Heating & Cooling outlook until 2050, EU-28

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Project Information

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Legal notice

The Hotmaps project

The EU-funded project Hotmaps aims at designing a toolbox to support public authorities, energy agencies and urban planners in strategic heating and cooling planning on local, regional and national levels, and in line with EU policies.

In addition to guidelines and handbooks on how to carry out strategic heating and cooling (H&C) planning, Hotmaps will provide the first H&C planning software that is

- **User-driven**: developed in close collaboration with 7 European pilot areas
- **Open source**: the developed tool and all related modules will run without requiring any other commercial tool or software. Use of and access to Source Code is subject to Open Source License.
- **EU-28 compatible**: the tool will be applicable for cities in all 28 EU Member States

The consortium behind

Scientific partners

Pilot areas for developing and testing the tool

Bistrita Municipality

Executive Summary

Heating and cooling planning requires a consistent, robust framework about possible future pathways of energy demand, energy carrier mix, CO2-emission factors and how developments in the electricity and transport sector may influence the heating and cooling sector. Thus, the Hotmaps project provides scenarios for the heating and cooling sector for EU-28 up to 2030/2050. These scenarios do not intend to predict the future nor are they normative settings how the energy system should evolve. Rather, the default scenarios are meant to be used by energy planners and users of the Hotmaps toolbox as starting point for the heat planning process on local, regional or national level. The predefined scenarios, on which the user may build to develop own, tailor made scenarios are stored in the data repository of the Hotmaps project (https://gitlab.com/hotmaps).

The scenarios include heat demand and supply in the building and the industry sector, the electricity generation and transport. They were developed on the country level, and partly distinguishing rural and urban areas. In this report, we developed a methodology to break down the relevant parts of scenario results from the country level to the local and regional level.

For the building sector (covered by the model Invert/EE-Lab), the scenarios are mainly driven by building renovation and construction activities and corresponding policy framework conditions, including the installation of decentral heating and cooling systems and the uptake of district heating. For the industry sector (covered by the model FORECAST-Industry), the scenarios comprise on the one hand the development of macro-economic drivers, e.g. the value added or industrial production and on the other hand energy-related indicators such as changes in the specific energy consumption due to the diffusion of energy-efficient technologies. The whole renewable energy system with a focus on cross-sectoral impacts, in particular biomass allocation and supply of district heating systems is covered by the model Green-X. Overall renewable energy policies and related policy targets (and their achievement) are main drivers of the scenarios. Scenarios for the transport sector build on the the DIONE fleet impact model.

For each sector two scenarios with different ambition level regarding climate and energy policy targets were developed. They are presented first by the means of fact-sheets, summarizing the characteristics and assumptions regarding policy intensity, energy prices, technology development and key results like energy demand or resulting share of renewable energy. These fact sheets are also available as a documentation of Secondly, the results are discussed in a comparative way and deriving conclusions regarding policy making and planning.

In the Hotmaps toolbox, the comparative assessment of heating and cooling planning strategies builds on predefined indicators like energy demand by energy carriers and end-use, share of renewable energy sources, CO2-emissions, total costs etc. The scenarios presented in this report and stored in the Hotmaps data repository will assist energy planners in this process. The detailed process how to build the energy planning process on pre-defined default scenarios will be described in the Hotmaps handbook, available in spring 2019.

Table of Content

1 Introduction

Scenarios are required for heating and cooling planning and are an important means to ensure consistency of local, regional, national and EU wide planning. Thus, the Hotmaps project provide two scenarios for the heating and cooling sector for EU-28 up to 2030/2050. Moreover, sectors of the energy system affecting the heating and cooling sector (transport, electricity) are also covered. Energy planners may use these scenarios as starting point for their heat planning process on local, regional or national level.

For this purpose, we build on models used and existing scenarios derived by the consortium in previous projects. The scenarios include heat demand and supply in the building sector, the industry sector and the electricity sector. Scenarios for transport have been derived from the DIONE fleet impact model. These scenarios have been developed on the country level, and partly distinguishing rural and urban areas. In this report, we developed a methodology to break down the relevant parts of scenario results from the country level to the local and regional level.

The predefined scenarios, on which the user may build to develop own, tailor made scenarios also on the local and regional level will be stored in the data repository of the Hotmaps project (https://gitlab.com/hotmaps). Since the consortium will be also working on further scenarios during the project duration (and probably beyond), we intend to update this scenario repository frequently.

For the building sector (covered by the model Invert/EE-Lab), the scenarios are mainly driven by building renovation and construction activities and corresponding policy framework conditions, including the installation of decentral heating and cooling systems and the uptake of district heating. For the industry sector (covered by the model FORECAST-Industry), the scenarios comprise on the one side the development of macro-economic drivers, e.g. the value added or industrial production and on the other side energy-related indicators such as changes in the specific energy consumption due to the diffusion of energy-efficient technologies. The whole renewable energy system with a focus on cross-sectoral impacts, in particular biomass allocation and supply of district heating systems is covered by the model Green-X. Overall renewable energy policies and related policy targets (and their achievement) are main drivers of the scenarios. Scenarios for the transport sector build on the the DIONE fleet impact model. DIONE is a tool for assessing key impacts of new road transport technologies (Thiel et al., 2016).

At first, we will describe the methodology of the models and the regional breakdown of national scenarios in chapter 2. Chapter 3 presents the scenario results by sector. Finally, we indicate the role of scenarios in the context of the project Hotmaps and for using the Hotmaps toolbox (chapter 4).

2 Methodology

In this chapter we describe the models used for the scenario development as well as the methodology for regional breakdown. We distinguish between the following sectors: (1) Building related H/C demand and supply – Invert/EE-Lab (chapter 2.1), (2) Industry related H/C demand and supply – Forecast-Industry (chapter 2.2), (3) Electricity generation and district heating generation mix – Green-X (chapter 2.3) and Transport – DIONE (chapter 2.4).

2.1 Building related H/C demand and supply – Invert/EE-Lab

2.1.1 Methodology for national scenario development

Invert/EE-Lab is a dynamic bottom-up building stock simulation tool. Invert/EE-Lab in particular is designed to simulate the impact of policies and other side conditions in different scenarios (policy scenarios, price scenarios, insulation scenarios, different consumer behaviours, etc.) and their respective impact on future trends of energy demand and mix of renewable as well as conventional energy sources on a national and regional level. More information is available on www.invert.at or e.g. in Müller, (2015), Kranzl et al., (2013) or Müller, (2012). The structure and concept is described in Figure 1.

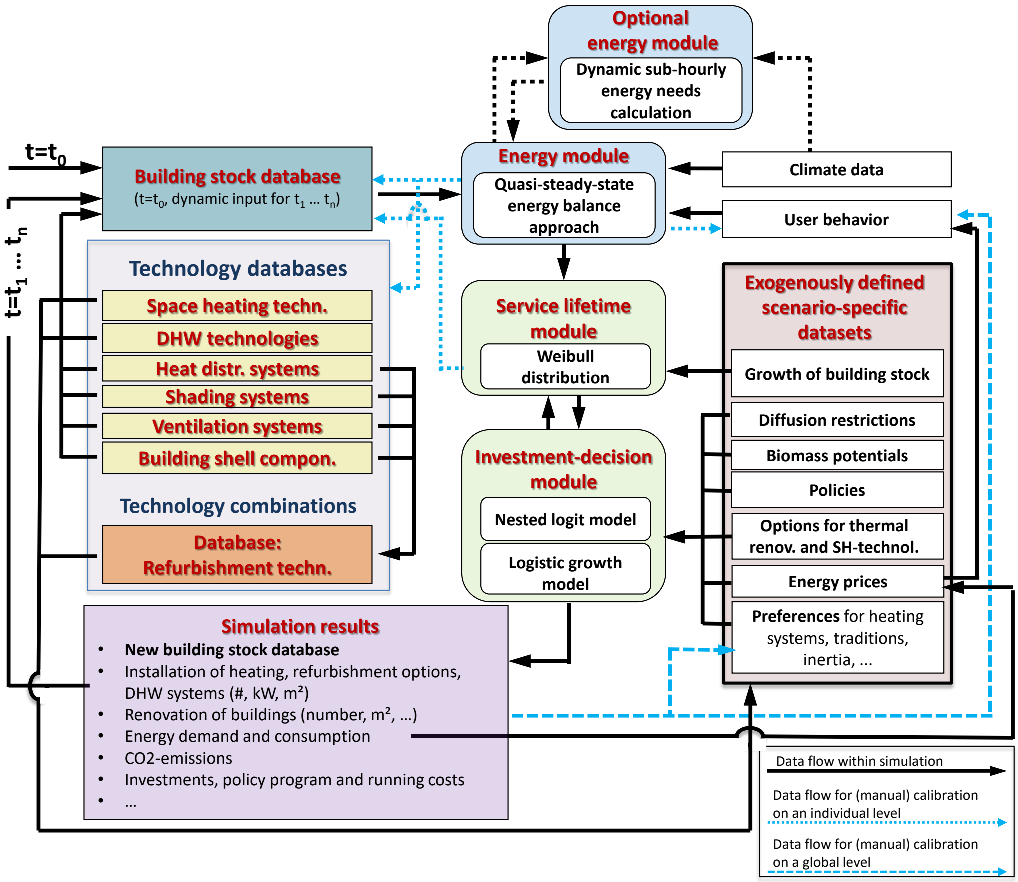


Figure 1: Overview structure of Simulation-Tool Invert/EE-Lab

The basic idea of the model is to describe the building stock, heating, cooling and hot water systems on highly disaggregated level, calculate related energy needs and delivered energy, determine reinvestment cycles and new investment of building components and technologies and simulate the decisions of various agents (i.e. owner types) in case that an investment decision is due for a specific building segment. The core of the tool is a myopical, nested logit approach, which optimizes objectives of "agents" under imperfect information conditions and by that represents the decisions maker concerning building related decisions.

Coverage and data structure

The model Invert/EE-Lab up to now has been applied in all countries of EU-28 (+NO, CH, IS etc.). A representation of the implemented data of the building stock is given e.g. at www.entranze.eu.

Invert/EE-Lab covers residential and non-residential buildings. Industrial buildings are excluded (as far as they are not included in the official statistics of office or other non-residential buildings). The level of detail as e.g. the number of construction periods depend on the data availability and structure of national statistics. We take into account data from Eurostat, national building statistics, national statistics on various economic sectors for non-residential buildings, BPIE data hub, Odyssee. The current base year used in our building stock database is 2012.

As efficiency technologies Invert/EE-Lab models the uptake of different levels of renovation measures (country specific) and diffusion of efficient heating and hot water systems.

Outputs from Invert/EE-Lab

Standard outputs from the Invert/EE-Lab on an annual basis are:

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

Moreover, due to the bottom-up character of the model, Invert/EE-Lab offers the possibility to derive more detailed and other type of result evaluations as well.

Building renovation

For each building class, the Invert-EE-Lab model considers up to 9 different renovation bundles, which consists of refurbishment options for different building components such as windows, upper ceiling, exterior walls, floor, shading systems, space heating distribution system and others at different levels of energy saving ambitious and associated investment needs. Usually, we use define three different renovation options (renovation bundle) per building, which are standard renovation and two intensified renovation options, as well as a maintenance option without any improvement of the building envelope.

Specific heating energy-uses covered

In the Invert/EE-Lab model, the following building related energy usage types and energy carriers are covered:

- Space heating: oil, gas and coal powered heating systems, biomass heating systems, electricity convectors, heat pumps and solar thermal collectors
- Domestic hot water: oil and gas systems, biomass powered water heating, electrical converters, heat pumps and solar thermal collectors
- Auxiliary energy: technology related auxiliary energy demand of heating systems
- Cooling: energy demand for cooling

Scenario-independent drivers

The energy demand of buildings and for the usage types mentioned above depends on a variety of exogenous drivers, which are the same for all scenarios. These drivers include, number of buildings/dwellings, floor area, climate development, solar yield, fuel prices.

Modelling of policy instruments

The model Invert/EE-Lab allows for a wide range of policies to be defined for each country. For existing policies a major data source for defining the inputs for the model is the MURE database which includes descriptions of polices measures such as:

- Minimum energy performance standards (MEPS) set by the Ecodesign directive

- Minimum energy performance standards for major refurbishments and newly constructed buildings, including the definition of Nearly Zero Energy Buildings (NZEBs) defined in the national implementations of the Directive on Energy Performance of buildings.
- Energy taxes for different energy carriers
- Investment subsidies, grants, soft loans (considering constrains regarding the absolute support level either per building or dwelling as well as restricted national budgets per country and support instrument) for different types of refurbish measures and building types as well as investments into technologies to utilize renewable energy carriers.
- “Soft measures” such as reducing the information barrier and increasing the compliance rate through the introduction of energy performance certificates, information campaigns, or reducing the diffusion barrier through workforce education, etc.

The policy descriptions lead to the following implementation in the simulation:

- Investment subsidies for building renovation (three options for building envelope refurbishment)
- Investment subsidies for heating supply systems
- Investment subsidies for solar thermal systems
- Country specific public budgets for subsidies
- Obligations regarding the implantation of renewable heating supply systems
- Building codes: improvement of technical building standards for new and renovated buildings (building envelope),

2.1.2 Methodology for regional breakdown

The trajectories derived by the Invert/EE-Lab model represent the developments in the sector at an aggregated regional level. For the current implementation of the building stock, this means the NUTS 0 level (countries) for the very most countries. In order to break down the scenarios to regional and local level, the national development needs to be transferred consistently to the regional building stock.

This breakdown is done by a two-step approach. In the first step, we derive consistent scenarios for the useful energy demand on the NUTS 3 level. In the second step, the development on the NUTS 3 level is transferred to the local level of the heat density maps. For the interpretation of the results it is important to bear in mind that this break-down is done based on a generic approach and generic data and that the local circumstances cannot fully be taken into account. However, the applied algorithm ensures that the results on the local level will consistently sum up to national development for each scenario.

Transfer of NUTS 0 scenario results to the NUTS 3 level

At the NUTS 3 level, the following indicators, which specify the energy needs (useful energy demand) are available:

For residential buildings:

- Data provided by the European Census Hub 2011 (Census 2011, Population and Housing Census 2011):
  - Useful floor area per dwelling
  - Population
  - Number of dwellings
  - Number of dwellings per building type
  - Number of dwellings per construction period
- Heating and cooling-degree days (HDD and CDD) on NUTS2-level based on Eurostat (Eurostat, 2013). Within the NUTS2 level, the HDD and CDD on the NUTS3 level are calculated based on the average HDD (18.5/18.5) and CDD (22.5/22.5) calculated from the observed daily temperatures on a 25 x 25 km grid for the period 2002-2012 (see (Haylock, M.R. et al., 2011)).

*For non-**residential** buildings:*

- Population, heating degree days (HDD) and cooling degree days (CDD), the final energy consumption(FEC) per m² floor area and building type based on the Invert/EE-Lab building stock database (Eurostat, 2011)
- The estimated share per construction periods based on the distribution of the construction periods of apartment buildings (Eurostat, 2011)
- The total value added of the service sector (Eurostat, 2016)
- The sectoral value added (VA): (a) Accommodation, restaurants, stores and warehouses, (b) other private services and (c) public buildings, research and education, art, culture and health sector (Eurostat, 2016).

Furthermore, on the NUTS0 level we use data such as the final energy consumption per m² floor area and building type based on Invert/EE-Lab model results. These data have been derived within the European project "Mapping_HC: Mapping and analysis of the current and future (2020-2030) heating/cooling fuel deployment (fossil and renewables)" (EC service contract ENER/C2/2014-641/SI2.697512) (Fleiter, Tobias et al., 2016) as well as scenarios for the development until 2050 from the H2020 project SetNav[1], which are currently under development.

In a first step, we estimate the **development of the population growth** for each NUTS 3 region[2]. This is done by putting the historic population growth (2002 – 2017, (Eurostat, 2018)) of each NUTS3 region (using an exponentially distributed weighting factor with a decline rate 0.25) in relation to the national population growth. The relative growth of a given NUTS3 region $\Delta_{gr,NUTS3}$ is calculated by using growth rate of the given NUTS3 region between 2002 and 2017 $gr_{NUTS3,2002,2017}$ minus the national growth rate $gr_{NUTS0,2002,2017}$ for the same period:

$$\Delta_{gr,NUTS3} = gr_{NUTS3,2002,2017} - gr_{NUTS0,2002,2017}$$

[1] http://www.set-nav.eu/

[2] Until March 2017, the projected change of the population by NUTS3 regions was available at Eurostat (Code: proj_13rpms3). Unfortunately, the data have been removed and only a map of the results exists anymore (see http://ec.europa.eu/eurostat/statistics-explained/images/f/f8/Projected_percentage_change_of_the_population%2C_by_NUTS_3_regions%2C_2015%E2%80%9350_%28%C2%B9%29_%28%25%29_RYB2016.png)

$$-0.05 \leq \Delta_{gr,NUTS3} \leq +0.08$$

The future annual growth rate of a given NUTS3 region in a given year t+1 $gr_{NUTS3,t,t+1}$ is then calculated by adding the relative growth multiplied by a weighting factor δ_t to the national growth rate in that given year and multiplied by a correction term. For the weighting factor, we assume it is 0.8 in 2018, declines linearly to 0.5 within a 10-year period and remains afterwards at this level.

$$gr_{NUTS3,t,t+1,uncorr} = \left(gr_{NUTS0,t,t+1} + \delta_t \cdot \Delta_{gr,NUTS3}\right) \cdot \min\left(POP_{NUTS3,t}, POP_{NUTS3,2002}\right)$$

$$POP_{NUTS3,t+1,uncorr} = POP_{NUTS3,t} \cdot gr_{NUTS3,t,t+1,uncorr}$$

$$\Delta_{POP,NUTS0,t+1} = POP_{NUTS0,t+1} - \sum_{1}^{NUTS3} POP_{NUTS3,t+1,uncorr}$$

$$f_{corr} = \Delta_{POP,NUTS0,t+1} \Big/ \left(\sum_{1}^{NUTS3 \,|\, sign(gr_{NUTS3,t,t+1,uncorr}) = sign(gr_{NUTS0,t,t+1})} POP_{NUTS3,t+1,uncorr} + 2 \sum_{1}^{NUTS3 \,|\, sign(gr_{NUTS3,t,t+1,uncorr}) \neq sign(gr_{NUTS0,t,t+1})} POP_{NUTS3,t+1,uncorr} \right)$$

The population is then calculated by

$$POP_{NUTS3,t+1} = \begin{bmatrix} POP_{NUTS3,t+1,uncorr} * (1 + f_{corr}) & \{x \in NUTS3 \,|\, sign(gr_{x,t,t+1,uncorr}) = sign(gr_{NUTS0,t,t+1})\} \\ POP_{NUTS3,t+1,uncorr} * (1 - 2 * f_{corr}) & \{x \in NUTS3 \,|\, sign(gr_{x,t,t+1,uncorr}) \neq sign(gr_{NUTS0,t,t+1})\} \end{bmatrix}$$

For the national population growth, we draw on forecast data published by Eurostat (Baseline projections, proj_15npms[3]). Based on this approach we get annual growth rates of the different European NUTS 3 regions in the range of – 1.3 %p.a. to about +1 %p.a. (Figure 2). The change of the population between 2015 and 2050 per region is depicted in Figure 3.

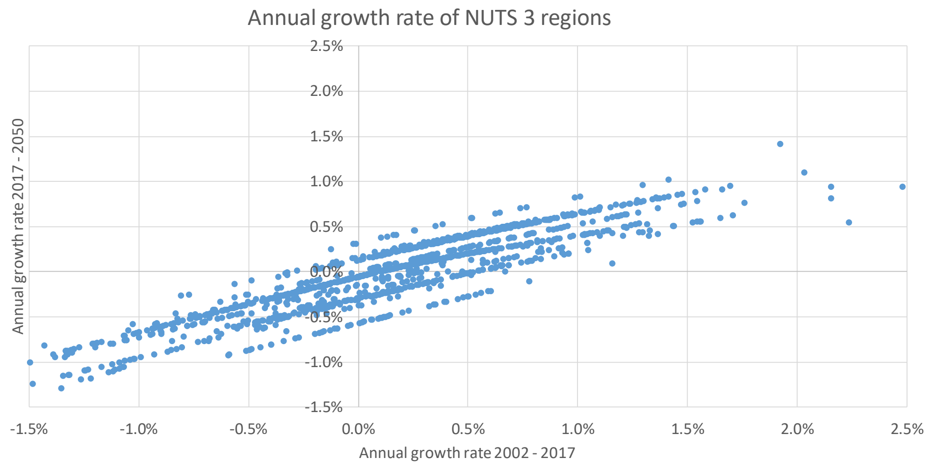


Figure 2: Future annual growth rate (2015 – 2050) versus historical growth rate (2002 – 2012) for the European NUTS 3 regions.

[3] Population on 1st January by age, sex and type of projection, Code: proj_15npms, Last update of data: 19/06/2017

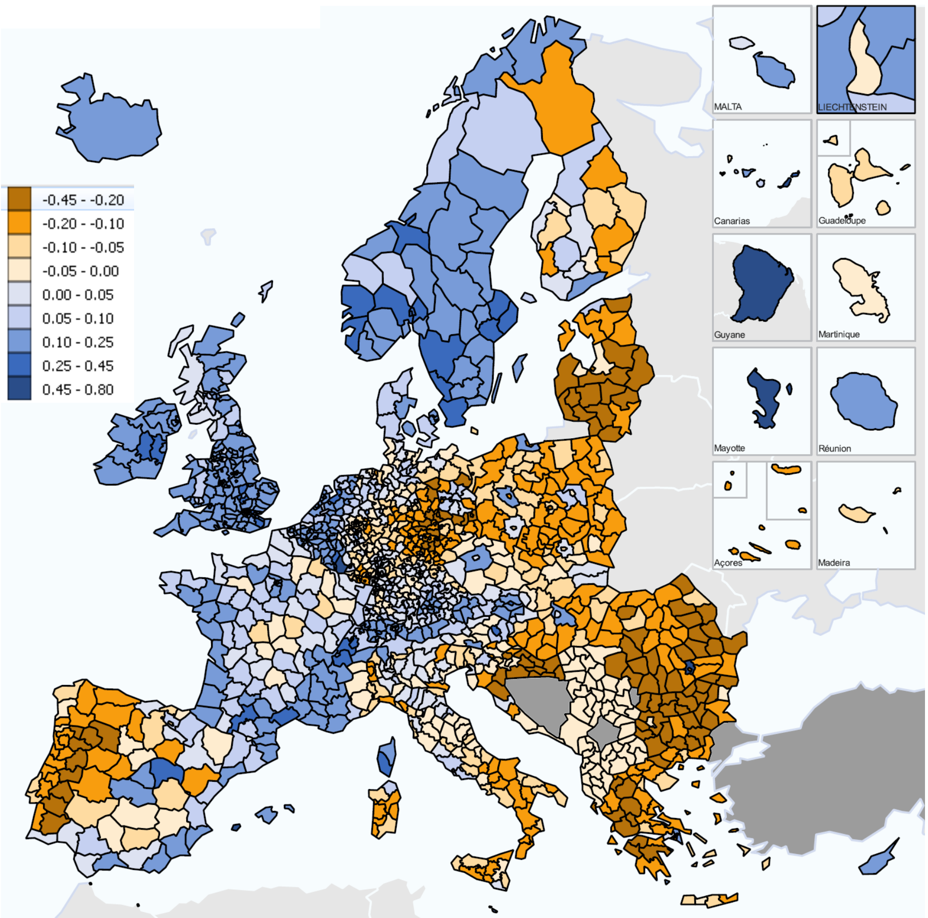


Figure 3: Estimated change of the population by NUTS3 regions, 2015 – 2050.

The heated net floor area of residential buildings is then derived by the net floor area per capita and the population of that region. For regions with currently low value added per capita (below 20 tds. Euros per capita and year), we consider an additional living space demand per capita in the future. For regions with a higher added value per capita in 2012 we assume a constant residential floor space per capita in the future (see Figure 44). For the development of the non-residential sector, we assume that the heated gross floor area increases (or decreases) with the population growth.

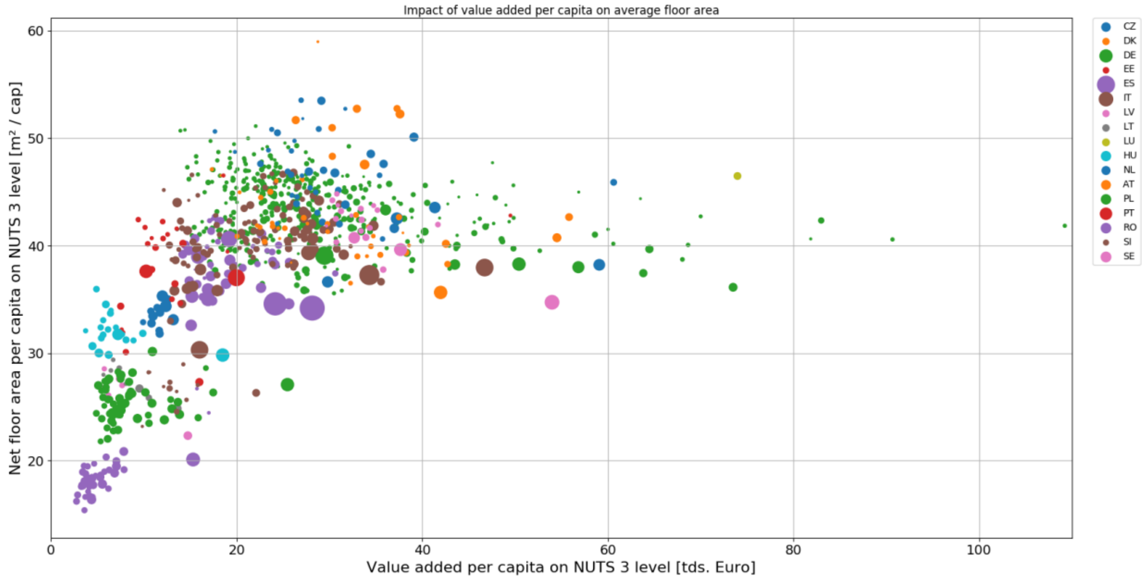


Figure 4: Correlation of economic activities and average net floor area per capita (base year 2012). (Source: Schremmer et al., 2017)

In a second step, we determine the building **demolition rate** per construction period and building type (small residential buildings: residential buildings with up to two apartments per building and row/terrace houses; medium and large residential building and non-residential buildings). Since statistical data on the construction period of non-residential buildings are currently not available, we assume that these building types have the same age distribution as medium and large residential buildings. We than apply the national demolition rate per building type and construction period (four different historical construction periods) on the NUTS 3 level.

