625	2420	2156	0.82
Poland	3113	3202	2980	0.96
Spain	1612	1625	1502	0.93
Sweden	4910	4785	4426	0.90
United Kingdom	3017	2753	2552	0.85
Romania	2786	2747	2545	0.91

Table 20: Number of cooling degree days considered in the modelling analysis.

	2015	2030	2050	Trend 2015-2050
Austria	226	280	359	1.59
Belgium	89	95	101	1.13
Czech Republic	117	161	228	1.95
Finland	24	49	88	3.67
France	236	254	275	1.16
Germany	118	149	194	1.64
Hungary	259	320	408	1.58
Italy	607	644	687	1.13
Netherlands	42	48	56	1.34
Poland	109	157	210	1.93
Romania	437	495	575	1.32
Spain	569	615	677	1.19
Sweden	18	39	71	3.93
United Kingdom	23	29	36	1.58

7.3 FORECAST model description

7.3.1 Overview

The FORECAST modelling platform aims to develop long-term scenarios for future energy demand of individual countries and world regions until 2050. It is based on a bottom-up modelling approach considering the dynamics of technologies and socio-economic drivers. The model allows to address research questions related to energy demand including scenarios for the future demand of individual energy carriers like electricity or natural gas, calculating energy saving potentials and the impact on greenhouse gas (GHG) emissions as well as abatement cost curves and ex-ante policy impact assessments.

7.3.2 Recent model applications

The model has been in recent years frequently applied to national as well as EU-wide studies. Some examples of recent EU-wide applications are as follows:

- Calculation of energy saving potentials in the industrial sector of the EU by member state until 2030 for DG ENER (Eichhammer et al. 2009)
- Contribution of energy efficiency to the EU 2050 climate protection scenarios for the German Environmental Ministry (Boßmann et al. 2012)
- Long-term electricity demand of the EU by member state until 2050 for all demand sectors (ESA² 2013; www.esa2.eu)
- Assessment of the impact of energy-efficiency policies on the electricity demand in the EU's tertiary sector by member state until 2035 (Jakob et al. 2012; Jakob et al. 2013)
- Evaluation of energy-efficiency policies for the EU by member state until 2020 and 2030 for DG ENER (Fraunhofer ISI et al. 2014)
- Mapping of heating and cooling energy demand and supply in the EU and scenarios for renewable energy diffusion (Fraunhofer ISI et al. 2017)

Examples of national studies:

- Long-term climate policy scenarios for Germany in all demand sectors (Schlomann et al. 2011)
- Saving potentials and costs in German energy-intensive industries (Fleiter et al. 2011a; Fleiter et al. 2012; Fleiter et al. 2013)
- Ex-Ante impact assessment of energy-efficiency policies in the Turkish residential sector (Elsland et al. 2013a)

- Ex-Ante impact assessment of energy-efficiency policies in the German residential sector (Elsland et al. 2013b)

7.3.3 Model structure

The FORECAST platform comprises four individual modules, each representing one sector according to the Eurostat (or national) energy balances: industry, tertiary, residential and others (agriculture and transport). While all sector modules follow a similar bottom-up methodology, they also consider the particularities of each sector like technology structure, heterogeneity of actors and data availability.