The difference between the remaining floor area of existing buildings and the total demand derived in the first step based on the population constitutes the demand for **newly constructed buildings.** For most countries, the national annual demolition rates are currently in the range of about 0.3 – 0.5 %p.a., whereas the construction rate lies in the order of about 0.7 – 1.5 % p.a. If the population declines with a higher rate than the demolition rate, this leads to the situation that the existing buildings stock would fulfil the required demand for living space and the construction rate would subsequently drop to zero. To prevent this outcome, we add the condition that demolition rate needs to exceed the population decline rate of at least 0.2 %p.a., which gives a lower boundary for the annual construction rate of 0.2 %.

In a third step, the **refurbishment rate of the existing building stock** on the NUTS3 level is calculated from the national results. This step again draws on the national refurbishment rates per building type and construction period and transfer the development derived on the NUTS0 level to the NUTS3 level. For the refurbishment rate, we don't consider a lower bound as we do for the construction rate. Instead, we assume that the thermal renovation rate scales with the heating cost. We use the heating degree-days as indicator for the distribution of heating costs within each country. The total annual energy costs for heating derive from the energy consumption for space heating and domestic hot water production. If we leave the impact of different heating systems and energy carriers aside, then the energy costs follow the heating degree days (very roughly) with an elasticity of about 0.7[4]. Based on this correlation we calculate the refurbishment rate at the NUTS3 level $r_{refurb,NUTS3}$ (for a given building type and construction period and the current policy scenario where no enforced building renovation policies are in force) based on:

$$r_{refurb,NUTS3} = r_{refurb,NUTS0} \cdot \left(\frac{HDD_{NUTS3}}{HDD_{NUTS0}}\right)^{50\% \cdot 0.7} \cdot f_{corr} \, ,$$

where HDD denotes for the heating degree days, $r_{refurb,NUTS0}$ is the refurbishment rate at the national level and f_{corr} is a correction factor to ensure that the sum of the regional refurbishment activities is consistent with the national results.

The energy needs for space heating, domestic hot water preparation and air conditioning at the NUTS3 level is then derived by the energy needs of the remaining existing buildings stock corrected by the effects of thermal building renovation
(1-$r_{refurb,NUTS3}$) $\cdot$ $(energy\ needs\ after/energy\ needs\ before)$ plus the energy needs of the newly constructed buildings.

Transfer of NUTS 3 results to the spatial heat density map on 100*100 m level

For the spatial distributed building stock properties of the local building stock we can only draw on estimates of the population, covered plot area (for different periods) as well as the openstreetmap project database, which however doesn't cover all areas and all buildings. Furthermore, the historic development of the population below the NUTS3 level is not available or uncertain for a larger share of regions, especially since the borders of the local administrative units (LAU) changed considerable within the last 2 decades in many countries. Therefore, we have to make additional presumptions and simplifications regarding the local development.

A first presumption is that the population growth rate of a given LAU region compared to the development of the whole NUTS3 region depends on the population density on areas (hectare) with a sealed soil of the LAU region ($densPOP_{LAU}$) compared to this indicator of the NUTS3 region ($densPOP_{NUTS3}$).

$$gr_{LAU,t,t+1} = gr_{NUTS3,t,t+1} \cdot \left(\frac{densPOP_{LAU}}{densPOP_{NUTS3}}\right)^{\delta} \cdot f_{corr}$$

The factor f_{corr} ensures again that the sum of the local development amounts to the overall development, the elasticity δ defines the strength of this individual population growth. If δ is set to zero then all areas within a NUTS3 regions have the same growth rate, it $\delta > 0$, then population growth is higher in densely populated areas, which leads to an additional densification of the population, reflecting the phenomenon of increasing urbanisation.

The second presumption is that the building demolition rate (per construction period, see Figure 5) is uniformly distributed within a NUTS3 region. For the refurbishment rate, we apply the same approach

[4] Based on the energy demand for space heating and domestic hot water preparation. In colder regions, the elasticity is higher, in warmer regions (still continental Europe) the elasticity is in the range of 0.4 to 0.5. Furthermore, the elasticity is lower for more energy efficient buildings than it is for buildings with higher area specific space heat demand.

as used by the breakdown of the national results to the NUTS3 level. On a very local level this leads to the paradox situation that individual buildings will be only partly torn down or refurbished. This should be interpreted as probability distribution that buildings will be demolished or refurbished in a certain area.

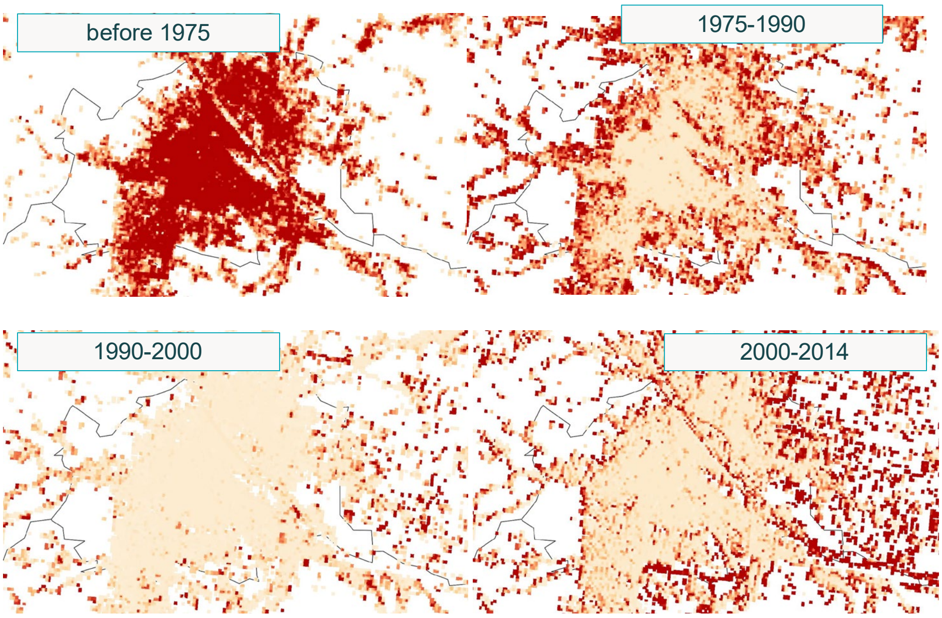


Figure 5. Estimated share of buildings per construction period for the region of Vienna. High shares (+75 %) are color-coded in red, low shares (<25%) in beige.

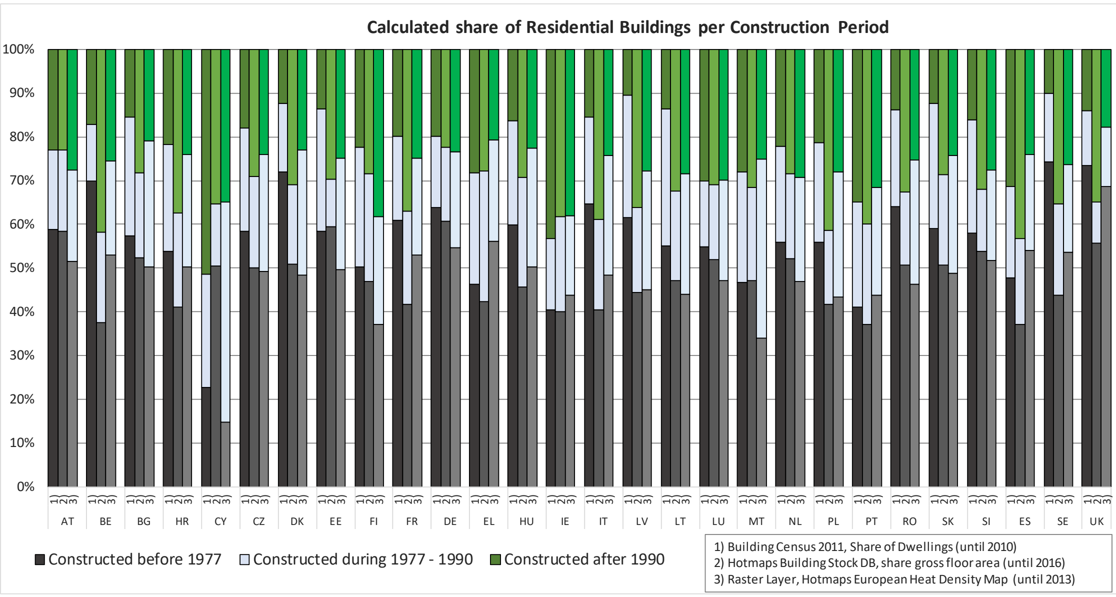


Figure 6. Comparison of the estimated share of residential floor area per construction period based three data sources for the Member states of the European Union.

In contrary to the existing building stock, there is no data for EU-28 where new buildings might be constructed in the future. Since spatial planning schemes are not available for EU28, new buildings could be constructed virtually on every suitable land plot. Therefore, rules how to distribute the new buildings need to be defined in our approach. In this project, we apply the following approach:

1. New buildings replace existing buildings, which were torn down according to the demolition rate.
2. The remaining share will be distributed between hectare cells on which buildings are already constructed (using the indicators: existing plot ratio and recent construction activities (past 15 years)), as well as hectare cells which, which have a low soil sealing and could be settled from its land cover type.

In the process of breaking down scenario data until 2030 and 2050 from NUTS3 to hectare level, we will define the share to which we will distribute newly constructed building among those possibilities, also taking into account calibration through Hotmaps pilot areas. By putting too much weight on the current plot ratio, the results will lead to an overestimation of the future heat densities and thus the suitability of district heating. The recent construction activities appear to be a plausible indicator for a few years. However, it's validity in the long run is not as obvious. From this point of view, we favour to set a higher weight on areas which are not settled or only partly settled but appear to be suitable for settlements based on Corine land cover data (Discontinuous urban fabric, Complex cultivation pattern) and are located next to current construction activities for the more distant future.

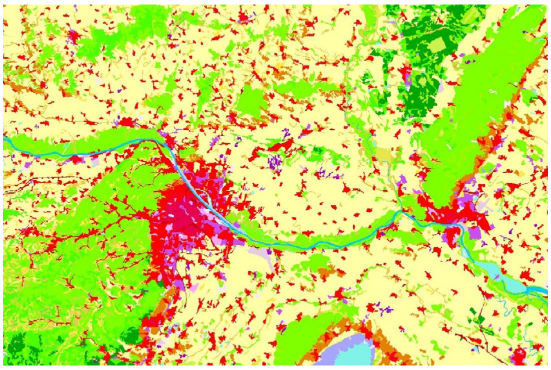


Figure 7. Corine land cover data on the information of land usage type on the hectare level. (Source: European Environment Agency (EEA), 2012)

The calculation of the energy needs for space heating and domestic hot water preparation will follow the same approach as described in the section above.

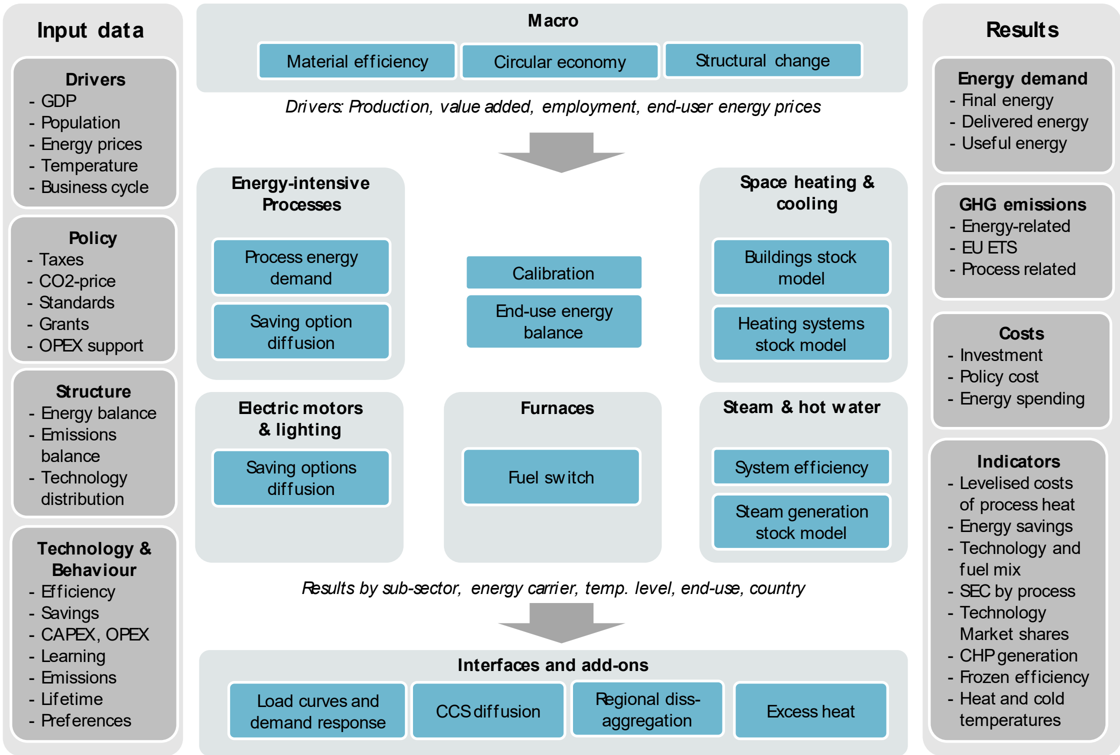
2.2 Industry related H/C demand and supply – Forecast-Industry

2.2.1 Methodology for national scenario development

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 addressing various 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.

FORECAST is a simulation model used to support investment decisions, taking into consideration barriers to the adoption of energy efficient technologies as well as various policy instruments such as standards, taxes and subsidies. Different approaches are used to simulate technology diffusion, including diffusion curves, vintage stock models and discrete choice simulation.

Figure 8 shows the simplified structure of FORECAST-Industry. Main macro-economic drivers are industrial production for over 70 individually modelled basic materials products, gross value added for less energy-intensive sub-sectors and the employment numbers. Five sub-modules cover: basic materials processes, space heating, electric motor systems, furnaces and steam systems.



Source: FORECAST

Figure 8: Overview of the bottom-up model FORECAST-Industry

For this study, the three sub-modules related to the CO2-intensive industries are of high importance:

1. **Energy-intensive processes**: This module covers 76 individual processes/products via their (physical) production output and specific energy consumption (SEC). The diffusion of about 200 individual saving options is modelled based on their payback period (Fleiter et al. 2013; Fleiter et al. 2012). Saving options can represent energy efficiency improvements, but also internal use of excess heat, material efficiency or savings of process-related emissions.
2. **Space heating and cooling**: Space heating accounts for about 9% of final energy demand in the German industry. We use a vintage stock model for buildings and space heating technologies.

The model distinguishes between offices and production facilities for individual sub-sectors. It considers the construction, refurbishment and demolition of buildings as well as the construction and dismantling of space heating technologies. Investment in space heating technologies such as natural gas boilers or heat pumps is determined based on a discrete choice approach (Biere 2015).

3. **Electric motors and lighting**: These cross-cutting technologies (CCTs) include pumps, ventilation systems, compressed air systems, machine tools, cold appliances, other motor appliances and lighting. The module captures individual units as well as the entire motor-driven system, including losses in transmission between conversion units. The diffusion of saving options is modelled in a similar way to the approach used for process-specific saving options.
4. **Furnaces**: energy demand in furnaces uses the bottom-up estimations from the module "energy-intensive processes". Furnaces are found across most industrial sub-sectors and are very specific to the production process. Typically, they require very high temperature heat. The furnaces module simulates price-based fuel switching using a random utility model (for more details, see (Rehfeldt et al. 2018)).
5. **Steam and hot water**: the remaining process heat (<500°C) is used in steam (and hot water) systems. The module covers generation and distribution of steam and hot water. For distribution, efficiency improvements for each scenario are based on available literature. Steam generation is modelled using a vintage stock model simulating the replacement of the entire steam generation technology stock. More than 20 individual technologies are taken into account including natural gas boilers, CHP units, biomass boilers, heat pumps, electric boilers and fuel cells. Fuel switch is determined as a result of competition among the individual technologies using the total cost of ownership (for more details, see (Biere 2015).

2.2.2 Methodology for regional breakdown

In this task, the national scenarios for industrial heating and cooling demand will be distributed regionally and locally. The development of industrial energy demand depends strongly on the sector, where the most energy intensive sub-sectors iron and steel, chemicals, non-metallic minerals and paper account for over 65% of the total heating and cooling demand in 2015. The regional scenarios will be based on the georeferenced database industrial sites developed in the Hotmaps project[5]. These site-specific emissions are used as a basis to break down the national energy demand into the regional distribution.

The industrial database developed in this project (https://gitlab.com/hotmaps/ industrial sites) includes industrial sites listed in the EU-ETS, E-PRTR and sectoral databases for energy-intensive sectors are included. With the E-PRTR database, the industrial sites can be georeferenced by coordinates. From the ETS database the greenhouse gases are used. The inclusion of sectoral databases adds information about the processes and annual production or production capacity from each site. As not all entries in the several databases can be matched to the other databases, the respective information is missing or needs to be completed by hand. Especially not all industrial sub-sectors can be included via sectoral

[5] https://gitlab.com/hotmaps/industrial_sites

databases, only energy intensive industries like steel, paper, glass, cement and chemicals industries. The distribution of sectors and emission across Europe is illustrated in Figure 9.

FORECAST Industry uses the national physical production in tonnes per year as a main driver for energy demand. As a distribution key to the individual sites, the physical production per process is a good indicator for site-specific energy demand. This implies that the process and the annual production of all industrial sites should be included in the database. As mentioned above, this is possible for energy intensive industrial sub-sectors, but not for all. Even for these sectors, some smaller plants could be missing.

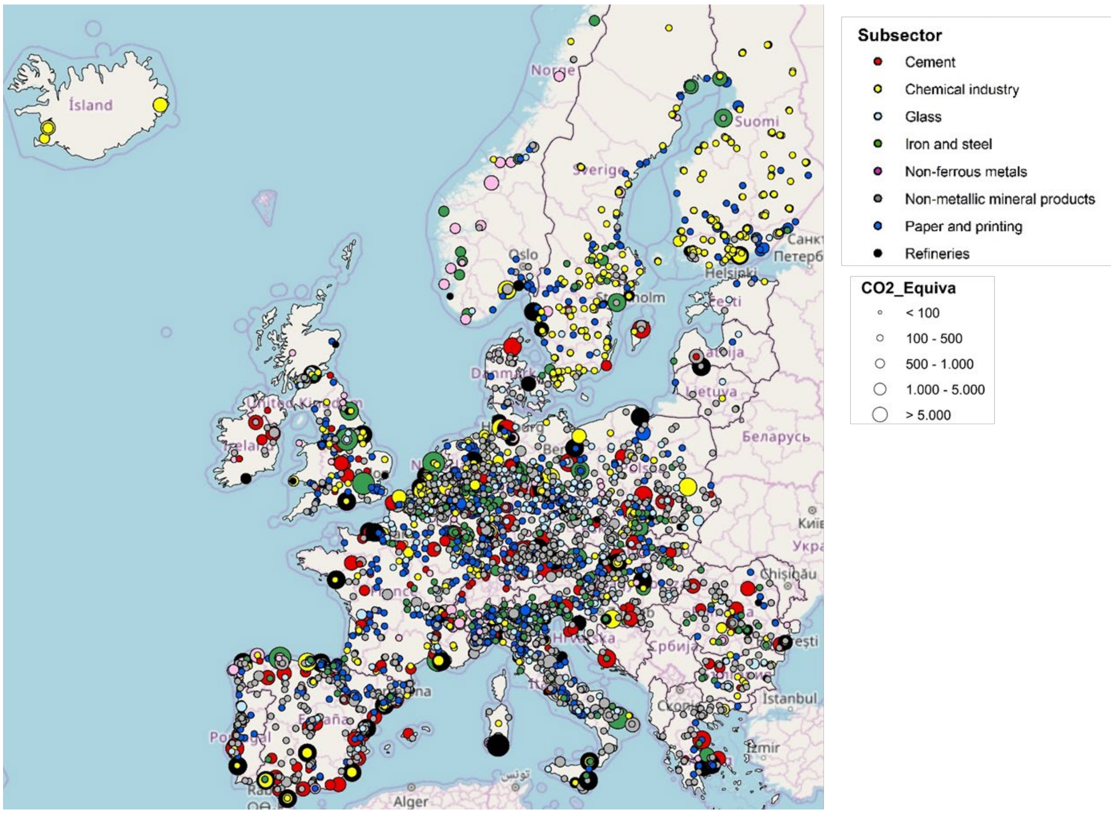


Figure 9: Industrial sites in the industrial database differentiated by subsector and emissions

The methodology for the breakdown of national industrial energy demand to the NUTS3 regions will therefore be different for the industrial sub-sectors, following two alternative methods, see Figure 10. First, for sub-sectors for which the physical production is known for almost all plants, the heating and cooling demand can be distributed based on the production data in the base year. In the time horizon until 2050 it should be stated that there are uncertainties about closure or opening of individual sites. As only the development of the production is projected based on the economic development, information about individual sites is lacking naturally. As it is impossible to predict these individual decisions of companies, it is decided to distribute the national development equally across the industrial sites of each sector. For example, if the cement industry has an increasing physical output until 2050, the individual sites have the same relative increase instead of opening another facility. Another case would be the change of a process or fuel switch. For decarbonisation of industry, a higher share of electric arc furnaces is needed. This change will happen as a binary decision. If a blast furnace reaches a certain age, it could be possible to switch to an electric arc furnace. This includes another dimension of distribution keys, as not only the physical production, but also the age of certain facilities plays a major role. For the steel sector, a stock model is applied in FORECAST industry, which can be also georeferenced by the database, as the age of the facilities is included from the sectoral database.

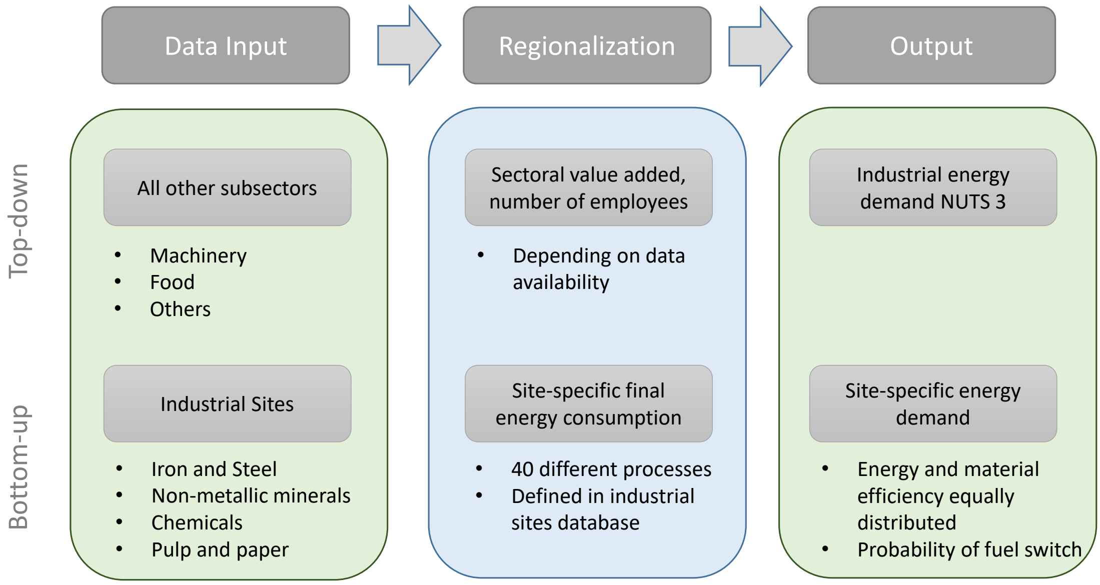


Figure 10: Methodology for regionalization of the energy demand, differentiated by industrial subsectors

Second, for sub-sectors, where no sectoral database is available, or it is not complete in terms of production capacity or age of facilities, the mentioned uncertainties can be much higher. Furthermore, it is not possible to distribute the energy demand of heterogeneous sectors to single industrial sites, where not all sites are included in the database. The reason for this could be that they do not emit greenhouse gases above the threshold value to be listed in the database, e.g. in the sectors machinery or food and tobacco. For these sectors another methodology needs to be chosen. The sectoral gross value added in the resolution of NUTS 3 level provides a suitable indicator for distributing the national energy demand. If that is not available for all countries, other indicators need to be chosen, e.g. number of employees or population density. Therefore, the industrial heating and cooling demand for those sectors is not available site-specific, only on a resolution of NUTS 3 regions.

2.3 Electricity generation and district heating mix

2.3.1 The applied modelling system: Green-X & Enertile

This analysis builds on modelling works undertaken by the use of TU Wien's Green-X model (cf. Box 1), closely linked to Fraunhofer ISI's Enertile model (cf. Box 2). More precisely, Green-X delivers a first picture of future RES developments under distinct energy policy trends, indicating details on technology trends (investments, installed capacities and generation) and the geographical distribution of RES deployment as well as related costs (generation cost), expenditures (capital, operation and support expenditures) and benefits (avoided fossil fuels and related carbon emissions). For assessing the interplay between RES and the future electricity market, Green-X was complemented by its power-system companion, i.e. the Enertile model. Thanks to a higher intertemporal resolution than in the RES investment model Green-X, Enertile enables a deeper analysis of the merit order effect and related market values of the produced electricity of variable and dispatchable renewables and, therefore, can shed further light on the interplay between supply, demand and storage in the electricity sector.

Box 1: Brief characterization of the Green-X model

> *Green-X is an energy system model that offers a* ***detailed representation of RES potentials and related technologies in Europe and in neighbouring countries****. It aims at indicating consequences of RES policy choices in a real-world energy policy context thanks to its comprehensive* ***incorporation of various energy policy instruments*** *including related design features. The model simulates technology-specific RES deployment by country on a yearly basis, in the time span up to 2050, taking into account the impact of dedicated support schemes as well as economic and non-economic framework conditions (e.g. regulatory and societal constraints). Moreover, the model allows for an appropriate representation of financing conditions and of the related impact on investor's risk. This, in turn, allows conducting in-depth analyses of future RES deployment and corresponding costs, expenditures and benefits arising from the preconditioned policy choices on country, sector and technology level.*

Box 2: Brief characterization of the Enertile model

> *Enertile is an energy system optimization model developed at the Fraunhofer Institute for System and Innovation Research ISI. The model focuses on the power sector, but also covers the interdependencies with other sectors, especially heating &cooling and the transport sector. It is used mostly for long-term scenario studies and is explicitly designed to depict the challenges and opportunities of increasing shares of renewable energies.*
> *A major advantage of the model is its* ***high technical and temporal resolution*** *– i.e. the model features a full hourly resolution: In each analysed year, 8,760 hours are covered. Since real weather data is applied, the interdependencies between weather regions and renewable technologies are implicitly included.*
> *Moreover, Enertile allows for a* ***full optimization of the investments into all major infrastructures of the power sector***[6]*, including conventional power generation, combined-heat-and-power (CHP), renewable power technologies, cross-border transmission grids, and flexibility options such as demand-side-management (DSM) and power-to-heat storage technologies. The model chooses the optimal portfolio of technologies while determining the utilization of these for all hours of each analysed year.*

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[6] For the purpose of this assessment, investments in RES technologies were taken from Green-X modelling. Thus, Enertile focussed on modelling complementary investment needs as well as power plant dispatch.

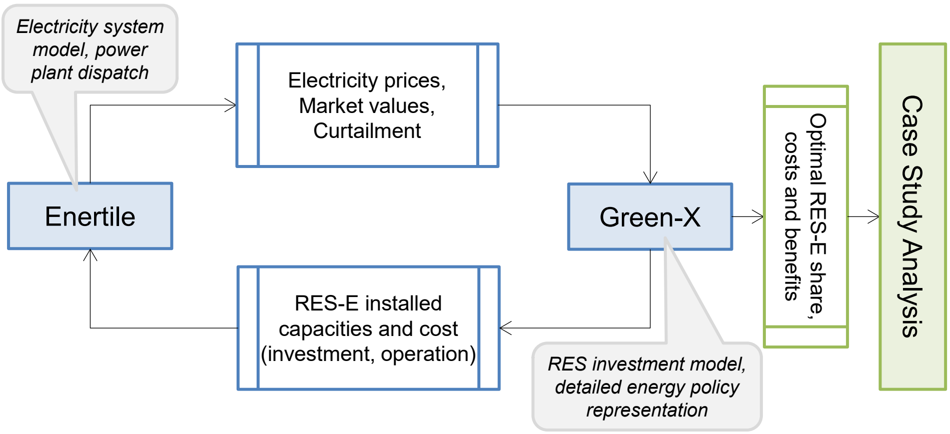


Figure 11: Model coupling between Enertile (left) and Green-X (right) for a detailed assessment of RES developments in the electricity sector

Figure 11 gives an overview on the interplay of both models. Both models are operated with the same set of general input parameters, however in different spatial and temporal resolution. Green-X delivers a first picture of renewables deployment and related costs, expenditures and benefits by country on a yearly basis (2010 to 2050). The output of Green-X in terms of country- and technology-specific RES capacities and generation in the electricity sector for selected years (2020, 2030 and 2050) serves as input for the power-system analysis done with Enertile. Subsequently, the Enertile model analyses the interplay between supply, demand, and storage in the electricity sector on an hourly basis for the given years. The output of Enertile is then fed back into the RES investment model Green-X. In particular, the feedback comprises the amount of RES that can be integrated into the grids, the electricity prices, and corresponding market revenues (i.e. market values of the electricity produced by variable and dispatchable RES-E) of all assessed RES-E technologies for each assessed country.

2.3.2 General input parameter and assumptions

In order to ensure maximum consistency with existing EU scenarios and projections the key input parameters of the scenarios presented in this report are derived from PRIMES modelling and from the Green-X database (www.green-x.at) with respect to the potentials and cost of RES technologies. As indicated in Table 13 (above), PRIMES comes into play for **energy demand developments** as well as **fossil energy and carbon price trends**. The specific PRIMES scenarios used are the latest publicly available reference scenario (European Commission, 2016f) and the climate mitigation scenarios PRIMES euco27 and PRIMES euco30 that build on the targeted use of renewables (i.e. 27% RES by 2030) and an enhanced use of energy efficiency (EE) compared to reference conditions – i.e. 27% (euco27) or 30% EE (euco30) by 2030, respectively. Please note that all PRIMES scenarios are intensively discussed in the EC's winter package, cf. the Impact assessment of the recast RED (SWD (2016) 410 final) (European Commission, 2016).

With respect to the underlying **policy concept and ambition level for RES and energy efficiency,** the following assumptions are taken for the assessed scenarios:

- *A common policy framework until 2020:* All scenarios build on common ground for the near future, i.e. the years up to 2020. Here, a strengthening of national RES policies is presumed, serving to meet the given 2020 RES targets. Each country uses national (in most cases technology-specific) support schemes in the electricity sector to meet its own 2020 RES target, complemented by RES cooperation between Member States in the case of insufficient or comparatively expensive domestic renewable sources. Please note that support levels are tailored to the national needs, in other words, they are generally based on the technology specific generation costs at country level.

- *A "least-cost" approach for RES post 2020:* For renewables, the default ambition level is set at 27% - i.e. ***achieving a RES share in gross final energy demand in size of at least 27% by 2030 and beyond***.[7] Conceptually, the scenarios follow a simplified policy concept for renewables: The underlying policy concept for incentivising RES can be characterised as a "least-cost" approach, enhancing an efficient use of RES for meeting the 2030 EU RES target in a cost-effective manner as outlined in Box 3.
  Please note that *this "virtual" policy concept matches perfectly with the objective of this case study*. Thus, the ***RES policy approach taken in modelling allows for deriving the optimal RES-E or RES-H share under given assumptions from a European least (policy) cost perspective*** – i.e. allowing for minimising support expenditures required for meeting a certain overall RES target by 2030 and beyond. Thus, the undertaken least cost allocation of the RES efforts to the available RES technologies across all energy sectors (electricity, heat, transport fuels) and countries (EU28 Member States) delivers an optimal RES deployment under given constraints.
- Concerning the role of *energy efficiency*, a moderate ambition level is presumed – i.e. in accordance with the PRIMES euco27 scenario, gross final energy demand is reduced by 27% in 2030 compared to baseline conditions.

Box 3: A least-cost approach to allocate investments in RES technologies post 2020

The selection of RES technologies in the period post 2020 in all assessed cases within this exercise follows a least-cost approach, meaning that all additionally required future RES technology options are ranked in a merit-order, and it is left to the economic viability which options are chosen for meeting the presumed 2030 RES target. In other words, a least-cost approach is used to determine investments in RES technologies post 2020 across the EU. This allows for a full reflection of competition across technologies and countries (incorporating well also differences in financing conditions etc.) from a European perspective. Support levels and related expenditures follow then the marginal pricing concept where the marginal technology option determines the support level (like in the ETS or in a quota/certificate trading regime, or similar to the concept of liberalised electricity markets).

[7] The overall RES target as presumed for 2030 – i.e. as default (at least) 27% RES share in gross final energy demand – is maintained in modelling as minimum target also for the period post 2030 (until 2050). Draft results show, however, that in all assessed scenarios the minimum target level is over fulfilled, meaning that RES deployment is then well above 27% in the years up to 2050.

2.4 Transport

2.4.1 Methodology for national scenario development

To simulate energy demand from the transport sector in 2050, the DIONE fleet impact model was used. DIONE is a tool for assessing key impacts of new road transport technologies (Thiel et al., 2016). The model consists of five modules: Stock, Cost, Mileage, Energy Consumption and Emission (for technical details about the model, see (EMISIA, 2014)).

Table 1: Vehicle categories, by powertrain

Powertrains	PC	LCV	HDV	Bus
Gasoline	X	X	X	
Diesel	X	X	X	X
FFV	X			X
LPG	X			
CNG	X			X
HEV	X			
PHEV / EREV	X			
BEV	X			
FCV	X			[8]

*Legend: **X** indicates that this option is available in DIONE. Source: DIONE model*

Four vehicle categories are included in DIONE: passenger cars (PCs), light commercial vehicles (LCVs), heavy-duty vehicles (HDVs), buses and two-wheelers. The latter is not included in this study. Table 1 shows powertrain availability in DIONE, for each vehicle category.

Table 2: Passenger car sizes, by engine capacity

Tiny	Small	Medium	Large
< 0.8 l	< 1.4 l*	1.4 l – 2.0 l	> 2.0 l

**Except for gasoline, which is defined as 0.8 l – 1.4 l because this powertrain also has the size 'tiny'.*

The calibrated base year in DIONE is 2010. For historical data, the model relies on TRACCS but adopts a classification based on engine capacity (for PCs, see Table 2). Electricity consumption factors were derived from real drive data from the Green eMotion project. For the future, DIONE follows the trends of PRIMES-TREMOVE 2012 (baseline scenario with adopted measures). DIONE can be used to construct scenarios until 2050, using an annual resolution. Table 3 shows powertrain availability by car size

[8] FFV: Flexible-fuel vehicle; LPG: liquefied petroleum CNG: Compressed natural gas vehicles; HEV: hybrid electric vehicle; PHEV/EREv: plug-in hybrid electric vehicle/extended-range electric vehicle; BEV: battery electric vehicle; FCV: fuel cell vehicle

Table 3: Passenger car sizes, by powertrain

Powertrains	Tiny	Small	Medium	Large
Gasoline	X*	X	X	X
Diesel		X*	X	X
FFV			X	
LPG		X	X	X
CNG		X	X	X
HEV			X	X
PHEV / EREV			X	
BEV			X	
FCV			X	

**Included in DIONE, but set to zero in the baseline scenario. Source: DIONE model*

2.4.1 Methodology for regional scenario development

The historical data points are extrapolated based on future trends for selected indicators: vehicle stock (NUTS1), energy demand (NUTS1), GDP/capita (NUTS3), population density (NUTS3) derived from the PRIMES –TREMOVE EU 2016 reference scenario and DIONE model. The geographical datasets on boundaries of NUTS 3 regions was obtained from the GISCO database (GISCO, 2018). Each of parameters was afterwards inserted in the GIS database using ArcGIS 10.4© software in layers as polygons, out of which the grids with a 8000 × 8000 m size of raster cell is created.

3 Heating & Cooling scenario outlook until 2050

In this chapter we describe the model based scenario results on country level for the building sector (chapter 3.1), the industry sector (chapter 3.2), district heating and electricity generation (chapter 3.3) and transport (chapter 3.4).

We will apply the structure of a factsheet for outlining and communicating the key characteristics, assumptions as well as input and output data of the scenarios. These fact sheets will also be uploaded as meta-data description in the GitLab data repository. The user of the toolbox will be able to download more detailed country and region specific data from the toolbox. Moreover, it is planned to upload additional scenarios later in in the project in the Hotmaps data repository (https://gitlab.com/hotmaps/). More details (beyond these two pages) should be provided as additional text in this report. However, only the fact sheet information will be uploaded in GitLab for the scenario characterisation.

3.1 Space heating, hot water and cooling in residential and non-residential buildings

This chapter presents scenario data for space heating, hot water and cooling in residential and non-residential buildings on country level for EU-28 until 2050. We show two scenarios: (1) A current policy scenario, assuming that currently existing policies remain in place and (2) a more ambitious policy scenario with moderately enhanced climate mitigation policies. However, also the second scenario is not a really strong decarbonisation scenario in line with Paris COP 21 targets. Stronger decarbonisation scenarios will be added later during the project duration to the Hotmaps data repository.

Both scenarios on the country level are based on scenarios developed in the H2020 project SET-Nav (http://www.set-nav.eu/).

Factsheet Scenario “Current policies”. Space heating, hot water and cooling in residential and non-residential buildings.

The current policy scenario assumes that current policies remain in place and are effectively implemented. In particular, we assume that in general building owners and professionals comply with regulatory instruments like building codes. National differences in the policy intensity continue to exist.

Policy intensity for RES-H

low moderate high

Policy intensity for buildings’ efficiency

low moderate high

Policy intensity for district heating

low moderate high

The policy intensity bars indicate qualitatively the range of policy ambition in different countries. The policy mix corresponds to the current packages in place, which in most countries is a mix of regulatory approaches (building codes,nearly zero energy buildings (nZEB) definitions, RES-H obligation), economic support (subsidies for building refurbishment and RES-H), energy taxation. Main sources for implemented policies are the Mure database (www.measures-odyssee-mure.eu/) and the projects ENTRANZE (www.entranze.eu/) Zebra2020 (www.zebra2020.eu/).

Energy prices

low moderate High

Energy prices increase moderately according to EU Reference Scenario 2016 (https://ec.europa.eu/energy/en/data-analysis/energy-modelling). The price increase lead to additional incentives for building renovation and renewable heating systems.

Technology development

low moderate high

The assumed technological learning is low and costs for efficient and renewable heating/cooling technologies only slightly decrease.

Results

Total final energy demand for space heating, hot water and cooling in EU-28 decreases from 3815 TWh (2012) to 2754 TWh (2050). This is mainly driven by a reduction of space heating energy demand (-39%), whereas final energy demand for hot water slightly increases (+8%). The energy demand for cooling strongly grows (+210%), resulting in a share on the sectoral final energy demand of about 8% across the EU-28 in 2050.

The share of decentral renewable heating increases from 15% (2012) to 37% (2050), where biomass keeps its leading role, while solar and ambient heat strongly increase their shares.

Figure 12 reveals significant differences in the energy supply structure in the base year 2015 in the sector, which also has a strong impact on the evolution until 2050 in this scenario. The challenge for decarbonisation is particularly high in countries like UK, IE or NL with a current (2015) share of fossil energy carriers, and only some of these achieve a strong reduction of fossil energy use. District heating shows strong inertia in this scenario. Due to a lack of stringent policies, in particular in countries with currently low district heating share, in most countries leads to only moderate growing – in some countries even declining – share of district heating. The latter one is the case in Eastern European countries where recent years have shown difficult framework conditions for new investment in outdated district heating infrastructure, which is prolonged in this scenario.

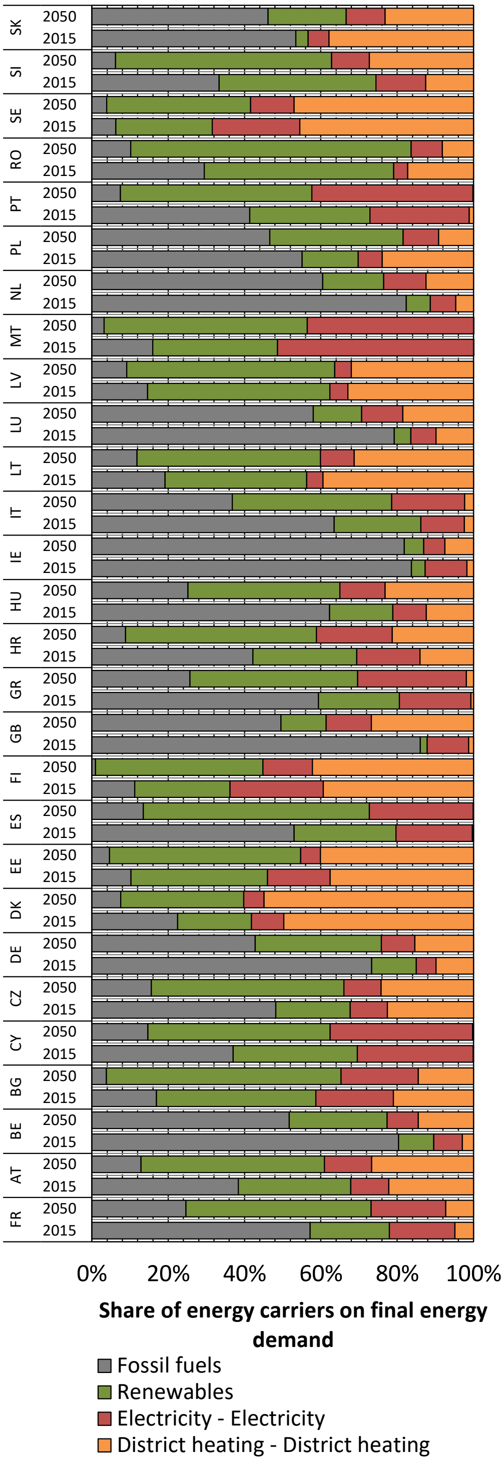


Figure 12. Energy carrier mix for space heating, hot water and cooling in EU-28 2015 and 2050 in the current policy scenario.

Factsheet Scenario “Ambitious policies”. Space heating, hot water and cooling in residential and non-residential buildings.

The ambitious policy scenario assumes that moderate, more ambitious policies are implemented. In particular, we assume that in general decision makers comply with regulatory instruments like building codes. National differences in the policy intensity continue to exist.

Policy intensity for RES-H

low	moderate	high

Policy intensity for buildings’ efficiency

low	moderate	high

Policy intensity for district heating

low	moderate	high

The policy intensity bars indicate qualitatively the range of policy ambition in different countries. The policy mix corresponds to policies discussed by policy makers in various projects (e.g. Zebra2020 (www.zebra2020.eu/).The assumed future policy packages foresee a strengthening of existing schemes, leading to a continued mix of regulatory approaches (building codes, nZEB definitions, RES-H obligation), economic support (subsidies for building refurbishment and RES-H), energy taxation. Enhanced policies build on the existing state of policies, which is the reason for the continuation of divergence of climate and energy policies in the building sector. Main sources for currently implemented policies are the Mure database (www.measures-odyssee-mure.eu/) and the projects ENTRANZE (www.entranze.eu/) Zebra2020 (www.zebra2020.eu/).

Energy prices

low	moderate	High

Energy prices increase moderately according to EU Reference Scenario 2016 (https://ec.europa.eu/energy/en/data-analysis/energy-modelling). The price increase lead to additional incentives for building renovation and renewable heating systems.

Technology development

low	moderate	high

The assumed technological learning is moderate and costs for efficient and renewable heating/cooling technologies decrease slowly.

Results

Total final energy demand for space heating, hot water and cooling in EU-28 decreases from 3815 TWh (2012) to 2483 TWh (2050). This is mainly driven by a reduction of space heating energy demand (-48%), whereas final energy demand for hot water slightly increases (+11%). The energy demand for cooling strongly grows (+232%), resulting in a share on the sectoral final energy demand of about 9% across the EU-28 in 2050.

The share of decentral renewable heating increases from 15% (2012) to 41% (2050), where biomass keeps its leading role, while solar and ambient heat strongly increase their shares.

Figure 13 reveals significant differences in the energy supply structure in the base year 2015 in the sector, which also has a strong impact on the evolution until 2050 in this scenario. The challenge for decarbonisation is particularly high in countries like UK, IE or NL with a current (2015) share of fossil energy carriers, and only some of these achieve a strong reduction of fossil energy use. District heating shows strong inertia in this scenario. The policy assumptions supporting district heating are not ambitious enough to drive this sector to a strong contributor of climate mitigation. In particular in Eastern European countries, the role of district heating is even slightly declining even in this more ambitious policy scenario.

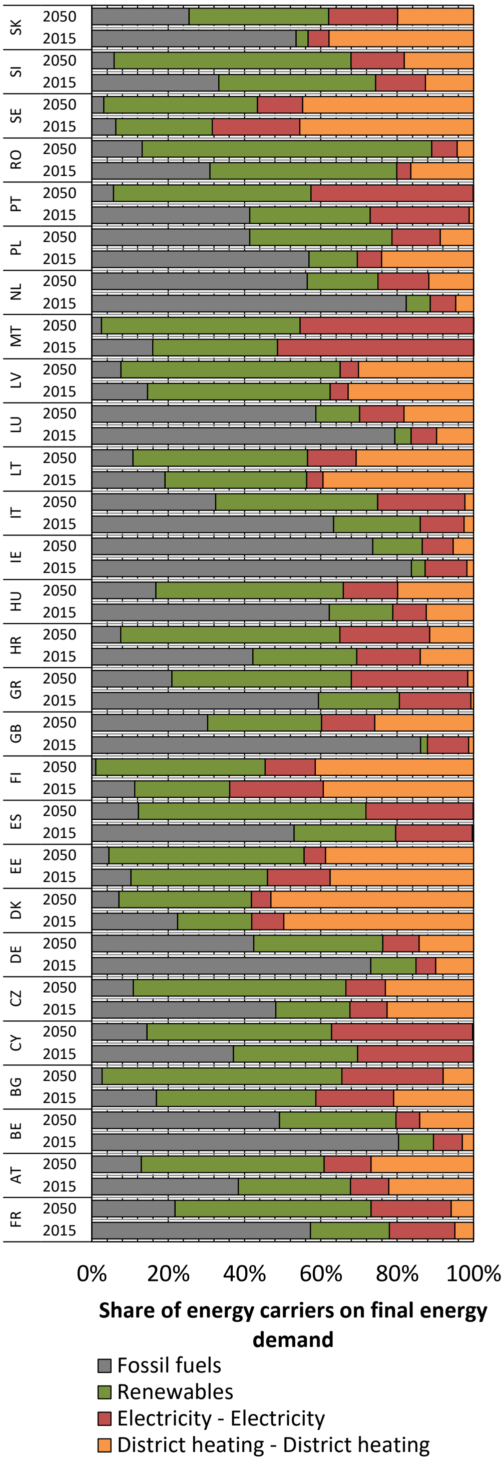


Figure 13. Energy carrier mix for space heating, hot water and cooling in EU-28 2015 and 2050 in the ambitious policy scenario.

3.1.1 Scenario specification

In addition to the short characterisation of the scenarios in the fact-sheets above, we present additional policy assumptions below.

Current-policy scenario

The current policy scenario incorporates decided or already implemented targets or measures concerning the diffusion of renewable heating and cooling and energy efficiency measures in building envelopes.

The implementation of the policy measures is specified per country and therefore depends on the country specific implementation of the policy programs shown in Table 1 (e.g.: importance of investment subsidies for renovation actions or mandatory building codes). Also monetary incentives for building renovation investment subsidies, ranging from about 10% to 40% of the investment subject to overall budget restrictions are implemented among member states.

As the main source for implemented policies the Mure database (www.measures-odyssee-mure.eu/) and findings from the ENTRANZE (www.entranze.eu/) as well as Zebra project (www.zebra2020.eu/) and (Fleiter et.al 2016) were used. For countries, which were not within the scope of the conducted surveys, or which have a rather small impact on overall scope of the EU28 the measure definition was done by scaling of measures from focus countries with similar characteristics.

Intensified building codes, reflecting the improvement of technical building standards for new and renovated buildings (building envelope) as far as they may be expected according to the national implementation of the EPBD (nZEB standards), were implemented by adjustment of the thermal quality of the main parts of buildings through tightening of the u-value definition. Policy driven changes of building codes were implemented on country level, covering about 80% of the European building stock.

Monetary measures for heating systems were implemented as investment subsidies, for each heating system, ranging from about 20% to 40%, restricted by overall public budget per member state.

In some member states also renewable heating obligations are implemented as share on the final energy demand per household which has to be covered by renewable sources, ranging from 20% to 50%.

An overview of the different policies targeting energy efficiency and RES in the end-uses categories space heating and cooling as well as domestic hot water heating considered in the current-policy scenario is given in Table 1.

Table 4: Overview of policy measures implemented in the current policy scenario

Regulations / Information	EU leg.	Current-policy scenario
Energy efficiency standards for renovation	EPBD	National building code requirements, 2015 or planned tightening as far as data available
Energy efficiency standards new buildings	EPBD	National implementation of NZEB standards after 2018 (for public buildings) and 2020 (for all buildings). Development of building codes until 2018/2020 according to national action plans for nZEBs.
Increase of renovation rate	EED	3% renovation rate achieved until 2020 in central government buildings. Renovation obligations in case of real estate transactions as far as they are currently implemented in some Member States.
RES obligation	RED	Current implementation in Member States (only for new buildings in few countries)
Technology standards	EDD	MEPS for all lots for which regulations have been implemented before 29 February 2016:
Support of CHP and DHC	EED	Realization of lower limit of economic feasible CHP and DHC potentials
Energy labelling	ELD	Mandatory for new H/C devices
Energy saving obligation	EED	Current implementation in Member States with regard to applicable and supported technologies
Energy and CO2 taxation	ETD	Taxes varying by fuel and sector
Subsidies for building renovation	National	Ongoing subsidy programs (MURE-DB)
Subsidies for efficient fossil fuel technologies	National	Ongoing subsidy programs (MURE-DB)
Subsidies for RES technologies	National	Ongoing subsidy programs (MURE-DB)

Ambitious policy scenario

In the ambitious policy scenario, policy instruments implemented in the current-policy scenario were intensified in order to evaluate the potential of the existing policy schemes. The policy approach regarding the applied set of instruments remain the same. Based on the implementation of policy instruments described above, modifications on the main drivers of building renovation and deployment of renewable heating systems were carried out.

The subsequently provided list of policy measures used for ambitious building stock development scenarios contains the variety of measures that were applied. Taking into account already implemented instruments and assumptions under current policy scenario conditions, a country specific mix of the following measures was utilized.

- Increased investment subsidies for thermal retrofit: to increase energy efficiency in the building stock by achieving higher renovation rates, subsidy rates for thermal retrofit were adjusted. For standard and low-level refurbishments the subsidy regimes in place were kept on the same level or moderately increased. For more ambitious renovation measures towards nearly zero energy building standards, subsides were substantially raised, ranging from 30% to 40% of investment costs.