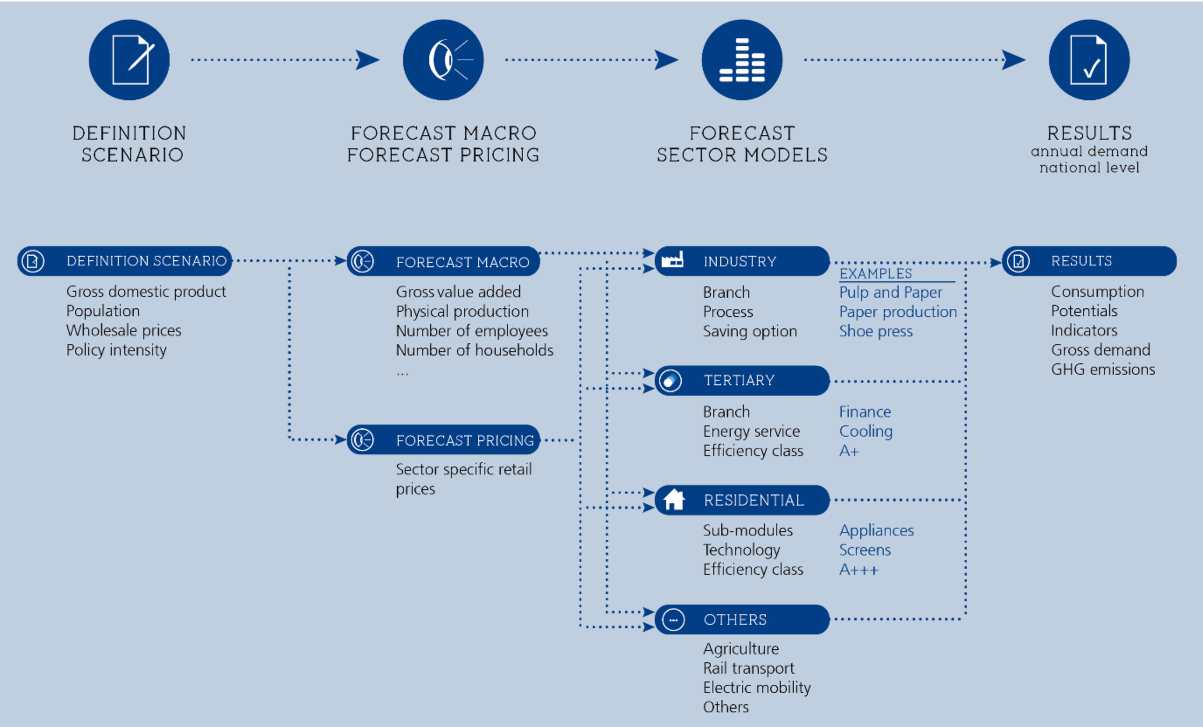

Figure 44: Overview of FORECAST model structure

The list of selected input data as shown in the following table provides a broad idea of the level of detail of each module. Each sector requires sector specific activity data, like industrial production in the industry sector and the number of households in the residential sector. Furthermore, end-consumer energy prices play an important role in each sector as they are distinguished by energy carrier. The third group of input data, the technology characterisation also reflects data availability of the individual sectors. While in the industry and tertiary sector the model works with so-called energy-efficiency measures (EEMs), which represent all kinds of actions that reduce specific energy consumption, in the residential sector the stock of alternative appliances and the market share of different efficiency classes is explicitly modelled. In all cases, energy savings can be calculated and traced back to technological dynamics including cost considerations.

Table 21: Main input parameters of FORECAST

TERTIARY	HOUSEHOLDS	INDUSTRY	AGRICULTURE
MAIN DRIVERS			
‣ No. of employees by sub-sector ‣ Floor area per employee by sub-sector	‣ No of households ‣ Building surface by type of building [m²]	‣ Physical production by process [t/a] ‣ Value added by sub-sector [Meuro/a]	‣ Production output ‣ Irrigated areas
PRICES			
‣ Energy prices	‣ Energy prices	‣ Energy prices ‣ EUA Prices	
TECHNOLOGY DATA			
Energy Services: ‣ Technology driver ‣ Installed power ‣ Annual full load hours **Saving options:** ‣ Saving Potential ‣ Costs ‣ Lifetime ‣ Diffusion **Buildings:** ‣ Insulation levels ‣ Heating system efficiency and shares	**Appliance data by efficiency class** ‣ Market share – Specific energy cons. ‣ Lifetime ‣ Standby power ‣ Standby hours **Building related data:** ‣ Insulation levels ‣ Heating system efficiency **Heating and lighting technology shares**	**Processes:** ‣ Specific Energy Cons. **Saving Options:** ‣ Saving Potential ‣ Costs ‣ Lifetime ‣ Diffusion **Buildings:** ‣ Insulation levels ‣ Heating system efficiency and shares	**Processes/Services** ‣ Technology driver ‣ Specific energy demand ‣ Saving potential

7.3.4 Modeling investment decisions

The bottom-up approach, which distinguishes individual technologies, allows modeling the diffusion of technologies as the result of individual investment decisions taken over time. For all types of investment decisions, the model follows a simulation approach rather than optimization in order to better capture the real-life behavior of companies and households.