- Subsidy budgets for investments in thermal retrofit: annual budget restrictions for investment subsidies in place in the current policy scenario were increased.
- Improvement of building performance standards: assuming the development of stricter building performance requirements regarding thermal quality of the building envelope, the thermal quality specification of building parts for renovation measures were adjusted by reducing heat transfer coefficients of building components after refurbishment and for new buildings.
- Cost developments: under the assumptions of technological learning, slightly decreasing costs for ambitious renovation measures were applied.
- The depreciation time for ambitious renovation measures was increased, while under the assumption of upcoming necessity to reach regulatory building performance requirements depreciation time for maintenance measures was decreased. This reflects also improvements in long-term attractive financing schemes of energy efficiency schemes.
- Increased investment subsidies for heating systems: to reach higher market penetration and heating system exchange rates towards renewable heating technologies, subsidies for biomass heating systems, air- and to a higher extent ground source heat pumps, solar thermal systems were increased; to some extent and under certain conditions, existing subsidies for fossil powered condensing boilers still remain in place.
- Subsidy budgets for heating system investments: annual budget restrictions for investment subsidies in place in the current policy scenario were increased
- Renewable heat obligation: applied obligations for the deployment of renewable heat sources to a certain share in case of heating system exchange were increased moderately.

The design of ambitious scenario assumptions was carried out as a generic approach of intensifying already defined country specific measure bundles. As the purpose was the evaluation of the potential of existing measure schemes, no overarching goal, like specific CO_2-emission reduction goals was pursued. The results show that the described policy set is not sufficient to achieve strong decarbonisation targets.

3.1.2 Scenario comparison and conclusions

This section provides an overview of aggregated results for total final energy demand of space heating, hot water and cooling. Results are shown for the EU28 building stock, although model runs have been performed for each member state separately.

Development of the final energy demand for heating and cooling in total

Figure 14 and Table 2 show the modelling results for total final energy demand in the EU28 member states from 2012 to 2050 for the current and ambitious scenario, differentiated by the main end use categories domestic hot water, space heating, cooling and auxiliary devices. In both scenarios total final energy demand is expected to decrease significantly.

In the current policy scenario final energy demand is expected to decrease from 3815 TWh in 2012 to 2754 TWh in 2050 which corresponds to a decrease of around -28%. The more ambitious policies implemented in the model lead to a further decrease to 2483 TWh in 2050 which is equivalent to a -35% reduction of final energy demand. In both scenarios the decrease is a result of increased investments in the thermal efficiency of the European building stock, which lead to lower space heating demand. Space heating accounts for about 84% of the overall heating demand and cooling demand in 2012, which amounts to about 3204 TWh, whereas hot water accounts for around 13% (497 TWh).

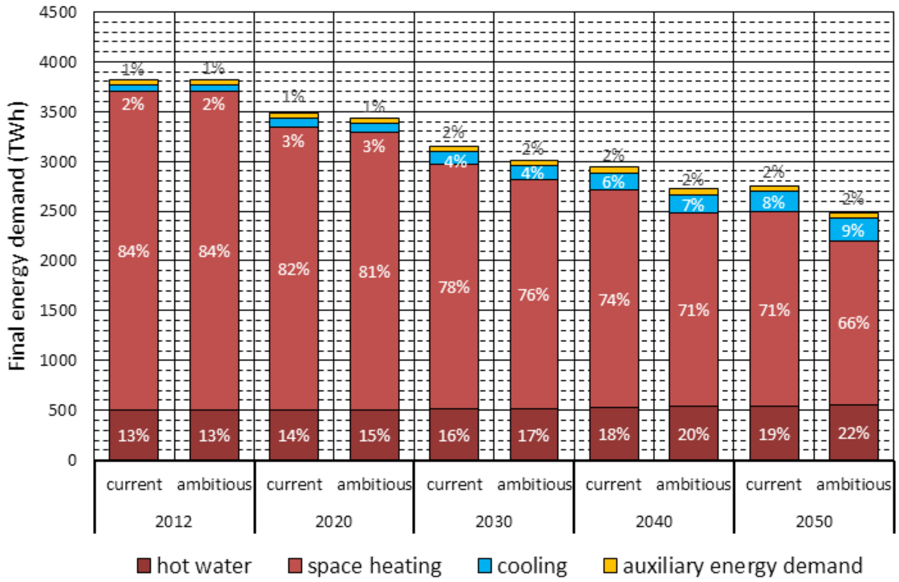


Figure 14: Total final energy demand by end use types for current and ambitious policy scenario for EU28 in TWh

Table 5: Final energy demand by usage types in TWh and change of final energy demand by usage types for current and ambitious scenario in % for EU28

Final energy demand (TWh)	hot water		space heating		cooling		auxiliary energy demand		TOTAL	
Scenario	current	ambitious	current	ambitious	current	ambitious	current	ambitious	current	ambitious
2012	497	497	3204	3204	67	67	47	47	***3815***	***3815***
2020	500	503	2847	2786	88	90	51	50	***3485***	***3429***
2030	512	519	2457	2297	127	135	55	54	***3150***	***3005***
2040	526	538	2187	1942	171	184	57	56	***2941***	***2720***
2050	536	554	1953	1651	207	222	58	56	***2754***	***2483***
Share 2012	13%	13%	84%	84%	2%	2%	1%	1%	100%	100%
Share 2050	19%	22%	71%	66%	8%	9%	2%	2%	100%	100%
Change 2012/2050	8%	11%	**-39%**	**-48%**	210%	232%	23%	20%	***-28%***	***-35%***

The decrease of the space heating demand is modelled to be around -39% in the current and -48% in the ambitious scenario. Hot water demand is expected to increase by about 8% (current scenario) and 11% respectively (ambitious scenario) due to population growth. This leads to an increase in the end use share for hot water from 13% to 19% (current scenario) and 13% to 22% (ambitious scenario) respectively. The results suggest that while energy demand for hot water and auxiliary devices stay rather constant in absolute terms, a noticeable shift in the total shares from space heating to water heating can be observed.

Table 2 reveals that final energy demand for space cooling, which is assumed to be covered by electricity, increases significantly from 67 TWh in 2012 to more than 200 TWh in 2050. The share of space cooling in total energy demand for heating and cooling the EU28 building stock increases from around 2% in 2012 to around 8%-9% in 2050 indicating that space heating and hot water will still account for the main share of final energy demand, despite the strong increase in cooling needs. It should also be noted that the development of electricity demand for cooling is mainly driven by the diffusion of air conditioning systems in Europe, which is subject to high uncertainties.

Figure 15 and Table 3 illustrate the development of final energy demand per energy carrier. Figure 16 shows the corresponding shares for each scenario. It can be clearly seen that fossil energy carriers decrease substantially in both scenarios.

Fuel oil and coal nearly disappear from the heat generation mix and are mainly substituted by biomass boilers, but also heat pumps and solar thermal systems. Despite a significant decrease gas demand of around -52% to -63%, natural gas still makes up for a large share of heat supply until 2050 in both scenarios. Even in the ambitious policy scenario natural gas is expected to account for around 25% of final heating and cooling supply in the EU28 building stock.

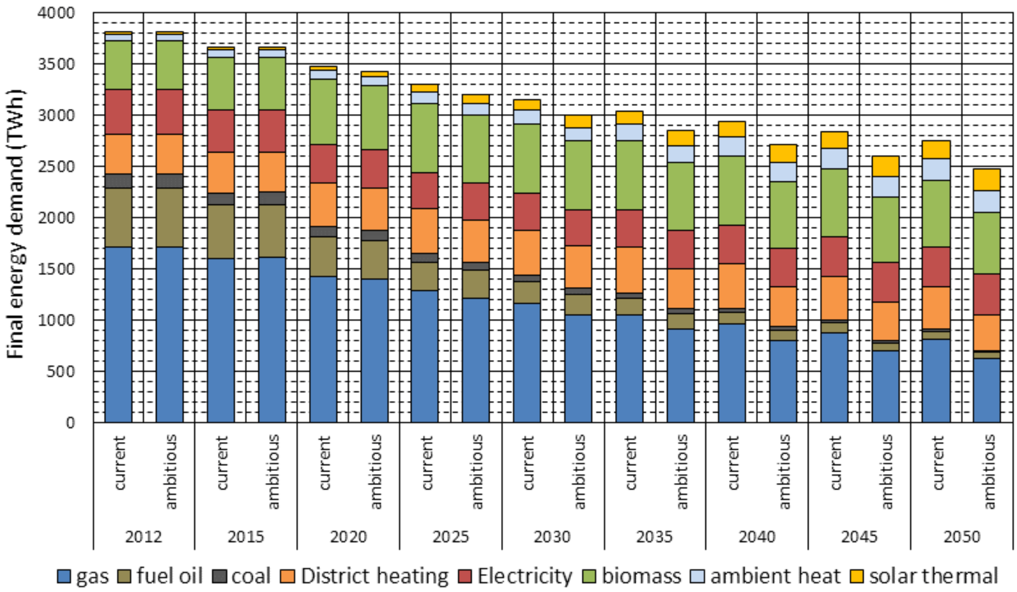


Figure 15: Total final energy demand by energy carrier for current and ambitious scenario for EU28 in TWh

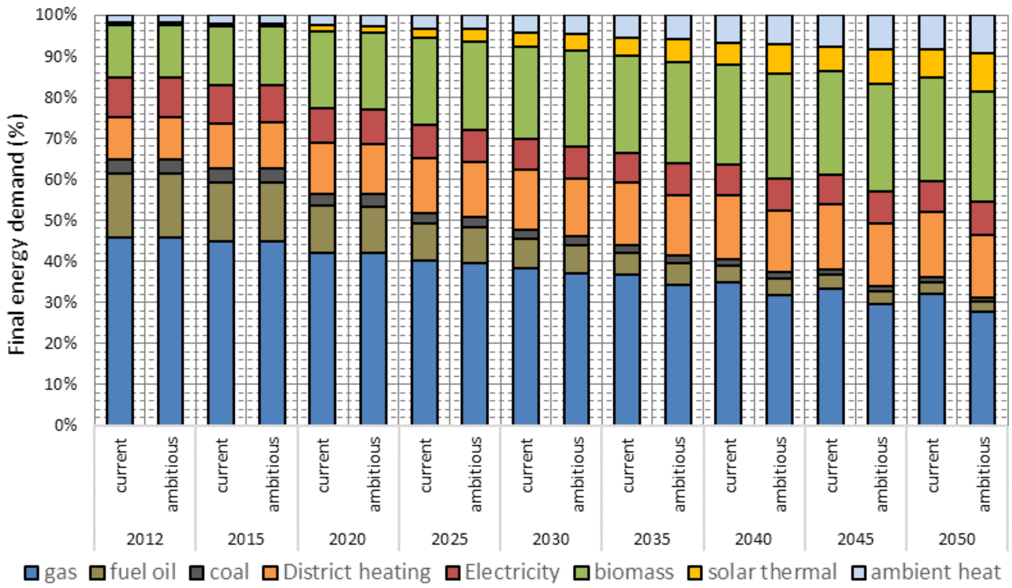


Figure 16: Share on total final energy demand per energy carrier for current and ambitious scenario for EU28 in %

Although district heating is expected to increase its market share in both scenarios, total energy demand from district heating networks in these scenarios remains rather constant (slight increase in current, moderate decrease in ambitious scenario) due to higher efficiencies of connected buildings.

Table 6: Final energy demand by energy carrier for current and ambitious scenario for EU28 in TWh and corresponding shares in %

Final energy demand	2012		2050				2050	2050
Scenario			current		ambitious		current	amb.
unit	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(+/- %)	(+/- %)
Gas	**1717**	45%	**819**	30%	**627**	25%	-52%	-63%
Fuel oil	**580**	15%	**74**	3%	**59**	2%	-87%	-90%
Coal	**133**	3%	**26**	1%	**18**	1%	-80%	-86%
District heating	**388**	10%	**408**	15%	**349**	14%	+5%	-10%
Electricity	**431**	11%	**397**	14%	**402**	16%	-8%	-7%
Biomass	**480**	13%	**643**	23%	**603**	24%	+34%	+26%
Ambient heat	**67**	2%	**216**	8%	**209**	8%	+225%	+213%
Solar thermal	**20**	1%	**172**	6%	**216**	9%	+766%	+988%
TOTAL	3815	100%	2754	100%	2483	100%	-28%	-35%

Electricity demand for heating and cooling in European buildings is expected to stay more or less constant, or slightly decreases (-7% to -8%). However, there is a noticeable shift from space heating to space cooling, which can be seen in Figure 17. Electricity demand for space heating and hot water supply in the two scenarios decreases by around -60% until 2050, despite a significant increase of market shares of electricity powered heat pumps that allow for exploiting ambient heat for space heating and hot water supply. Heat pumps are expected to be deployed in particular in new buildings but also as substitution of existing direct electric heating systems. According to our model results, cooling would account for about 61%-64% of the electricity demand for heating and cooling in 2050.

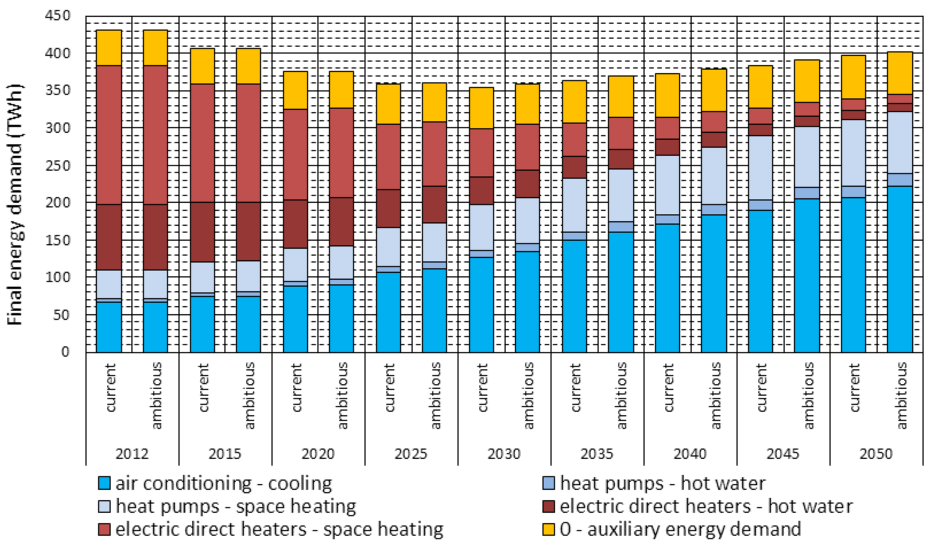


Figure 17: Total electricity demand heating and cooling for current and ambitious scenario for EU28 in TWh

In both scenarios the share of biomass doubles from 13% in 2012 to around 23% (current policy) to 24% (ambitious policy) in 2050. Total biomass use for decentral heating increases by +34% in the current policy scenario and +26% in the ambitious policy scenario until 2050. The increased thermal efficiency of the building stock in the ambitious policy scenario therefore also helps to conserve limited biomass resources. Biomass is as a valuable renewable energy carrier for higher temperature levels needed in other sectors for ambitious decarbonisation targets.

Figure 18 shows the results for total final energy demand only for space heating and Figure 19 for domestic hot water. It can be seen, that the increase in supply from renewables for water heating is covered by solar thermal systems to a large extent which are assumed to be installed in combination with other heating systems. Figure 19 also indicates that the additional subsidies in the ambitious policy scenario are expected to significantly support the uptake of solar thermal systems. Note that electricity generation from on-site PV systems are included in final energy demand for electricity in these illustrations.

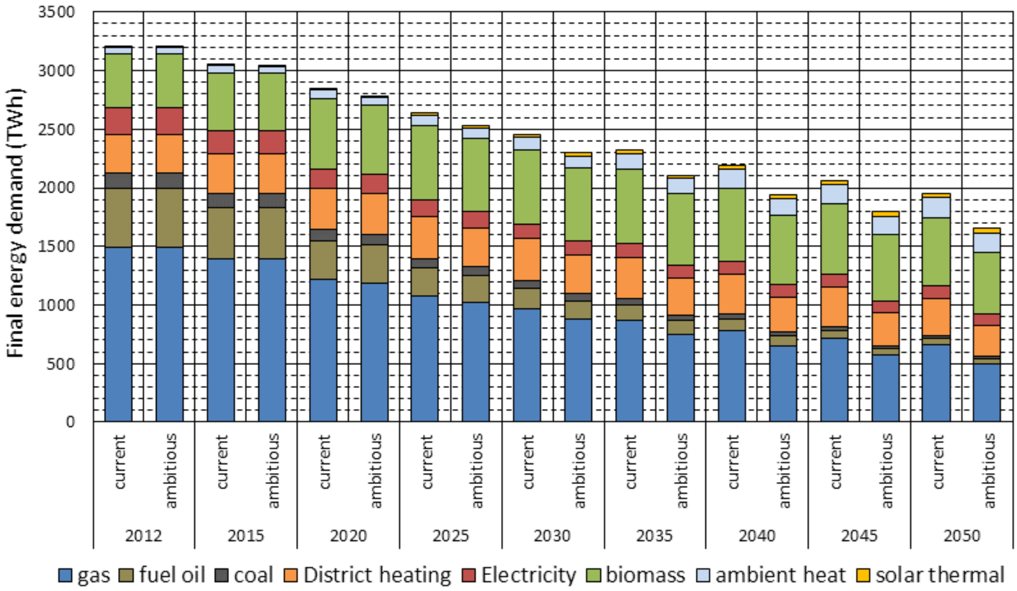


Figure 18: Total final energy demand for space heating by energy carrier for current and ambitious scenario for EU28 in TWh

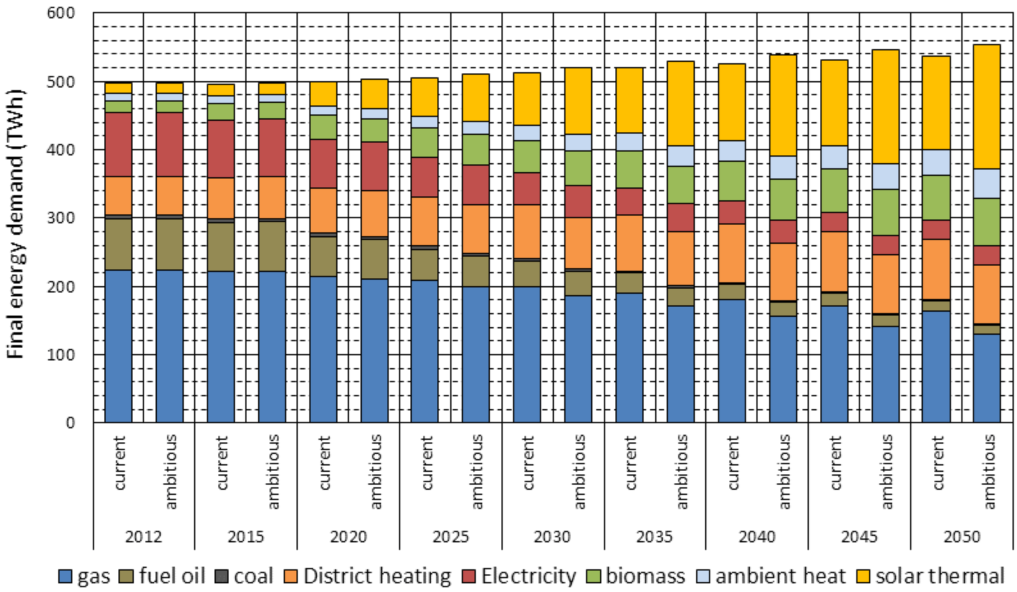


Figure 19: Total final energy demand for water heating by energy carrier for current and ambitious scenario for EU28 in TWh

Figure 20 summarizes the results by showing aggregated shares of fossil and renewable energy carriers as well as shares of the secondary energy carriers electricity and district heating in final energy supply for heating and cooling. The share of fossil energy carriers is strongly reduced from 64% in 2012 to 33% in 2050 for the current policy scenario settings and 28% in the ambitious policy scenario, respectively. Note that natural gas accounts for more than 90% of fossil energy carriers in 2050 because, as described above, coal and fuel oil in our model remove due to the implemented policies and assumptions on energy price developments. Renewable energy carriers (biomass, ambient heat and solar thermal) are expected to increase from their share from 15% in 2012 to 37% in the current policy scenario and 41% in the ambitious policy scenario. The increasing shares of final energy supply from electricity are a result of increasing cooling demand while the share of electricity supply for heating decreases in the scenarios. The share of district heating according to our model results increases from 10% to 15% in the current policy and 14% in the ambitious policy scenario respectively.

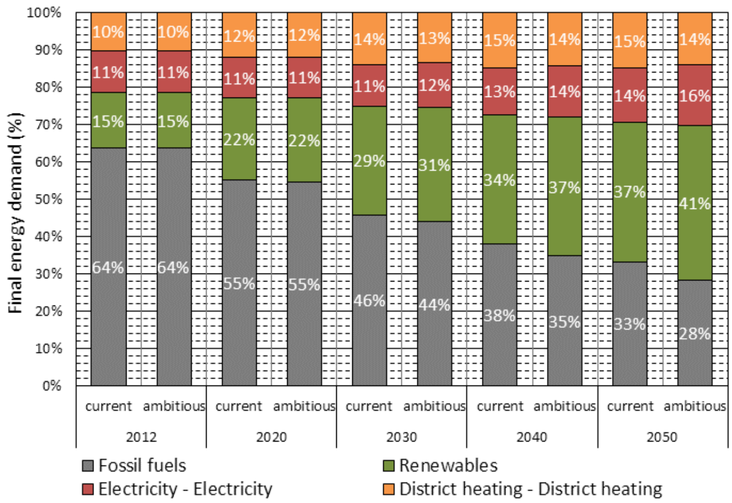


Figure 20: Shares of fossil fuels, renewables, electricity and district heating on final energy demand for space heating, hot water and space cooling supply in EU28 until 2050

It has to be noted that also heat from district heating and electricity is partly supplied by renewable energy carriers. The total share of renewables in primary energy for heating and cooling depends on developments in the energy carrier mix for electricity and district heating which is not modelled in INVERT/EE-Lab. With respect to CO_2 emission reductions the results indicate that while emissions decline significantly, reductions of more than -80% until 2050 constitute a major challenge. Even if it is assumed that district heating and electricity supply is almost fully decarbonized until 2050, emission reductions amount to around -77% in the current policy scenario and -83% in the ambitious policy scenario. To reach emission reductions of more than 90% which is assumed to be necessary to reach ambitious climate goals, the use of natural gas would have to be reduced even more than in the calculated scenarios. Given the high market shares of natural gas in particular in urban areas and the relatively long lifetime of heating systems in the European building stock this can be seen as the major challenge for decarbonizing heating and cooling supply. At the end of this section Figure 21, Figure 22 and Figure 23 illustrate exemplary results on country level.

Figure 21 provides modelling results for total final energy demand in the ambitious policy scenario on country level differentiated by end use categories.

Figure 22 shows the expected shares of energy carriers on the total final energy demand for the ambitious scenario in the year 2050. As discussed before on EU28 level, the share of fossil energy carriers is expected to decrease substantially. However there are significant differences between countries concerning remaining fossil energy carriers within the modelling results.

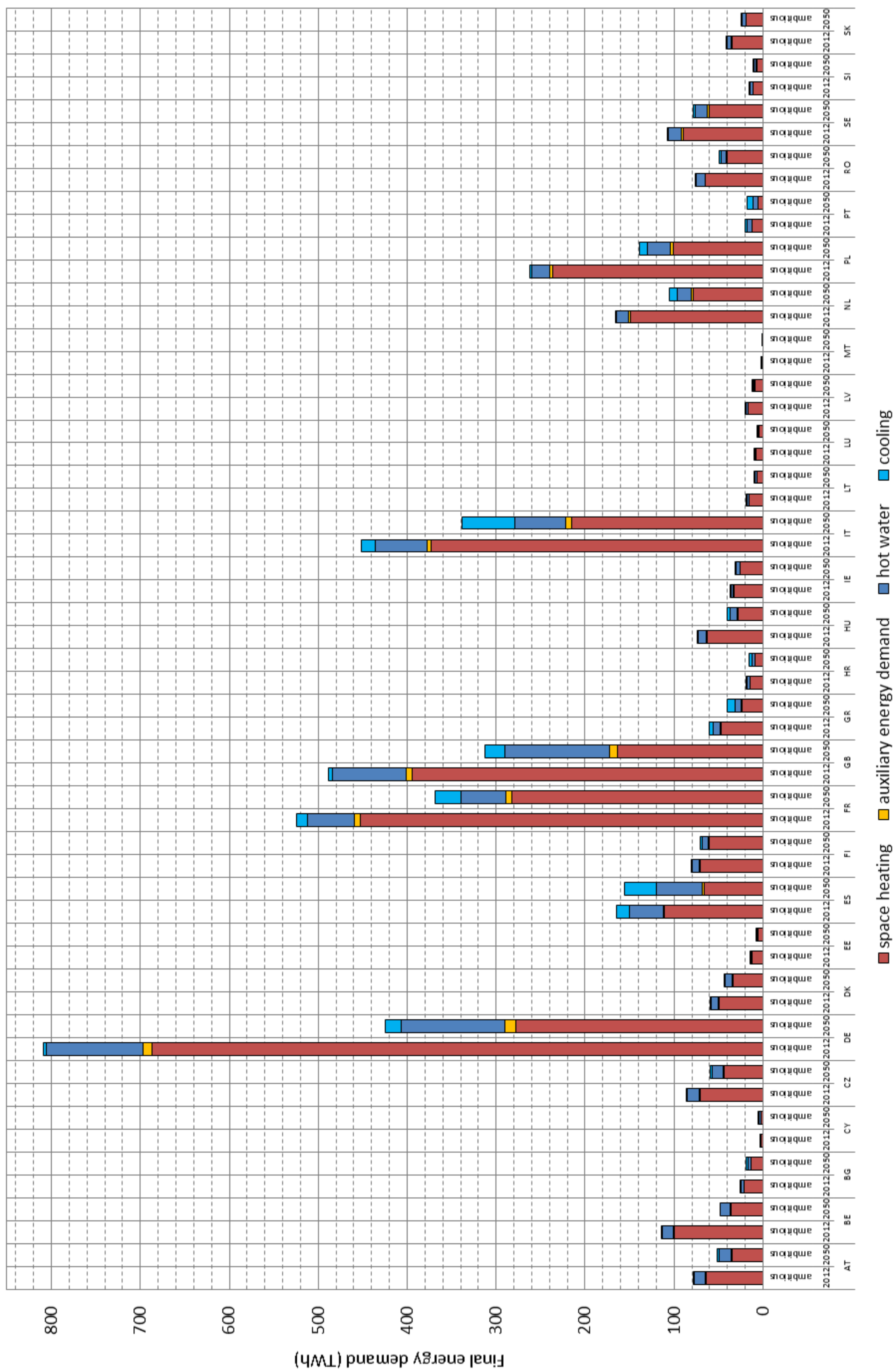


Figure 21: Total final energy demand in the year 2012 and 2050 by usage types for the ambitious policy scenario on country level for EU28 in TWh

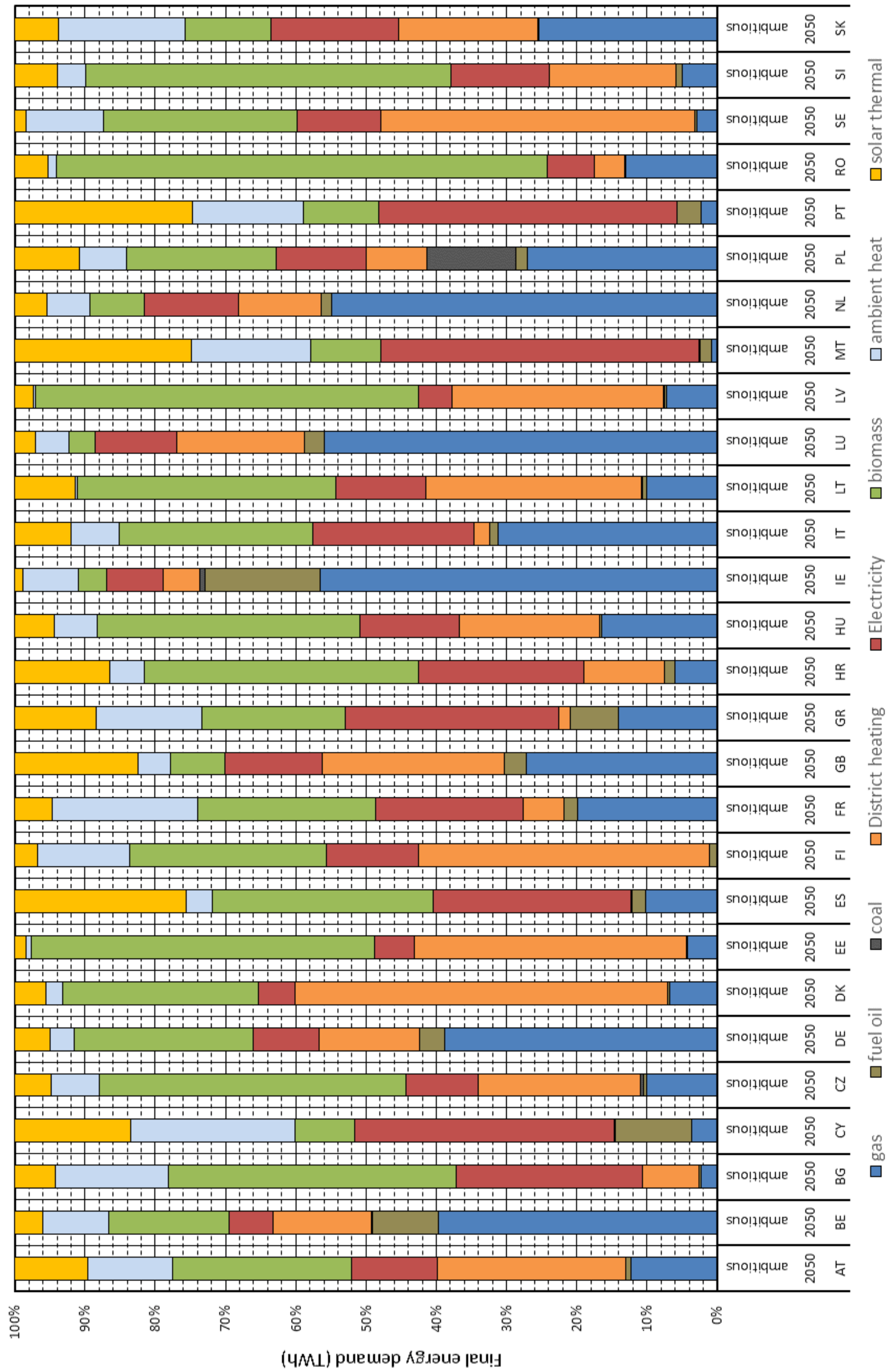


Figure 22: Total final energy demand by energy carrier in the year 2050 for the ambitious policy scenario on country level for EU28 in TWh

Figure 23 illustrates the total final energy demand for selected countries. It can be seen, that the trends towards lower energy demand, higher deployment of renewable energy carriers and disappearance of fuel oil and coal is present across all selected countries. However, the differences in the scale of decrease in final energy demand or the energy carrier mix are clearly noticeable.

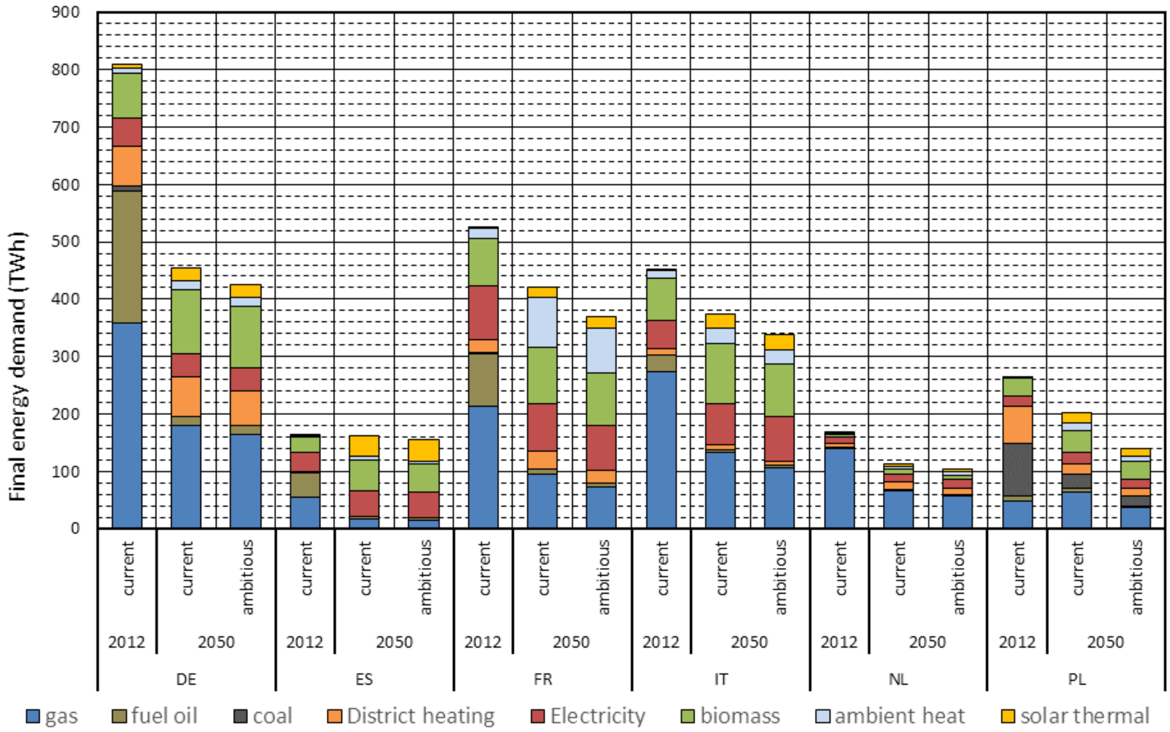


Figure 23: Total final energy demand by energy carrier for space heating, hot water and cooling for selected countries in the current and ambitious policy scenario, EU28 in TWh.

Conclusions for heating and cooling in buildings until 2050

- **Thermal refurbishment and development of final energy demand for heating and cooling**

The scenario calculations demonstrate that the final energy consumption for space heating and hot water can be significantly reduced until 2050 through thermal refurbishments of the existing building stock. While existing policy measures already incentivize efficiency increases in the European building stock more ambitious policies are needed to reach climate targets in line with the Paris agreement.

Our modelling results show that policies regarding the efficiency in the building can significantly influence the investment decision of building occupants and owners. They also show that measures need to be taken early because of the long life time of the building stock.

Energy price increase (and taxation) as well as economic incentives (e.g. subsidies) for building refurbishment to some extent are relevant triggers to increase renovation activities. However, there are numerous barriers and settings which lead to the fact that even under a very favourable economic framework, building owners do not decide to refurbish their building e.g.:

- Owner/tenant dilemma: needs to be addressed via corresponding legislative provisions
- Lack of information on refurbishment measures: One stop-shop approaches that facilitate the process for investors and building owners can trigger more renovation activities. Also standardization of refurbishment packages can support the uptake of renovation activities and reduce financing costs.
- Status-quo bias of building owners and high implicit discount rates of building owners.
- Also a lack of capital to carry out refurbishment work, in particular in households affected by energy poverty is a main barrier for the uptake of renovation acitivities.

Well-designed policy packages which address the full range of actors, building types, economic hurdles, legislative aspects etc. and linking regulatory approaches with economic incentives and well-tailored advice are needed to increase renovation activities.

- **Uptake of renewable heating systems and energy carrier mix**

The scenario calculations presented here result in a significant uptake of renewable heating systems. Biomass heating systems, heat pumps and solar heating systems can substitute the use of fuel oil and coal for decentral heat supply until 2050. The main fossil energy carrier left in the heat supply mix by 2050 in both calculated scenarios is natural gas which currently shows high market shares in particular in urban areas. With regard to ambitious climate targets those high market shares of natural gas are critical as natural gas will be the main source for CO_2 emissions in the European heat supply. Again, it should be noted that resulting emissions in the calculated ambitious policy scenario are higher than the required reduction of 90% or more to reach the Paris climate targets. In light of those results also the financial support of condensing gas boilers have to be evaluated as they are not in line with CO_2 reduction targets of more than 85% to 90% compared to current emissions.

Biomass use for heating increases in both scenarios but lies within available potentials under the precondition that thermal efficiencies of the buildings` envelopes increase substantially. For very ambitious overall CO_2 emission targets however potentials for biomass supply for space heating and hot water still have to be seen critical. Biomass will also be heavily used in other sectors where higher temperature levels are needed (e.g. process heat for industry or electricity production from biomass).

Also heat pumps play an important role in the energy transition. Provided that they substitute existing direct electric heating systems and that the use of heat pumps is restricted to heat distribution systems with low temperature levels (below 50°C) the electricity demand for space heating does not increase significantly in both scenarios. Increasing shares of heat pumps therefore appear to be feasible from an electricity system perspective. However it has to be noted that the use of electrical heat pumps will only lead to substantial CO_2 reductions if the electricity system is decarbonized as well.

In contrast to the refurbishment of the building envelope, in general the installation of a new heating system is associated with a lower amount of technical, economic and other barriers. Thus, the economic framework and in particular the energy prices play a considerable role in the decision-making process. However, again a number of non-economic barriers affect the heating system choice considerably:

- Strong role of intermediaries, in particular installers
- Status-quo bias: People tend to keep the type of heating system, just because they are used to it
- Technical restrictions, e.g. availability of grid bound heating systems (gas, district heating), available space for ground source collectors for heat pumps, available space for fuel storage of biomass heating systems, available space for heat storage etc.

Those barriers also need to be taken into account when designing policies to support the uptake of renewable heating systems until 2050.

- **Future role of district heating:**

District heating can be an enabler for decarbonisation as it is a substitute for the use of natural gas in urban areas. District heating networks allow for the integration of waste heat and other local renewable energy sources. Furthermore, it can provide flexibility for the electricity system if CHPs in combination with large scale heat pumps are applied for generating heat.

Due to building refurbishment, heat demand will strongly decrease in ambitious decarbonisation scenarios. Of course, the economic effectiveness of district heating grids is strongly correlated to the heat densities. In rural areas, this leads to the fact that district heating may lose attractiveness. However, additional analysis of heat densities across Europe show that even in scenarios with strong uptake of renovation activities, a large share of the heat demand can be covered by heat distribution costs below cost threshold that allow district heating to compete with decentral heating options.

It should be noted that for the uptake of district heating tradition and culture also plays a strong role. For example, our analysis showed that in Ireland and the UK there would be quite large economic potentials for district heating grids. However, they are not exploited partly due to lack of experience and for cultural reasons. A key precondition for an economic operation of district heating grid (as every type of infrastructure) is a strong use of this investment, i.e. a high connection rate. Typically, high market shares within a region can only be achieved in reasonable time periods by corresponding zoning of district heating priority areas. Zoning and identification of district heating priority areas are therefore one of the most important policy measures to improve the economic effectiveness and support the uptake of district heating.

3.2 Industry

3.2.1 Scenario definition and fact sheets

Two scenarios are calculated and described more in detail in the following:

1. A **Current Policy Scenario (CP)**, which reflects the effects of currently implemented policies and serves as a benchmark scenario. The macro-economic development reflects a continuation of past trends.

2. An **Ambitious Policy Scenario (AP)** describes the pathway for industrial sector decarbonisation with a high level of ambition in the order of -80% GHG emissions compared to 1990. The AP scenario uses similar framework data as the CP scenario but draws on a broad set of additional mitigation options. The macro-economic assumptions are summarised in section 3.2.2. The AP scenario assumes strengthened and new policies as well as additional more technical mitigation levers.

The following fact sheets summarise the two scenarios main assumptions and key results, before the following section describes assumptions in more detail.

Factsheet Scenario “Current policies”. Industry

The current policy scenario assumes that today’s policies remain in place and are effectively implemented. National differences in the policy intensity continue to exist.

Policy intensity for RES

low moderate high

Policy intensity for industrial energy efficiency

low moderate high

Policy intensity for low-carbon Innovations

low moderate high

Policy intensity for material efficiency and circular economy

low moderate high

The policy intensity bars indicate qualitatively the range of policy ambition. The policy mix corresponds to the current packages in place. The policy mix strongly focuses on the EU ETS, supported by some R&D funding and subsidies/requirements for energy efficiency measures like energy management or audits

CO2 prices in EU Emissions Trading

low moderate High

2030: 31 Euros/t; 2050: 85 Euros/t

Energy prices

low moderate High

Energy prices increase moderately according to EU Reference Scenario 2016.

Technology development

low moderate high

Incremental improvement of technologies, but not fundamental change

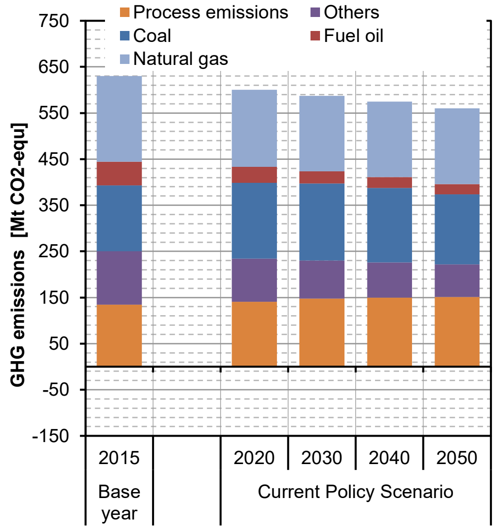
Framework data: Economic growth

low moderate high

Continuous economic development according to EU Reference Scenario 2016: GDP: +1.5% per year; GVA industry +1% per year

Results

In the current policy scenario, the direct (energy and process related) emissions of the industry sector decrease from 630 to 560 Mt CO_2-eq. between 2015 and 2050. This corresponds to a reduction of 70 Mt CO_2-eq. or 11%. The reduction is driven by slow fuel switch and energy efficiency improvements, which together slightly overcompensate the growing industrial value added.



Note: only direct emissions from energy use and processes covered. Emissions from electricity and district heating use are excluded

Figure 24. GHG emissions in industry from 2010 to 2050 current policy scenario EU28.

Factsheet Scenario “Ambitious policies”. Industry

The ambitious policy scenario assumes the implementation of new policies to achieve the targeted GHG reduction by 2050. National differences in the policy intensity are reduced in the long-term.

Policy intensity for RES

low | moderate | high

Policy intensity for industrial energy efficiency

low | moderate | high

Policy intensity for low-carbon Innovations

low | moderate | high

Policy intensity for material efficiency and circular economy

low | moderate | high

The policy intensity bars indicate qualitatively the range of policy ambition. Extension of the policy mix including the financial support for RES-H, CO2-prices beyond the EU ETS, carbon floor price, ambitious energy efficiency programs and support for the market introduction of low-carbon innovations. Comprehensive policies to foster circular economy and material efficiency.

Target: By 2050 at least 80% GHG reduction for industry compared to 1990

CO2 prices in EU Emissions Trading

low | moderate | High

2030: 42 Euros/t; 2050: 150 Euros/t

Energy prices

low | moderate | High

Energy prices increase moderately according to EU Reference Scenario 2016. Particularly higher electricity prices.

Technology development

low | moderate | high

Radical innovations (new low-carbon production processes) start to enter the market in 2030. Ambitious assumptions on the availability of new technologies.

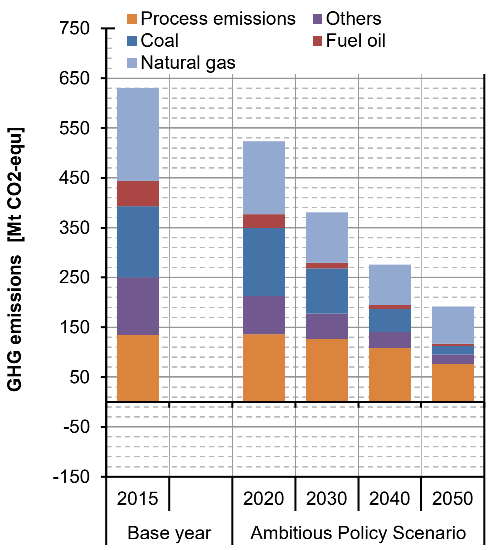
Framework data: Economic growth

low | moderate | high

Continuous economic development according to EU Reference Scenario 2016: GDP: +1.5% per year; GVA industry +1% per year

Results

In the ambitious policy scenario, industrial GHG emissions decrease by 70% between 2015 and 2050 from about 630 Mt CO2-equ in 2015 to about 191 Mt CO2-equ in 2050. A particularly strong decrease is observed for emissions from fuel oil, coal and other fossil fuels, which only account for some minor remaining emissions in 2050. Emissions from natural gas and industrial processes (mainly cement production) also decrease, but they together account for the major share of remaining emissions in 2050 with each about 40%.



Note: only direct emissions from energy use and processes covered. Emissions from electricity and district heating use are excluded

Figure 25. GHG emissions in industry from 2010 to 2050 ambitious policy scenario EU28.

3.2.2 Scenario specification

The types of mitigation options considered in both scenarios are summarised in Table 4. The CP scenario also assumes substantial progress in energy efficiency, but is restricted to incremental improvements and best available technologies, while the CP scenario also includes radical process shifts and new technologies, which are today at least on TRL 5. Fuel switching in the CP scenario is mainly driven by changes in energy prices plus the assumed ETS CO2 price. In the AP scenario, financial support for RES and even more for power-to-heat (PtH) accelerates the switch to biomass and electricity. For recycling, the CP scenario assumes continuation of past trends, while the AP scenario shows an accelerated increase in the share of secondary production (e.g. electric steel, secondary aluminium, recycled paper fibres). Downstream material efficiency and product substitution is only considered in the AP scenario and reflected by a reduction in the demand and production of selected basic materials products compared to the production in the CP scenario (e.g. steel, cement, paper, ethylene, glass).

Table 7: Scenario characterization for different mitigation options

Clusters of mitigation options	Current policy scenario	Ambitious policy scenario
Incremental efficiency improvement	Energy efficiency progress according to current policy framework and historical trends	Faster diffusion of incremental process improvements (BAT & INNOV ≥TRL[9] 5). Exploitation of BAT efficiency potentials in processes and cross-cutting technologies
Fundamental processes improvement energy efficiency, process emissions	-	Introduction of radical process changes (INNOV ≥TRL 5)
Fuel switching to RES towards decarbonized electricity and/or hydrogen	Fuel switching driven by energy prices and assumed EU ETS CO_2-price increase No additional fuel-switching incentives	High financial support for RES technologies: Stronger fuel switching to biomass, power-to-heat and power-to-gas technologies Radical changes in industrial process technologies drive fuel-switch (e.g. switch to hydrogen).
Carbon capture and storage (**CCS)**	-	-
Recycling and re-use	Slow increase in recycling rates based on historical trends	Stronger switch to secondary production (e.g. electric steel, secondary aluminium)

[9] Technology readiness level.

Material efficiency and substitution	-	Decrease in clinker factor, increase in material efficiency & substitution

TRL: Technology Readiness Level; RES: Renewable Energy Source; BAT: Best Available Technology; ETS: Emissions Trading Scheme

Macro-economic framework

The macroeconomic framework data as well as the wholesale fossil fuel prices (gross domestic product, gross value added, population, prices for coal, gas, and oil) are taken from the European Reference Scenario 2016 (Capros et al. 2016) and are the same across all scenarios. This assumption allows better comparability in the model-based analysis of changes in policy parameters and technology assumptions between scenarios.

The macroeconomic framework data shown in Table 5 indicates that industry is expected to continue growing until 2050. However, energy-intensive industries like the iron and steel industry and the non-ferrous metals industry grow below industrial average (<1% p.a.) in the scenarios. An exception is the chemical industry, which is growing at a slightly above average rate (probably caused by growth in the less energy intensive pharmaceutical industry compared to the energy-intensive basic chemicals) and the non-metallic minerals sector (including cement production). Stronger growth is to be expected in non-energy-intensive sectors like engineering (including vehicle construction) and the food industry, which reflects structural change in industry towards less-energy-intensive branches.

Table 8: Macroeconomic framework assumptions

EU 28	CAGR '15-'50
Population (in million)	**0.1 %**
Gross domestic product (GDP) (in 000 M€13)	**1.5 %**
Gross value added (GVA) industry (in 000 M€13):	**1 %**
Iron and steel	0.3 %
Non-ferrous metals	0.5 %
Chemicals	1.1 %
Non-metallic minerals	0.9 %
Paper	0.8 %
Food, drink, tobacco	1.1 %
Engineering	1.3 %
Textiles	-1.2 %
Other	0,9 %

Source: Capros et al. 2016

Energy carrier prices are increasing up to 2050. Only **electricity prices** differ across scenarios, assuming a stronger increase for the policy cases compared to the reference case due to the higher share of renewables expected/necessary in the energy system.

Current policy scenario

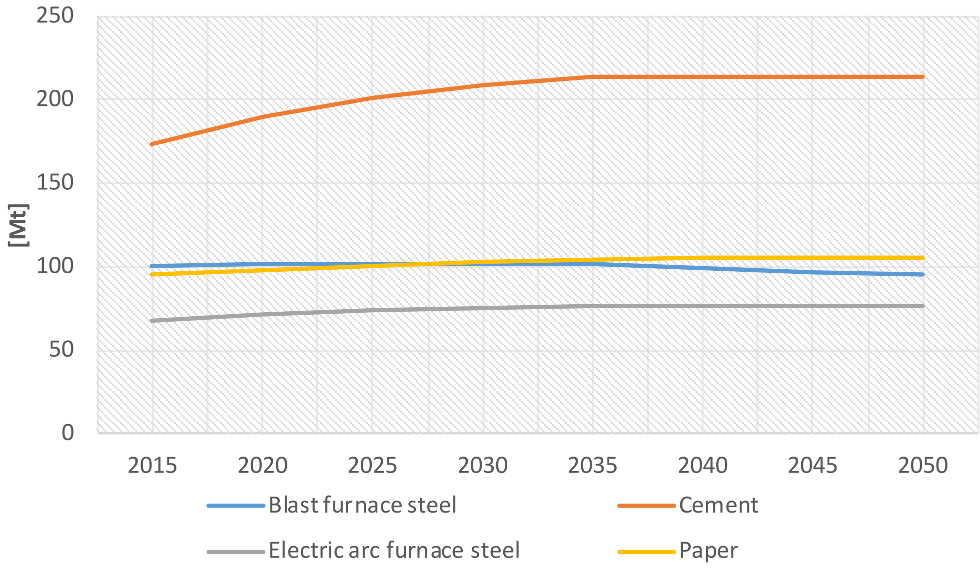
A main characteristic of the current policy scenario is the reflection of energy and climate policies implemented today. The scenario assumes that these policies are continued in the future, but they will not be strengthened. The main policies and policy packages considered are listed in Table 6.

Table 9: Assumed policies in the current policy scenario for the industry sector

	EU leg.	Current policy scenario
Regulations / Information		
Energy audits and energy management	EED	Requirements for energy audits in companies
Energy efficiency standards for renovation	EPBD	National building code requirements, 2015 or planned tightening as far as data is available
Energy efficiency standards new buildings	EPBD	National implementation of NZEB standards after 2018 (for public buildings) and 2020 (for all buildings). Development of building codes up to 2018/2020 according to national action plans for nZEBs.[10]
Technology standards	EDD	MEPS for all products for which regulations have been implemented
Support of CHP and DHC	EED	Realisation of lower limit of economically feasible CHP and DHC potentials
Financial policies		
EU Emission allowances	ETD	CO_2 price: increase to ~90 EUR/tCO_2-equ by 2050 Scope to remain as in phase 3
Energy and CO_2 taxation	ETD	Taxes varying by fuel and sector
National energy audit and energy efficiency programs	National	Ongoing programs based on MURE database
Subsidies for RES technologies	National	Ongoing subsidy programs (MURE database)
Subsidies for industrial CHP	National	Ongoing subsidy programs (MURE database)

Abbreviations: EPBD: Energy Performance of Buildings Directive, EED: Energy Efficiency Directive, RED: Renewable Energy Directive, EDD: Ecodesign Directive, ELD: Energy Labelling Directive, ETD: Emissions Trading Directive, National: National measures

[10] Detailed nZEB definitions are very hard to compare and to implement at a detailed level. Simplifications are necessary regarding the specific definition of indicators and national calculation methodologies.