Whenever possible, the investment decision is modeled as a discrete choice process, where households or companies choose among alternative technologies to satisfy a certain energy service. It is implemented as a logit-approach considering the total cost of ownership (TCO) of an investment plus other intangible costs. This approach ensures that even if one technology choice is more cost-effective than the others, it will not gain a 100% market share. This effect reflects heterogeneity in the market, niche markets and non-rational behavior of companies and households, which is a central capability to model policies. Still, the resulting technology development (and energy demand) is price sensitive.

The replacement of equipment/buildings/technologies is based on a vintage stock approach allowing to realistically model the replacement of the capital stock considering its age distribution. Some parts of the industrial and the tertiary sector are not using a vintage stock approach, due to the huge heterogeneity of technologies on the one hand and data scarcity on the other.

Technology diffusion, however, is modeled based on a similar simulation algorithm taking heterogeneity and non-rational behavior into account.

7.3.5 Modeling policies

Modeling energy-efficiency policies is a core feature of the FORECAST model. The simulation algorithm and the vintage stock approach are well suited to simulate most types of policies.

Minimum energy performance standards (MEPS), e.g. for appliances or buildings, can easily be modeled by restricting the market share of new appliances starting in the year the standards come into force. See Elsland et al. (2013) and Jakob et al. (2013) for examples of ex-ante impact assessments of the EU-Ecodesign Directive.

Energy taxes for end-consumers can be modeled explicitly on the basis of more than 10 individual energy carriers (electricity, light fuel oil, heavy fuel oil, natural gas, lignite, hard coal, district heating, biomass, etc.).

Information-based policies are generally the most complicated to model due to their rather "qualitative character". The discrete-choice approach, however, allows to consider such qualitative factors. E.g. labeling of appliances resulting from the EU Labeling Directive can be modeled by adjusting the logit parameters and thus assuming a less heterogeneous market, in which a higher share of consumers will select the appliance with the lowest total cost of ownership. See for example Elsland et al. (2013).

EU emissions trading can be modeled in the form of a CO_2 tax for energy-intensive industries. The detailed technology disaggregation in the industrial sector considering more than 60 individual products allows to consider the scope of the EU ETS on a very detailed level (examples of products are: clinker, flat glass, container glass, primary and secondary aluminium, oxygen steel, electric steel, coke, sinter, paper, ceramics, ammonia, adipic acid, chlorine). See Fleiter et al. (2012) for a case study on the German paper industry taking EUA prices into account.

7.3.6 Database

The FORECAST database has improved continuously incorporating the results/extensions from the above-mentioned studies.

The main economic input like **energy balances, employment, value added** or **energy prices** are calibrated to most recent EUROSTAT statistics whenever possible. When such data was not available (prices for certain energy carriers) IEA data was used to fill the gaps.

In the following an overview of the main sources is provided by model segment for technology-related data not available in EUROSTAT:

Buildings and heating systems: Buildings Performance Institute Europe (BPIE), IEE project TABULA, IEA Building Energy Efficiency Policies (BEEP), IEE project EPISCOPE, ODYSSEE database, country specific research e.g. for heat pumps

Appliances residential sector: Ecodesign Directive preparatory studies, ODYSSEE database, market research data from GfK

Appliances tertiary sector: Ecodesign Directive preparatory studies and additional individual technology studies.

Industrial production: PRODCOM when possible, UN commodity production database, US geological survey, UNFCCC, industry organizations (World steel organization, CEPI, Cembureau, Eurochlor, etc.)

Industry cross-cutting technologies: various technology studies of which many are EU projects

Industry process technologies: IPPC BREF studies, numerous technology/sectoral studies

Besides these sources, many more, even country specific sources, statistics and reports are used to feed the model database.

7.3.7 Selected references for model description

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