Source: FORECAST

Figure 26: Development of production data of important industrial processes in the current policy scenario [Mt]

In terms of physical production, blast furnace steel, electric arc steel, paper and cement are among the most important industrial products. Figure 26 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 only slightly higher compared to 2015 production level, it becomes more important than blast furnace steel, which shows a clear decrease in production. Production and absolute percentage changes for these and other industrial products are provided in Table 7.

Table 10: Production data of selected industrial processes in the current policy scenario for the EU28 [Mt and absolute percentage change]

Industrial process	2015	2030	2050	% 2015-2030	% 2030-2050
Chemical industry					
Ammonia	18.00	18.60	19.49	3.3%	4.8%
Chlorine, membrane	7.38	10.32	10.41	39.8%	0.9%
Ethylene	16.30	17.69	19.08	8.5%	7.9%
Methanol	2.17	2.27	2.41	4.6%	6.2%
Oxygen	32.90	32.90	32.90	0.0%	0.0%
Iron and steel					
Blast furnace and converter	100.62	101.86	94.96	1.2%	-6.8%
Coke oven	40.71	41.90	38.87	2.9%	-7.2%
Electric arc furnace	67.64	75.23	76.72	11.2%	2.0%
Rolled steel	151.15	159.02	154.44	5.2%	-2.9%
Sinter	110.58	115.38	111.41	4.3%	-3.4%

Industrial process	2015	2030	2050	% 2015-2030	% 2030-2050
Food, drink					
Bread & bakery	24.75	25.04	25.11	1.2%	0.3%
Brewing	38.61	39.23	39.36	1.6%	0.3%
Dairy	70.11	71.84	72.86	2.5%	1.4%
Meat processing	56.24	57.47	58.33	2.2%	1.5%
Sugar	15.92	16.33	16.53	2.5%	1.2%
Non-ferrous metals					
Aluminium, primary	3.26	3.27	3.18	0.5%	-2.7%
Aluminium, secondary	3.30	3.52	3.79	6.9%	7.5%
Non-metallic minerals					
Bricks	80.78	82.59	83.22	2.2%	0.8%
Cement	173.64	208.08	213.32	19.8%	2.5%
Clinker calcination-dry	124.29	154.85	154.25	24.6%	-0.4%
Container glass	22.87	23.56	21.59	3.0%	-8.3%
Flat glass	13.06	14.61	15.10	11.8%	3.4%
Gypsum	117.29	119.68	120.38	2.0%	0.6%
Lime burning	37.56	45.54	50.90	21.3%	11.8%
Preparation of limestone	147.36	166.09	170.26	12.7%	2.5%
Pulp and paper					
Mechanical pulp	9.79	10.54	10.48	7.6%	-0.5%
Chemical pulp	27.06	28.59	29.31	5.7%	2.5%
Paper	95.65	103.06	105.64	7.7%	2.5%

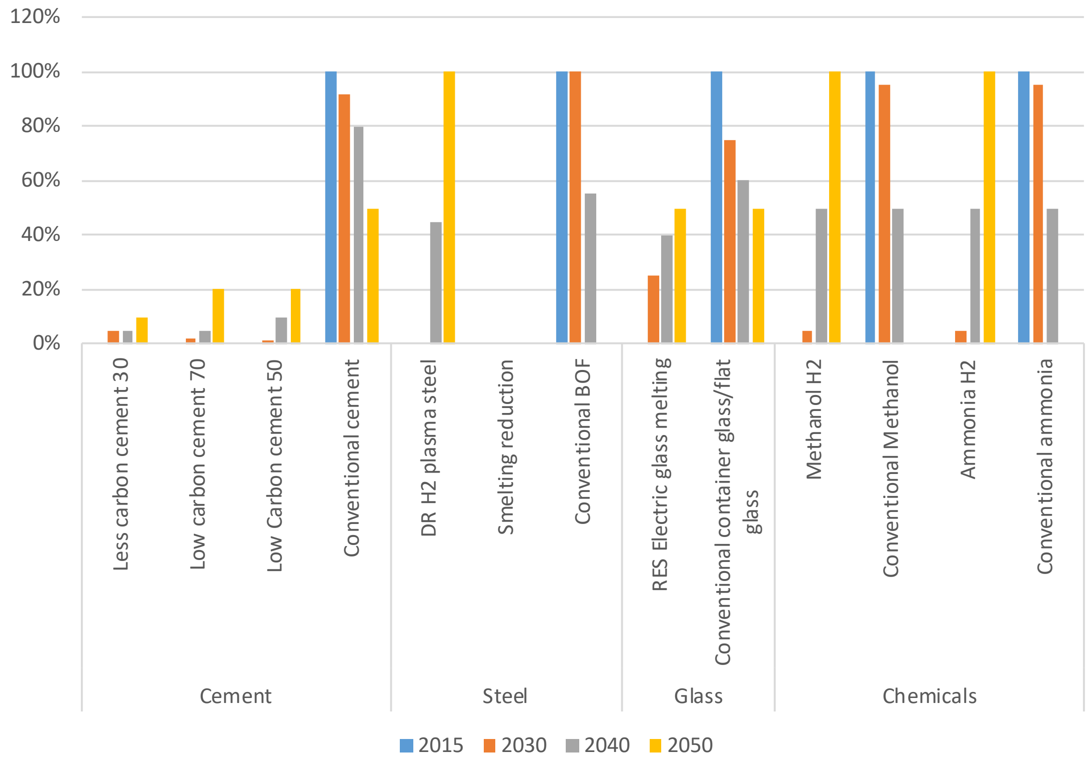
Source: FORECAST

Ambitious policy scenario

The ambitious policy scenario builds on the assumptions and policy instruments defined in the current policy scenario but extends and tightens these to achieve an ambitious GHG reduction by 2050. An overview on the main assumptions in both scenarios is given in Table 4. Main differences are observed in each field of mitigation. Some of the inputs are related to policy instruments (CO2 price, and fuel switch), others are rather exogenous assumptions on changes in the industrial structure (e.g. emergence of low-carbon processes, material efficiency and secondary production).

Assumptions on the market introduction and diffusion of **radical process innovations** are defined as exogenous input. The AP scenario assumes that from 2030 onwards, low-carbon innovations are introduced and diffuse through the technology stock reaching market saturation in 2050. Table 8 shows the assumptions for low-carbon cement types, steel based on direct reduced iron via EE-hydrogen, electric glass melting and methanol and ammonia production based on EE-H2. The production of the required H2 in steel and chemicals is assumed to take place via electrolysis on-site. Consequently, the resulting final energy balances only show the electricity consumption used for hydrogen production, but not the quantity of hydrogen needed.

Table 11: Diffusion of radical process innovations in the Ambitious Policy Scenario



	Technology	2015	2030	2040	2050
Cement	Less carbon cement 30	0%	5%	5%	10%
	Low carbon cement 70	0%	2%	5%	20%
	Low Carbon cement 50	0%	1%	10%	20%
	Conventional cement	100%	92%	80%	50%
Steel	DR H2 plasma steel	0%	0%	45%	100%
	Smelting reduction	0%	0%	0%	0%
	Conventional BOF	100%	100%	55%	0%
Glas s	RES Electric glass melting	0%	25%	40%	50%
	Conventional container glass/flat glass	100%	75%	60%	50%
Chemicals	Methanol H2	0%	5%	50%	100%
	Conventional Methanol	100%	95%	50%	0%
	Ammonia H2	0%	5%	50%	100%
	Conventional ammonia	100%	95%	50%	0%

Assumptions on **material efficiency** are summarised in Table 9. We take exogenous assumptions on material efficiency progress and implement it via a reduced demand (and production) for selected products. The material progress is shown for the year 2050, but assumed to increase linearly towards 2050. The values are based on the (scarce) literature available.

Table 12: Changes in material production related to material efficiency and demand pattern in 2050 compared to the current policy scenario

	Technology	**Reduction by 2050**	**Comment**
Steel	Rolled steel	10%	
	Crude steel	10%	
	Aluminium, primary	3%	
	Zinc	5%	Material efficiency
Paper	Paper	10%	Material efficiency consumer policies and packaging
Non-metallic minerals	Cement	10%	Material efficiency in construction industry
	Lime	60%	Reduced demand by blast furnaces and power plants
	Container glass	10%	Material efficiency
Chemicals	Adipic Acid	10%	Material efficiency
	Ammonia	46%	Reduced demand for fertilisation in agriculture
	Chlorine	5%	Material efficiency
	Methanol	5%	Material efficiency
	Nitric Acid	10%	Material efficiency
	Ethylene	10%	Related to plastics
	Polycarbonate	10%	Related to plastics
	Polypropylene	10%	Related to plastics
	Polyethylene	10%	Related to plastics
Food	Diary	60%	Change in nutrition towards vegetarian food
	Meat	60%	Change in nutrition towards vegetarian food
	Plastics processing	10%	Material efficiency consumer policies

Recycling and secondary production routes are considered for steel, aluminium, copper, paper and glass. For cement production, a reduction of the clinker ratio (share of clinker input compared to cement output) is considered. For all products, the technical restrictions vary and the starting point of the individual countries is very different, which requires to take such assumptions on a country level. The main assumptions are summarised in Table 10 for the EU28. More specific country developments are explored in the following.

Table 13: Summary of recycling and secondary production assumptions in the current policy and the ambitious policy scenario until 2050

Indicator		**Current Policy Scenario**		**Ambitious Policy Scenario**	
	2015	**2030**	**2050**	**2030**	**2050**
Share electric steel	40%	42%	45%	51%	68%
Share secondary aluminium	50%	52%	54%	65%	70%
Share recycled paper fibres	58%	58%	60%	60%	62%
Clinker to cement ratio (for remaining market segment)	78%	74%	72%	70%	43%

The share of electric steel increases from about 40% in 2015 to 68% in 2050 in the AP scenario, while it only increases to 4% in the CP scenario. The development of individual countries is shown in Figure 27. Particularly the countries starting on a low level in 2015 show a tremendous speed in the increase of the electric steel share. This development is very ambitious and follows the maximum possible with the given scrap availability until 2050. Certainly, the development also assumes increase quality of electric steel products to attain new markets, currently only supplied by blast furnace steel (e.g. vehicle production).

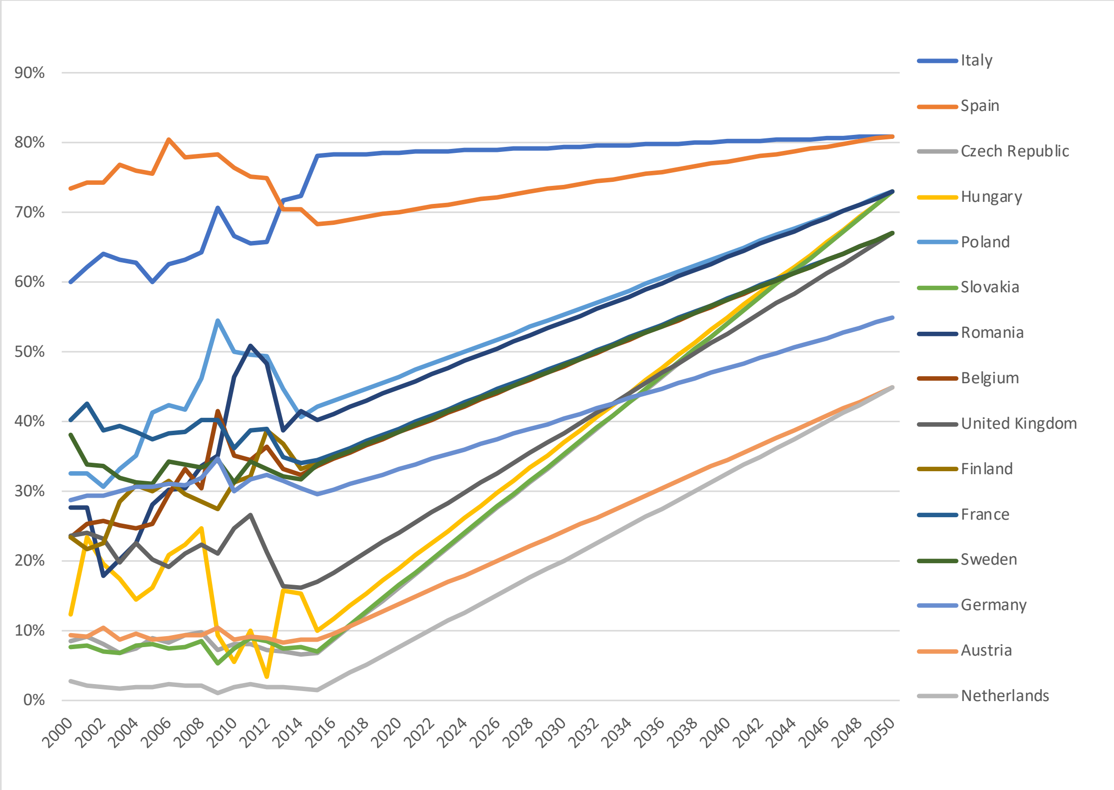


Figure 27: Share of electric steel in total crude steel production for main steel producing countries in the ambitious policy scenario

The clinker-to-cement ratio for the EU28 decreases from currently about 78% to about 70% in the current policy and to 42% in the ambitious policy scenario. This, however, also reflects a change in statistics, because it is only related to the remaining cement market segment that is not converted to new low-carbon cement types. These actually mostly replace Portland Cement clinker, which explains the sharp drop of the clinker ratio in the remaining segment.

Table 14: Clinker-to-cement ratio assumed in the Ambitious Policy scenario by country for the remaining market segment not addressed by new cement processes

Country	2000	2015	2030	2050	Change 2050/2015
Austria	0,80	0,71	0,64	0,57	-20%
Belgium	0,60	0,62	0,58	0,50	-21%
Cyprus	0,88	0,92	0,81	0,72	-22%
Czech Republic	0,65	0,66	0,58	0,52	-22%
Denmark	0,31	0,70	0,39	0,19	-73%
Finland	0,81	0,76	0,67	0,60	-22%
France	0,81	0,84	0,70	0,59	-30%
Germany	0,77	0,72	0,65	0,58	-19%
Greece	0,85	0,57	0,50	0,45	-22%
Hungary		0,74	0,68	0,61	-18%

Country	2000	2015	2030	2050	Change 2050/2015
Ireland	0,83	1,29	1,14	1,02	-22%
Italy	0,76	0,72	0,63	0,55	-24%
Latvia		0,18	0,17	0,15	-15%
Luxembourg	0,79	0,77	0,72	0,65	-15%
Netherlands	0,35	0,61	0,57	0,52	-15%
Poland	0,61	0,76	0,73	0,66	-13%
Portugal	0,71	0,95	0,84	0,75	-21%
Slovakia	0,73	0,70	0,62	0,54	-22%
Slovenia	0,74	0,80	0,70	0,63	-22%
Spain	0,65	1,04	0,91	0,81	-21%
Sweden	0,90	0,80	0,71	0,63	-22%
United Kingdom	0,79	0,80	0,73	0,64	-20%
Romania	0,73	0,92	0,93	0,85	-7%
Bulgaria		0,76	0,67	0,58	-25%
Croatia	0,79	1,00	0,94	0,85	-15%

As a result of the above discussed assumptions on new production processes, material efficiency and recycling, the resulting production outlook for the ambitious policy scenario is summarised in Table 12

Table 15: Production data of selected industrial processes in the ambitious policy scenario for the EU28 [Mt]

	2015	2030	2050
Chemical industry			
Adipic acid	0.59	0.56	0.53
Ammonia	17.67	13.94	-
Ammonia H2	-	1.79	9.10
Calcium carbide	0.33	0.33	0.33
Carbon black	1.55	1.53	1.51
Chlorine, diaphragma	1.69	1.39	1.22
Chlorine, membrane	7.07	9.77	9.56
Chlorine, mercury	2.73	-	-
Ethylene	15.63	16.28	16.57
Methanol	1.29	1.26	-
Methanol H2	-	0.07	1.36
Nitric acid	16.99	16.26	15.29
Oxygen	32.85	32.85	32.85
Poly carbonate	0.94	1.31	1.79

	2015	2030	2050
Poly ethylene	9.12	9.69	10.48
Poly propylene	8.82	9.37	10.13
Poly sulfones	0.41	0.57	0.91
Soda ash	8.02	8.02	8.02
TDI	0.48	0.64	0.93
Titanium dioxide	0.46	0.53	0.65
Food, drink and tobacco			
Bread & bakery	24.35	24.64	24.71
Brewing	37.96	38.54	38.63
Dairy	69.35	52.74	28.76
Meat processing	54.46	41.19	22.40
Sugar	15.65	16.05	16.25
Iron and steel			
Bath smelting	-	-	-
Blast furnace and converter	100.62	81.33	-
Coke oven	40.58	33.36	-
Direct reduction	0.66	0.63	0.59
DR RES electrolysis	-	-	-
DR RES hydrogen	-	-	48.96
Electric arc furnace	65.50	85.68	101.76
Rolled steel	150.55	151.24	136.64
Sinter	109.84	91.19	-
Smelting reduction	-	-	-
Non-ferrous metals			
Aluminium rolling	3.78	3.72	3.64
Aluminum extruding	2.21	2.18	2.13
Aluminum foundries	2.47	2.44	2.42
Aluminum, primary	1.98	1.77	1.49
Aluminum, secondary	3.03	3.27	3.57
Copper further treatment	4.76	4.77	4.77
Copper, primary	1.93	1.93	1.93
Copper, secondary	0.84	0.84	0.84
Zinc, primary	2.45	2.40	2.33
Zinc, secondary	0.09	0.09	0.08
Non-metallic mineral products			
Bricks	80.42	82.18	82.76

	2015	2030	2050
Cement grinding	167.16	176.75	92.53
Clinker calcination-dry	120.03	123.61	39.87
Clinker calcination-semidry	7.30	-	-
Clinker calcination-wet	3.25	-	-
Container glass	22.85	16.89	9.71
Fiber glass	2.59	3.03	3.12
Flat glass	13.06	10.96	7.55
Gypsum	117.67	120.06	120.77
Houseware, sanitary ware	0.58	0.64	0.73
Less-carbon cement - 30%	-	9.61	18.51
Lime burning	37.18	33.46	20.16
Lime milling	27.88	25.09	15.12
Low-carbon cement - 50%	-	1.92	37.01
Low-carbon cement - 70% (recarbonating)	-	3.84	37.01
Other glass	1.71	1.99	1.99
Preperation of limestone	142.97	148.46	82.85
RES Electric melting furnace	-	9.28	17.26
Technical, other ceramics	0.70	0.75	0.83
Tiles, plates, refractories	4.81	5.22	5.63
Other non-classified			
Blow moulding	4.88	5.18	5.60
Extrusion	17.95	19.08	20.63
Injection moulding	8.30	8.82	9.54
Paper and printing			
Chemical pulp	26.40	26.26	24.95
Mechanical pulp	8.32	7.90	7.04
Paper	93.19	95.79	92.22
Recovered fibers	48.72	51.70	53.13

3.2.3 Results: Comparison of scenarios

In 2015, 74% of EU industrial final energy consumption (FEC) was used for the generation of heat and cold (see Figure 28). This equals to about 2400 TWh. The major use of H&C FEC was process heating, which equally split into industrial furnaces (>500°C) and steam and hot water generation (<500°C) with each about 950 TWh FEC. The share of space cooling and process cooling was relatively low with 1 and 2%, respectively. Consequently, the focus of the following analysis will be on industrial process heating including both, furnaces and steam and hot water generation.

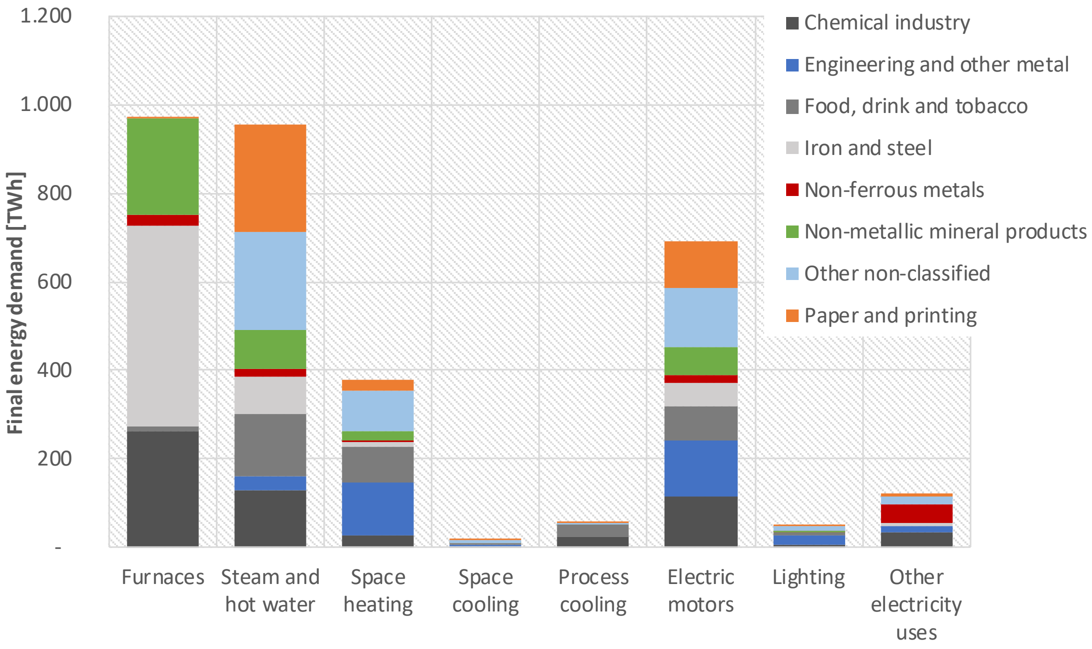


Figure 28: Final energy demand in industry by end-use and sub-sector in 2015 (source: FORECAST)

In the CP scenario, the direct (energy and process related) emissions of the industry sector decrease from 630 to 560 Mt CO_2-eq. between 2015 and 2050. This reflects a future development based on current policies and past trends and corresponds to a reduction of 70 Mt CO_2-eq. or 11%. In AP scenario, industrial GHG emissions decrease by 70% between 2015 and 2050 (see Figure 29). Note that this is based on counting only direct GHG emissions from energy use and processes. Emissions from electricity and district heating use are not accounted for.

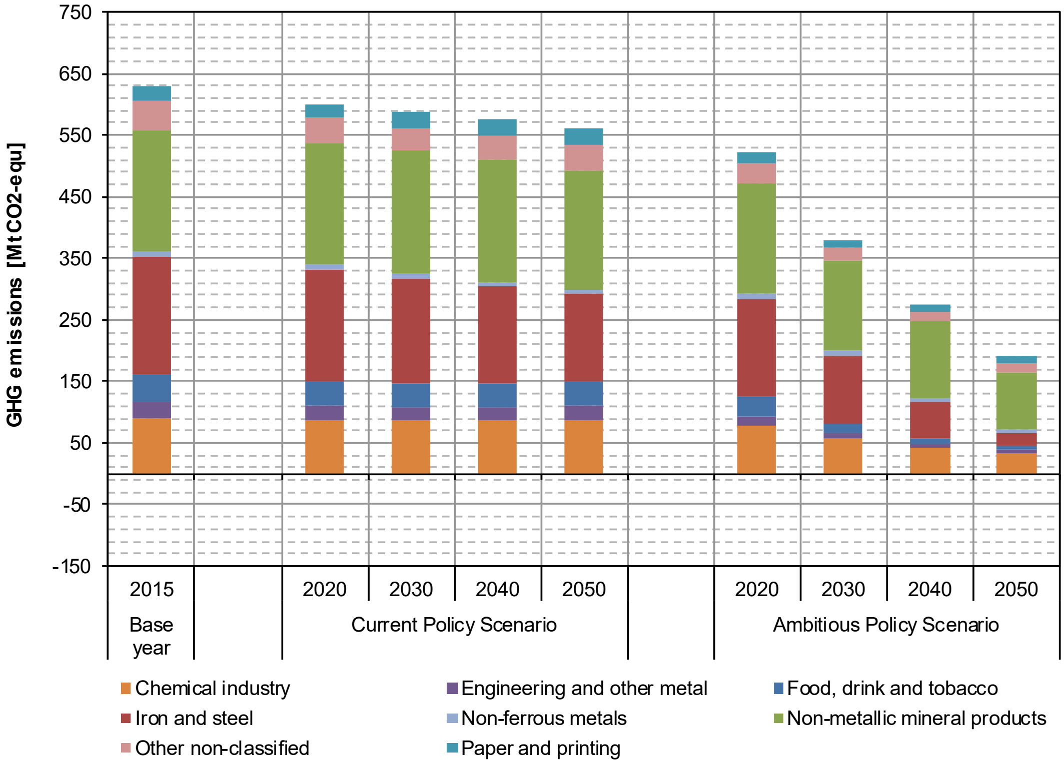


Figure 29: Evolution of EU28 industry GHG emissions by scenario and sub-sector

In the AP scenario, emissions from the iron and steel industry are reduced by almost 90% in 2050 compared to 2015 by replacing oxygen steel with electric steel and substituting the remaining blast furnace route with renewable-hydrogen-based steel (see Figure 33). Conventional cement production is partly substituted in the AP scenario by innovative types of cement using new binders and reducing the specific energy- and process-related cement emissions by between -30 and -70%. Additional potentials in the non-metallic minerals sector are tapped using electric melting processes in the glass industry as well as incremental process improvements (e.g. oxyfuel combustion incl. waste heat recovery) and fuel switching. Overall, the direct emission reductions in the non-metallic minerals sector amount to -54% in 2050 compared to 2015.

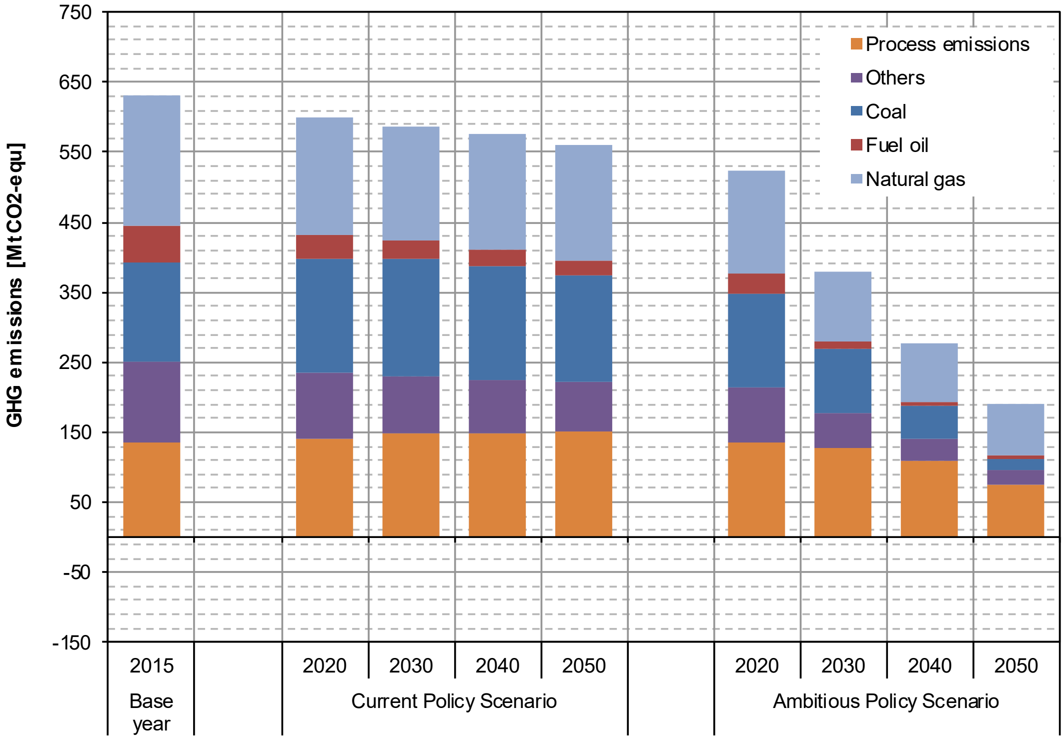


Figure 30: Evolution of EU28 industry GHG emissions by scenario and energy carrier / emission source

In the CP scenario industrial final energy consumption (FEC) for the EU28 is only slightly decreasing as efficiency effects are nearly equalled out by activity effects (e.g. gross value added growth) from 3233 TWh in 2015 to 2928 TWh in 2050. In the AP scenario, FEC is also decreasing until 2050, however, a lot slower than GHG emissions: By 25% to 2430 TWh in 2050 compared to 2015 (Figure 31).

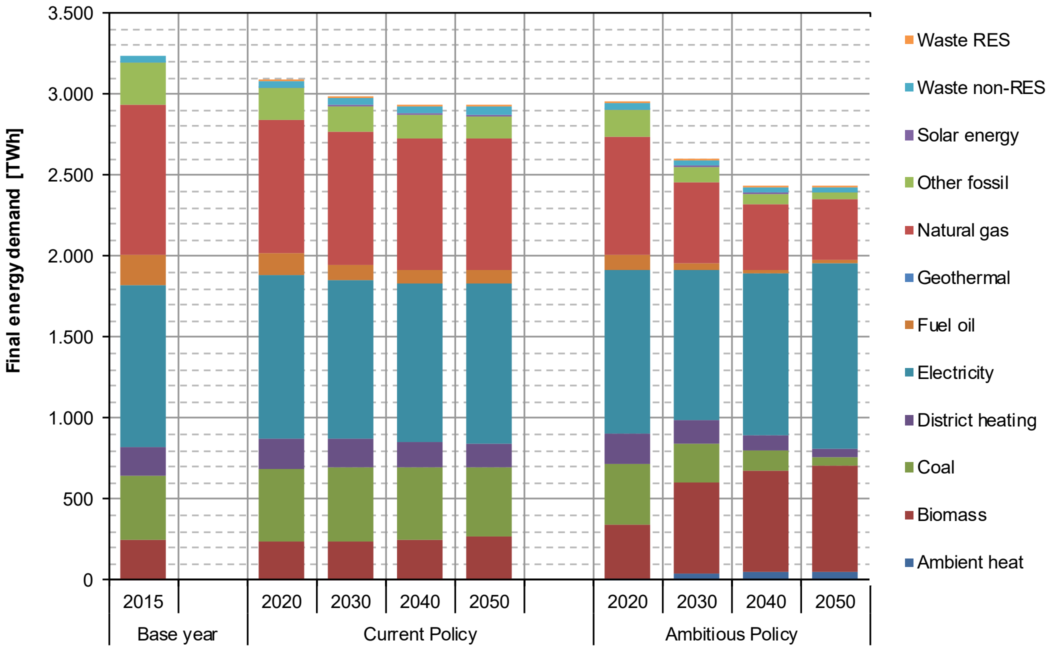


Figure 31: Evolution of EU28 final energy demand by scenario and energy carrier

Steam and hot water generation is used across all industries, but has very high demands in chemicals, pulp and paper as well as the food industry. It covers a temperature range of up to 500°C and uses relatively comparable technologies in all sectors. The temperature range allows the use of combined heat and power (CHP) technologies. In total, final energy demand for steam and hot water accounts for about 25% of industrial final energy demand in the EU28.

Figure 32 shows the evolution of the fuel mix in the final energy demand used for steam and hot water generation in the ambitious policy scenario. It can be seen that the share of biomass increases in nearly all sectors, driven by high financial support for RES. Similarly, the share of electricity (power-to-heat) is also increasing. Again, this is due to financial support, which is also provided for RES-based PtH. The use of fossil fuels on the other side is decreasing. Coal and fuel oil are nearly completely phased out and also natural gas is decreasing drastically. Still, in 2050, some natural gas is remaining in most sectors. The main reason is a slow turnover of the technology stock in combination with new gas-based capacities being constructed in the coming years. A more drastic phase-out of gas would require a stronger policy frame, which could include either stronger financial incentives or a ban on the use of fossil fuels even before 2030.

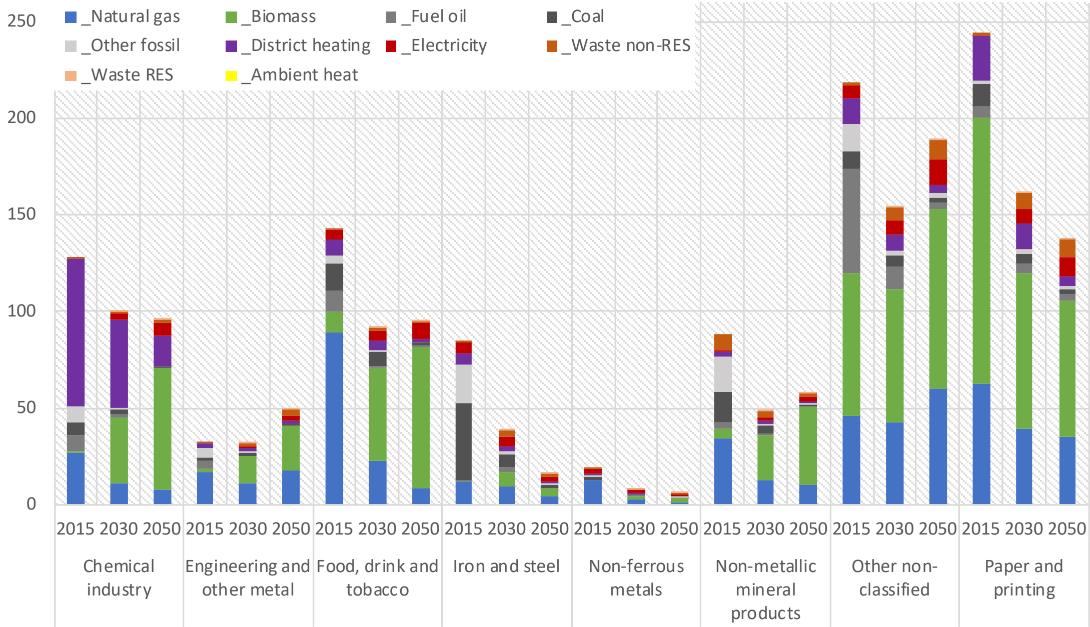


Figure 32: Evolution of final energy demand for process heating in steam and hot water generation in the AP scenario until 2050 for EU28

Another important field for fuel switching are **industrial furnaces**. Compared to steam systems, furnaces are very diverse and specific to the related production process. They often work at high temperatures above 1000°C, e.g. in the cement, glass and steel production. Fuel switching is possible, but the use of energy carriers is limited due to several technical restrictions and RES are more difficult to integrate at high temperature levels.

Figure 33 shows the fuel shares in final energy demand for process heating via furnaces in the three main industries: Chemicals, iron and steel and non-metallic minerals (cement, lime and glass). The AP scenario experiences a strong shift towards biomass and electricity. Here, financial support for biomass is high, leading to a more comprehensive use where technically possible like in the cement and lime production. The increase in electricity demand is driven by fundamental process changes that include e.g. the use of hydrogen for DRI-steel production, completely replacing the conventional oxygen steel route. Across all sectors and scenarios, also in 2050 still a substantial amount of natural gas is used.

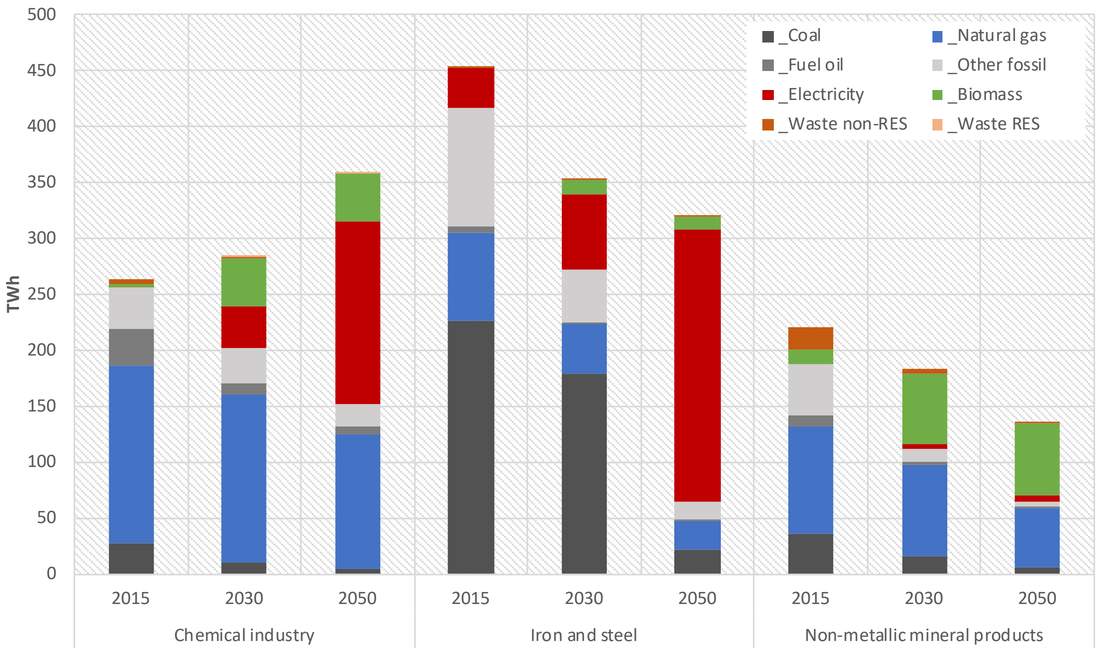


Figure 33: Evolution of final energy demand for process heating in furnaces in the AP scenario until 2050 for EU28

3.2.4 Conclusions

The scenarios show that today's policies are not on track to decarbonise industry, although GHG emissions are slightly falling even in the current policy scenario. The ambitious policy scenario achieves a substantial reduction of industrial GHG Emissions by about 70% in 2050 compared to 2015 (The relative reduction would be higher when compared to 1990).

The following main conclusions can be drawn with regard to the contribution of mitigation options and the resulting transition pathways:

- Deep emission cuts require substantial changes in the iron and steel, cement and chemicals industries, but also support for RES and energy efficiency in other sectors and companies.
- Radical shifts in steel and chemicals towards the use of EE-hydrogen might increase electricity use drastically.
- Biomass is the most important RES in industry, particularly in the medium term. However, biomass resource potentials and their sustainability are limited and might be needed also in other sectors.
- In the long-term, RES-based electricity (power-to-heat) can play a more important role, particularly if electricity generation has very low emission levels. However, electricity is not yet cost-competitive with biomass even in the most ambitious transition policy scenario under the policy definitions taken and the assumed development of energy

prices. Replacing biomass by electricity would require policies to reduce the operation costs of PtH.
- Improved material efficiency and the circular economy have a huge mitigation potential. However, it is still unclear what an effective policy mix would look like and this probably encompasses a wide range of individual measures.

The AP scenario envisages radical changes to industrial production systems like innovative processes and large-scale power-to-heat for steam generation mainly in the time horizon after 2030. Before 2030, energy efficiency improvements combined with fuel switching to biomass and progress towards a circular economy are the main mitigation options that drive CO_2 emissions downward. However, in order to have new process technologies and innovations ready by 2030, substantial research, development and innovation activities need to take place in the coming decade. Pilot and demonstration plants need to be built to prepare for market introduction. It might easily take 10 years for new processes in the materials industry to progress from lab-scale to market. Certification processes such as those needed for new cement types can prolong the time taken even more.

3.3 Electricity generation and district heating

3.3.1 Scenario definition and fact sheets

Aiming at an analysis of the future evolution of renewable energies in the electricity sector and in district heating under distinct policy and market trends, two representative scenarios are selected from a set of in total 12 different future scenarios derived in the course of the H2020 project SET-Nav (www.set-nav.eu):

- **Scenario A – current policy scenario** where an overall **RES share of 27%** has to be achieved at EU level **by 2030** under trend electricity market design.
- **Scenario B – ambitious policy scenarios**: here the policy ambition is stronger for renewables and for energy efficiency, assuming that the EU aims for a **RES share of 33% by 2030** under optimal electricity market design.

An overview on their definition is given in Table 13, providing a key characterisation of the individual scenarios and listing key input parameters and assumptions.

Table 16: Overview on assessed scenarios

Scenario acronym	**27% RES - trend market design** **(Scenario A: current policy scenario)**	**33% RES with strong EE, optimal market design** **(Scenario B: ambitious policy scenario)**
Characterisation	Trend market design (non-optimal framework conditions for RES integrat.)	Strong policy ambition for RES and EE by 2030
Energy demand trend	**27% EE by 2030** (PRIMES euco27)	**30% EE by 2030** (PRIMES euco30)
Fossil energy price trend	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)
Carbon price trend	**Default** (PRIMES reference)	**Default** (PRIMES reference)
Market design / Flexibility provision	**Trend** (delayed grid ext., capacity markets, no demand response)	**Optimal** (grid extension, energy only markets, demand response)
RES ambition	at least **27% by 2030** (and beyond)	at least **33% by 2030** (and beyond)
RES policy concept	**Least cost** (support expenditures)	**Least cost** (support expenditures)

*Abbreviation: EE ... energy efficiency

Common key input parameter and assumptions have been described in chapter 2.3.2.

Factsheet Scenario “Current policies: 27% RES – trend market design”. Electricity generation and district heating.

FACTSHEET SCENARIO A (Current policy scenario): 27% RES – trend market design

Under the current policy scenario we assume that an overall RES share of 27% has to be reached by 2030 at EU level, combined with an energy efficiency target of 27%.

The underlying **policy concept** for incentivising RES can be characterised as a “least-cost” approach, enhancing an efficient use of RES for meeting the 2030 EU RES target in a cost-effective manner:

- The selection of RES technologies across all Member States is done cost-effectively, meaning that all additionally required future RES technology options are ranked in a merit-order, and it is left to the economic viability which options are chosen for meeting the presumed 2030 RES target.

- Support levels and related expenditures follow then the marginal pricing concept where the marginal technology option determines the support level (like in the ETS or in a quota/certificate trading regime, or similar to the concept of liberalised electricity markets).

Concerning the impact of electricity market design on the RES uptake and related costs, a **trend electricity market design** is assumed, characterised by a delayed grid extension, capacity markets prevailing in some EU countries and no measures that allow for demand response.

Policy intensity: The policy intensity bars indicate qualitatively the range of policy ambition at EU level, here exemplified for RES in the electricity sector and in district heating. In accordance with the scenario conception this intensity can be classified as low to moderate.

Policy intensity for RES-E

low	moderate	high

Policy intensity for RES in district heating

low	moderate	high

Assumptions on **energy and carbon prices** are aligned to PRIMES modelling, specifically the latest PRIMES reference scenario (EC, 2016). Generally, this price trend can be classified as moderate to high.

Energy and carbon price trends

low	moderate	high

Expected **future RES developments in the electricity sector**:

- Results show a moderate but steady increase of electricity generation from RES at EU 28 level. More precisely, in the years up to 2035 a decline of the pace of RES deployment compared to past efforts is apparent. Later on, in the final years up to 2050, the transition is accelerated.

- At EU level this implies an increase of the RES share (in gross electricity demand) from 28.8% by 2015 to 48.8% in 2030. By 2050 RES are expected to achieve 85.6%.

Whereas this transition process is observable across the whole EU, large differences between MSs in the resulting RES shares by 2030 and by 2050 remain, cf. Figure 34 – caused by differences in starting points and available cost-effective RES potentials.

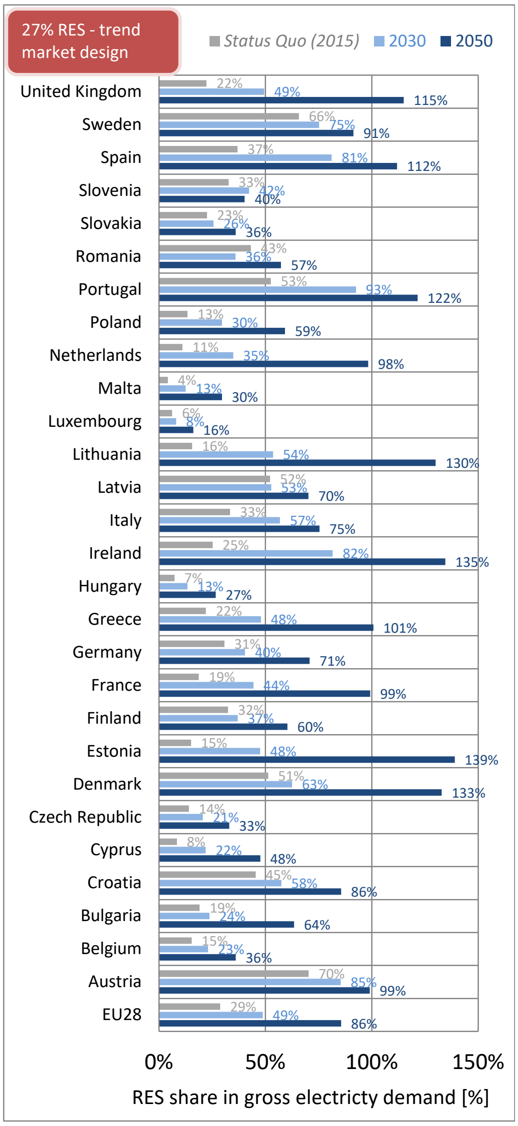


Figure 34: Country-specific RES shares in gross electricity demand today (2015), by 2030 and by 2050 according to the current policy scenarios

Expected **future RES developments in the (grid-connected) heat sector**: Similar trends than for the electricity sector are applicable for RES in district heating / grid-connected heat supply. Here Figure 35 informs on the expected RES shares at MS level by 2030 and 2050. At EU level an increase of the RES share from about 22% (2015) to more than 50% (52.5%) by 2030, and to 87.2% by 2050 is projected.

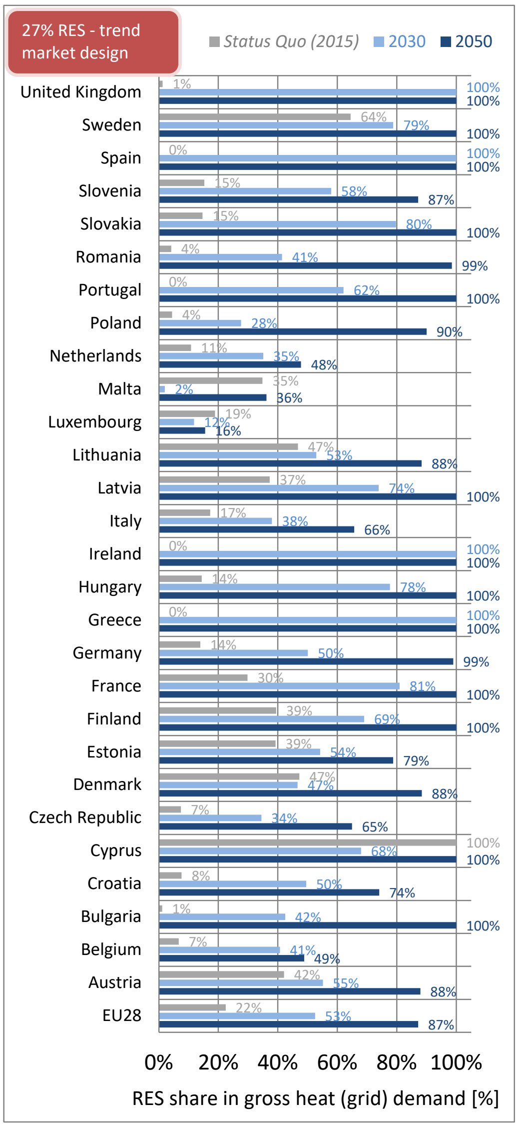


Figure 35: Country-specific RES shares in gross grid-connected heat demand today (2015), by 2030 and by 2050 according to the current policy scenarios

Factsheet Scenario “Ambitious policies: 33% RES – optimal market design”. Electricity generation and district heating.

The ambitious policy scenario builds on the assumption that an overall RES share of 33% has to be reached by 2030 at EU level, combined with an energy efficiency target of 30%.

The underlying **policy concept** for incentivising RES can be characterised as a “least-cost” approach, enhancing an efficient use of RES for meeting the 2030 EU RES target in a cost-effective manner:

- The selection of RES technologies across all Member States is done cost-effectively, meaning that all additionally required future RES technology options are ranked in a merit-order, and it is left to the economic viability which options are chosen for meeting the presumed 2030 RES target.
- Support levels and related expenditures follow then the marginal pricing concept where the marginal technology option determines the support level (like in the ETS or in a quota/certificate trading regime, or similar to the concept of liberalised electricity markets).

An **optimal electricity market design** is assumed for the impact of electricity market design on the RES uptake and related costs, characterised by a timely grid expansion, energy-only markets in all EU countries and proactive measures to facilitate demand response.

Policy intensity: The policy intensity bars indicate qualitatively the range of policy ambition at EU level, here exemplified for RES in the electricity sector and in district heating. In accordance with the scenario conception this intensity can be classified as moderate to high.

Policy intensity for RES-E

Policy intensity for RES in district heating

Assumptions on **energy and carbon prices** are aligned to PRIMES modelling, specifically the latest PRIMES reference scenario (EC, 2016). Generally, this price trend can be classified as moderate to high.

Energy and carbon price trends

Expected **future RES developments in the electricity sector**: Results indicate a strong increase of electricity generation from RES at EU level in the period up to 2030. As illustrated in Figure 36, a RES-E share in gross electricity demand of 62.1% is reached by then. In subsequent years, specifically up to 2035, only a slow rise of the RES-E share can be observed. In the final years up to 2050, deployment of renewables is again accelerated, leading to a RES-E share of 95.8% by 2050. The temporary deceleration is caused by the policy assumptions used in modelling: here a strong RES target is imposed for 2030. This binding minimum RES share is however not imposed to increase post 2030. Thus, RES use speeds up again in later years once full competitiveness is reached with other generation options.

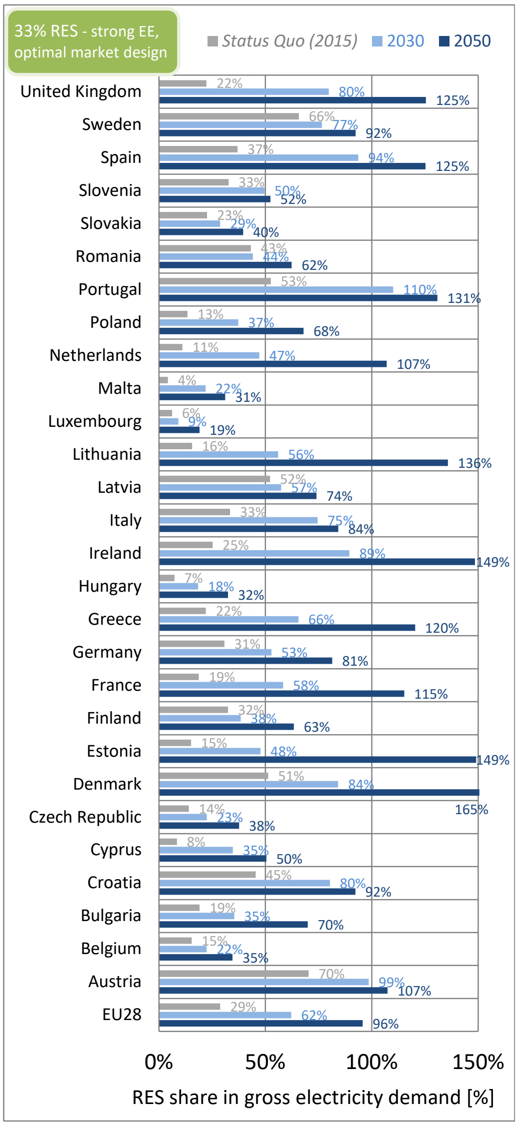


Figure 36: Country-specific RES shares in gross electricity demand today (2015), by 2030 and by 2050 according to the ambitious policy scenarios

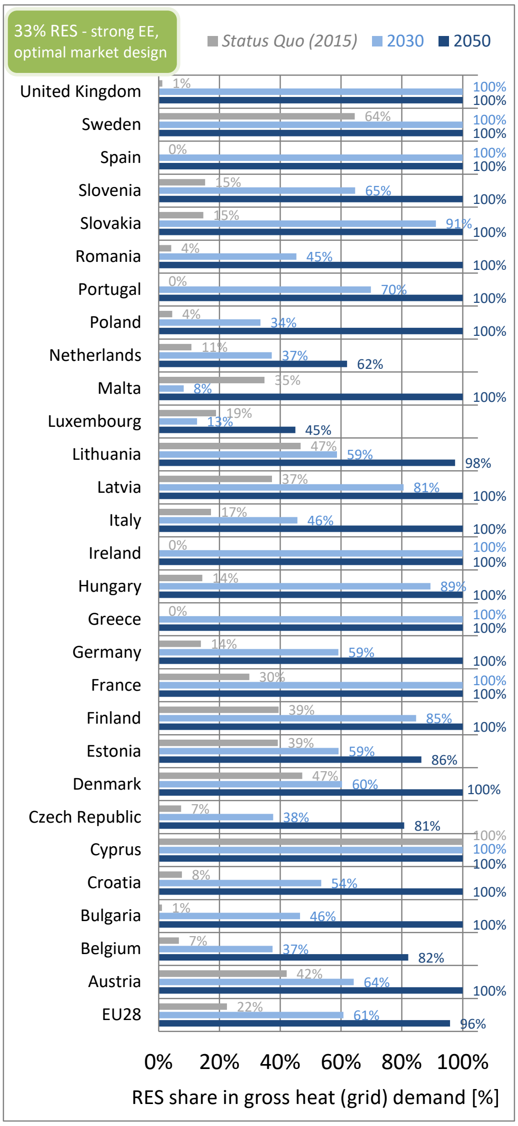


Figure 37: Country-specific RES shares in gross grid-connected heat demand today (2015), by 2030 and by 2050 according to the ambitious policy scenarios

Expected **future RES developments in the (grid-connected) heat sector**: For RES in district heating / grid-connected heat supply similar trends than for the electricity sector are applicable. In this context Figure 37 shows the expected RES shares at EU and at MS level by 2030 and 2050. At EU level a strong increase of the RES share from about 22% (2015) to 60.8% can be observed until 2030, and for 2050 a RES share of 95.8% is expected.

Generally, the transition from a fossil-based to a renewables-based system is observable across the whole EU within all energy sectors. Large differences between MSs in the resulting RES shares, specifically for RES in the electricity sector, are however applicable, cf. Figure 36 or Figure 37. This is a consequence of different starting points and available cost-effective RES potentials.

3.3.2 Scenario-specific assumptions (by topical area)

Market design / Flexibility provision:

The design and operation of electricity markets are broad topics of their own. Within our related topical assessment, we thus focus on some core issues that impact RES-E integration, including grid development, electricity market design, and sector coupling / demand-side response. The underlying question is how distinct trends within abovelisted areas might affect the provision of flexibility required to accommodate variable generation stemming from renewable sources. Concerning the approach taken and the assumptions used, we partly base our model-based assessment on related analysis done within SET-Nav, specifically the case study analysis of centralised and decentralised electricity supply and the infrastructure requirements imposed. For the definition of scenarios and related assumptions, we build on the lessons learnt and the approach taken within the Intelligent Energy for Europe project towards2030-dialogue (www.towards2030.eu) where electricity market design trends have been subject of a thorough analysis. Box 4 (below) summarises some of the key electricity market design trends identified within this project.

Box 4: Electricity market design trends across Europe
(Source: towards2030-dialogue, cf. Resch et al. (2017))

The integration of renewable energy sources is only one out of several challenges governments face. Many changes in electricity market design can be traced back to the liberalisation process. In total, six trends have been analysed in more detail.

Regional pricing *describes the integration of markets to ensure efficient use of generation capacity. Market coupling and the adjustment of bidding zones to network constraints are mainly steered from the European level. Member states announce their willingness to cooperate, but at the same time, they try to prevent effects of international trade in their markets. Technically, the process is ongoing on the transmission level, but there are first attempts to open markets also on distribution grids level to balance out demand and supply locally instead of building additional lines.*

Capacity payments *are often justified by the "missing-money problem". Generators that set the marginal price for electricity have problems to recover their total generation costs. This missing-money problem is known in any liberalised market, but it is aggravated by increasing shares of variable renewable energies with negligible variable costs. The decision in favour or against capacity payments is currently taken on Member State level, but the European Commission increasingly monitors the discussed systems to prevent barriers for free trade of electricity. Capacity payments are common in balancing systems and other security strategies that are operated by transmission grid operators. For security on the distribution grid level, they play a minor role.*

Incentivising demand response *is another electricity market design trend. Historically, demand was assumed to be inflexible. Tariff structures and technical prequalification standards for markets have been designed accordingly. Member states and the European Commission increasingly demand for changes in the systems. Markets are to be opened for demand side bidding, prequalification standards are changed to allow for demand side participations. Consumers are equipped with metering technology that allows for variable tariffs. Many of the ongoing pilot projects are established on the distribution grid level (smart grid pilot projects). Big industrial consumers and pooled smaller consumers are increasingly influencing the development on the transmission grid level.*

Short-term trading *describes the trend to allow for trading close to the time of physical delivery. Forecasts for the infeed from fluctuating renewable energy sources are better the closer they are in time to the delivery date. Balancing responsible parties increasingly need opportunities to balance*

their schedule by buying electricity at "last minute". This is facilitated by the introduction of intraday markets which are currently only implemented on Member State and transmission grid level.
Accountability of renewables: *Renewable energy sources are increasingly integrated into market systems. On the one hand, this opens new opportunities for profits, and, on the other hand, they are increasingly subject to competition. The European Commission pushes for stronger accountability of renewables, while the implementation varies broadly on Member State level, depending on the support scheme. Renewables are increasingly used to balance variations in demand and supply on the transmission grid level as well as in smart grid projects on the distribution grid level.*

Scenarios reflecting major market design trends: The electricity market design trends described above needed to be concretized in the form of assumptions that can be used to operate electricity market models. Concrete design elements that have been included are capacity markets vs. Energy-Only markets (CM vs. EOM), the enabling and regulation of demand response participation (HIGH/REF), and progress in international high-voltage grid expansion (REF/DELAY). An overview on the modelled scenarios is given in Figure 38.

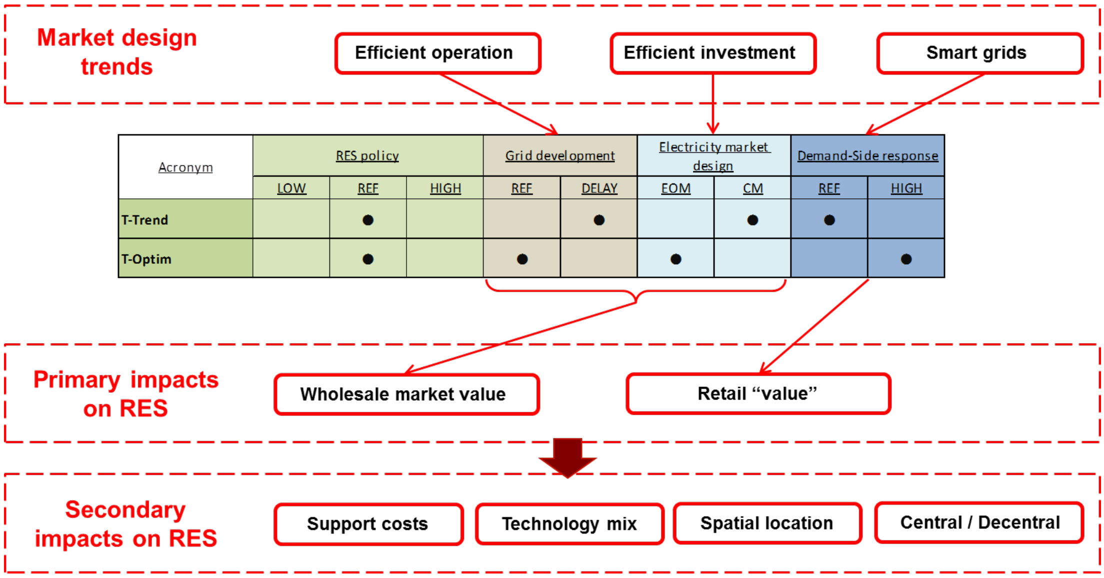


Figure 38: Mapping electricity market design trends to scenarios
(Source: based on towards2030-dialogue, cf. Ortner et al. (2016)).

The trends were summarized within the three categories efficient operation, efficient investment, and smart grids. For each of these trend packages, a dedicated set of modelling assumptions was foreseen. As a next step, two scenarios were derived: one representing selected ongoing trends (Trend) and another one reflecting a first-best solution to have optimal framework assumptions (Optimal) in the sense of efficiently working markets according to standard economic theory. In modelling, we take the following assumptions:

- **Trend market design**, characterised by a delayed grid extension, capacity markets prevailing in some EU countries and no measures that allow for demand response, is presumed in the **current policy scenario** where an overall RES share of (at least) 27% has to be reached by 2030.
- **Optimal market design**, characterised by a grid extension in line with plans, the clear dominance of energy only markets and accompanying measures to stimulate demand

response, is assumed in the **ambitious policy scenario** where 33% RES are presumed as 2030 target.

A comparison of the model results from both scenarios will, thus, allow us to derive quantitative insights on the relevance of selected electricity market framework conditions for revenues of RES-E technologies and their future deployment.

Policy-related aspects / Policy ambition:

Energy and climate policy provides the guiding framework for all market actors in the energy sector. Thus, policy decisions can stipulate certain developments in energy markets, ambitious policy targets may facilitate the uptake of specific energy technologies and/or may hinder others, etc... Without digging into details of how energy policy instruments are or should be designed, we take an umbrella view on how policy decisions may affect the optimal share of RES in the electricity sector and in district heating.

More specifically, in our assessment we assess how the overall policy ambition for renewables (and for energy efficiency) determines the required uptake of RES in the electricity sector, exemplified by the assumed overall target set for RES within the EU by 2030:

- Under the **current policy scenario** we assume that an overall **RES share of 27%** has to be reached **by 2030** at EU level, combined with an **energy efficiency target of 27%.**
- The **ambitious policy scenario** builds on the assumption that a stronger RES (and EE target) is established for 2030, i.e. assuming a **2030 RES target in size of 33%** instead of 27%, and **an energy efficiency target of 30%** instead of 27%.

3.3.3 Scenario comparison and conclusions

RES deployment and technology developments

Next we take a closer look at the expected *future development of RES in the electricity sector* at EU level according to the scenarios derived. More precisely, Figure 39 provides a comparison of the expected development of the RES share in gross electricity demand according to the assessed modelling cases. Striving for 27% RES by 2030 under trend market conditions, i.e. with delayed grid expansion, a patchwork of capacity and energy-only markets across MSs and no proactive demand response, implies to achieve a RES-E share around 49% (48.8% according to the current policy scenario) at the same point in time – if a least-cost policy approach is followed as conditioned in this exercise. Increasing the RES ambition to 33% by 2030 alongside the establishment of optimal market design would, in contrast to above, lead to an increase of the RES-E share to more than 62% (i.e. 62.1% by 2030 according to the ambitious policy scenario). The gap in the resulting RES-E share between both scenarios remains but is getting smaller over time. The dominance of RES in electricity supply in the long term (by 2050) appears however indispensable within both cases: according to the current policy scenario (27% RES – trend market design) a RES-E share of 85.6% is expected for 2050. The resulting RES-E share in the ambitious policy scenario is about 10 percentage points higher, reaching a share of 95.8% by then.

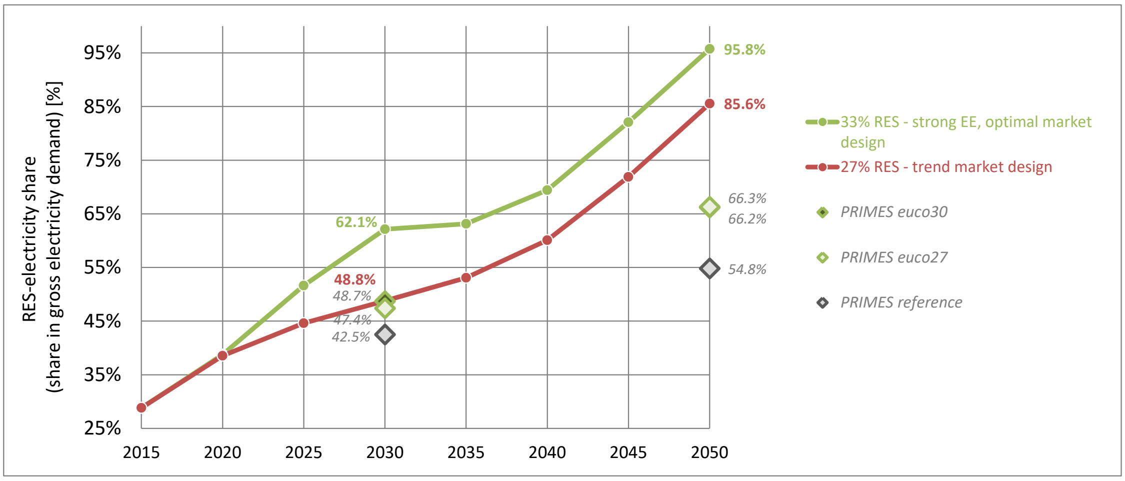


Figure 39: RES-E deployment in relative terms (i.e. as share in gross electricity demand) over time in the EU 28 for assessed scenarios

The corresponding illustration for the RES use in grid-connected heat supply is given in Figure 40. This graph shows the expected future development of the RES share in grid-connected heat supply at EU 28 level in relative terms according to both assessed policy scenarios, expressing heat supply from renewables in relation to the corresponding demand. Similar trends are applicable as discussed above concerning renewables in the electricity sector: under a 27% RES target for 2030 combined with trend market conditions it can be expected that by 2030 about half of the grid-heat demand would be met from renewables, i.e. a RES share of 52.5% is projected for the current policy scenario. An increase of the RES ambition to 33% by 2030, combined with a stronger target for energy efficiency (i.e. 30% instead of 27% by 2030) and with the establishment of optimal market design as assumed for the ambitious policy scenario (33% RES – strong EE, optimal market design) would lead to a comparatively stronger increase of RES in grid-connected heat supply: here a RES share of 60.8% is achieved by 2030. The corresponding figures for 2050 are 87.2% (current policy scenario) and 95.8% (ambitious policy scenario), respectively.

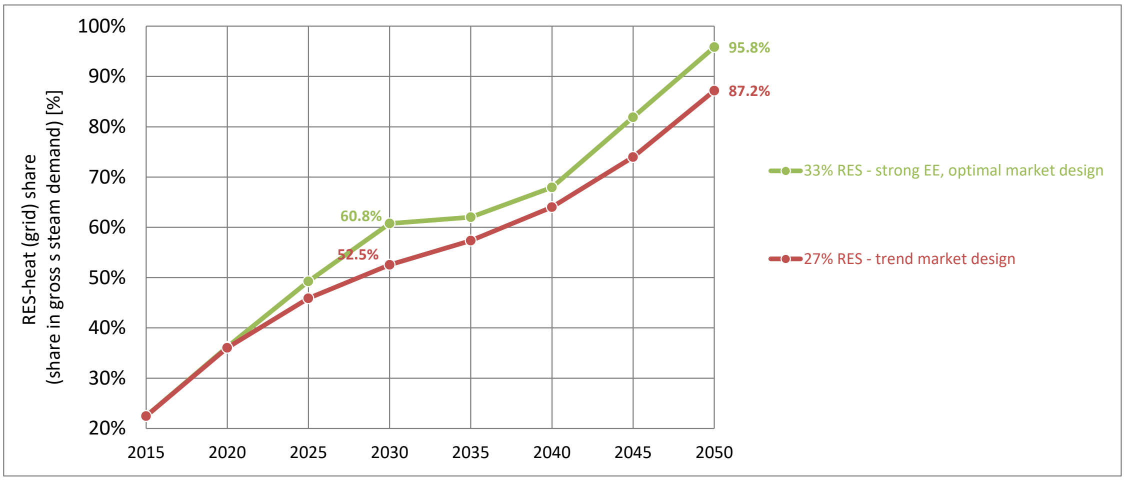


Figure 40: RES deployment in relative terms in heating & cooling (grid-connected heat supply) (i.e. as share in gross heat (grid) demand) over time in the EU 28 for assessed scenarios

The underlying technology mix

Complementary to the above, Figure 41 and Figure 42 provide a *technology breakdown of RES deployment* in the analysed sectors of electricity and grid-connected heat supply at EU 28 level according to both assessed scenarios by 2030 (Figure 41) and by 2050 (Figure 42), respectively. Additionally, both figures also indicate the status quo (as of 2015) at technology level.

Differences in the technology-specific RES deployment between assessed scenarios are generally larger by 2030 compared to 2050. These differences in the 2030 context are a consequence of the varying policy ambition for renewables – i.e. an overall RES target of 27% under the current policy scenario vs 33% in the ambitious policy scenario. By 2050 differences are getting smaller thanks to the steady and strong uptake of RES that comes along within both scenarios thanks to improved competitiveness of the various RES technologies in the mid- to long-term, by that point in time according to modelling independent from any policy intervention. A few illustrative examples for this general trend are:

- On average RES deployment within the electricity sector is 23% larger in the ambitious policy scenario compared to the current policy scenario by 2030. By 2050 the deviation declines to 12%.
- Largest differences between both scenarios are applicable for offshore wind in 2030: here electricity generation is more than twice as high in the ambitious policy scenario compared to the reference trend (i.e. +126% compared to the current policy scenario). By 2050 it is however only 21% larger in the ambitious compared to the current policy scenario.
- By 2050 largest differences between the distinct scenarios can be seen for biogas (i.e. +75% higher in the ambitious compared to the current policy scenario), geothermal heat (+56%) and solid biomass used for power generation (+32%).
- Photovoltaics and wind onshore are in a medium range when it comes to assess differences driven by the underlying policy ambition. In the case of PV deployment is 31% larger in the ambitious compared to the current policy scenario by 2030 whereas by 2050 the difference shrinks to 5%. Corresponding figures for onshore wind are 14% (higher in ambitious compared to current policy case) for 2030, declining again to 5% by 2050.
- In contrast to above, an almost identical deployment is observable for technologies like hydropower, electricity and heat from biowaste and solid biomass but also for novel technologies like CSP or tidal stream and wave power. (This shows that the policy ambition and the corresponding financial support has a strong impact on offshore deployment in underpins the need for dedicated strong support in the mid-term if offshore wind is expected to the difference amounts to deployment is from RES is only 12% larger in than. amounts to only

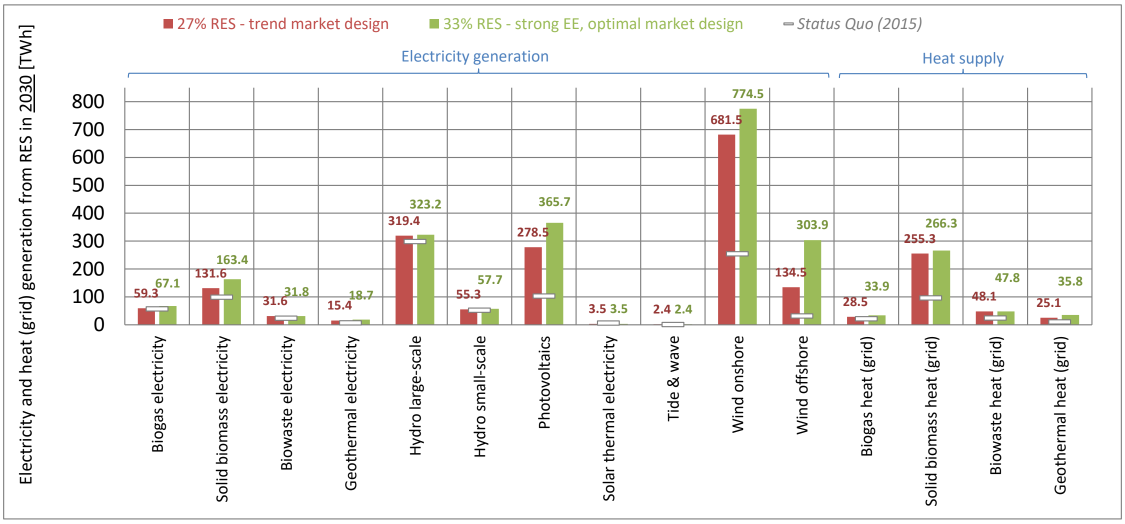


Figure 41: Technology-specific breakdown of RES-E and RES-H (grid) generation by 2030 at EU 28 level for all assessed scenarios.

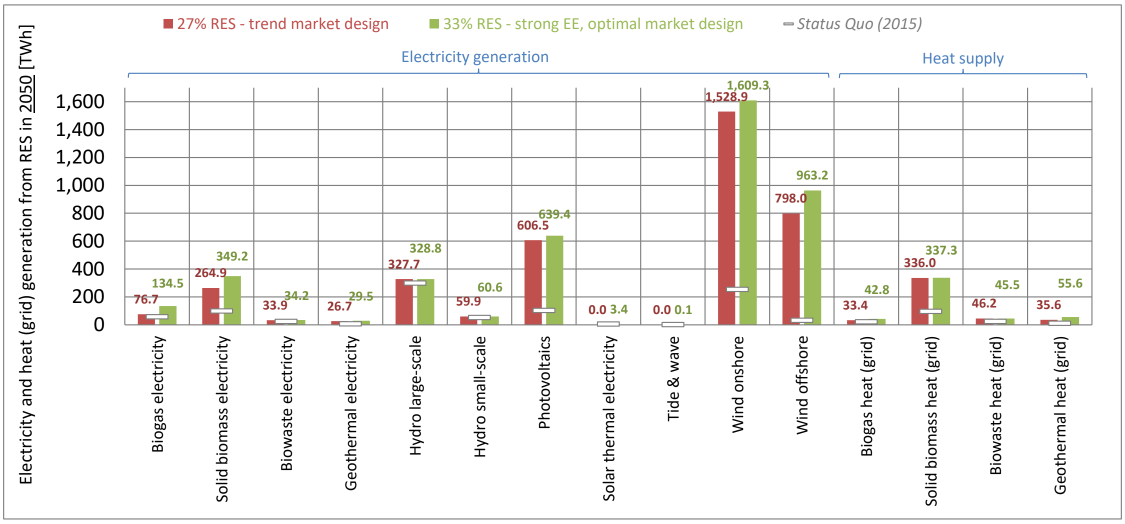


Figure 42: Technology-specific breakdown of RES-E and RES-H (grid) generation by 2050 at EU 28 level for all assessed scenarios.

Next we highlight some general technology trends, observable within both assessed cases and as such less affected by the underlying policy ambition for 2030: Noticeably, wind onshore is expected to become the dominant source of electricity supply in 2030 and 2050 within both scenarios. Offshore wind and photovoltaics also achieve significant contributions and both even surpass (large-scale) hydropower – the dominant renewable source as of today (2015) – in the long term (2050). Bioenergy, comprising a broad set of conversion technologies and feedstock sources, gains importance as well, specifically in the long term when fossil fuels are expected to diminish also in combined heat and power supply.

Investments in RES technologies

This is dedicated to assess the *investments* needed for the above discussed take-up of RES in the electricity sector and in grid-connected heat supply. In this context, Figure 43 provides a comparison of the future development of required investments in assessed RES technologies and sectors at EU 28 level in the period 2016 to 2050. More precisely, this graph depicts average yearly expenditures where the averaging is done over 5 year time slides. Capital expenditures are shown separately at sectorial level, distinguishing between RES in the electricity sector (incl. CHP) and in grid-connected heat supply.

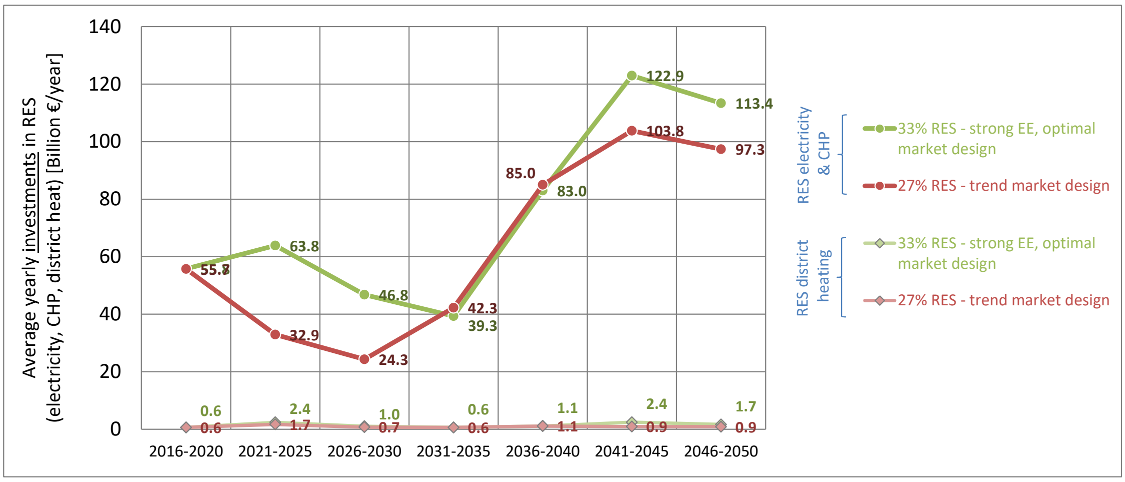


Figure 43: Average yearly investments in RES technologies in the electricity sector and in heating & cooling (grid-connected heat supply) over time in the EU 28 for assessed scenarios

As a general trend, one can observe after a period of declining investments in the near to mid future (up to 2035) a strong increase of investments in RES in the follow-up period, peaking around 2040 to 2045 and remaining at high levels in the final years up to 2050. Differences between assessed policy scenarios are applicable – i.e. investments are on average over the whole period about 19% higher in the ambitious policy scenarios (of striving for 33% RES by 2030) compared to the current policy scenario (aiming for a 27% RES share by 2030). The largest differences occur in the forthcoming decade (2021 to 2030) where investments would roughly remain at current levels in the ambitious policy scenario whereas under a moderate RES target of 27% a decline to half of that can be observed. Identical patterns are then followed within both cases in the period from 2030 to 2040, and in the final years after 2040 differences are again observable but somewhat lower in magnitude than in the early years.

The need for dedicated RES support

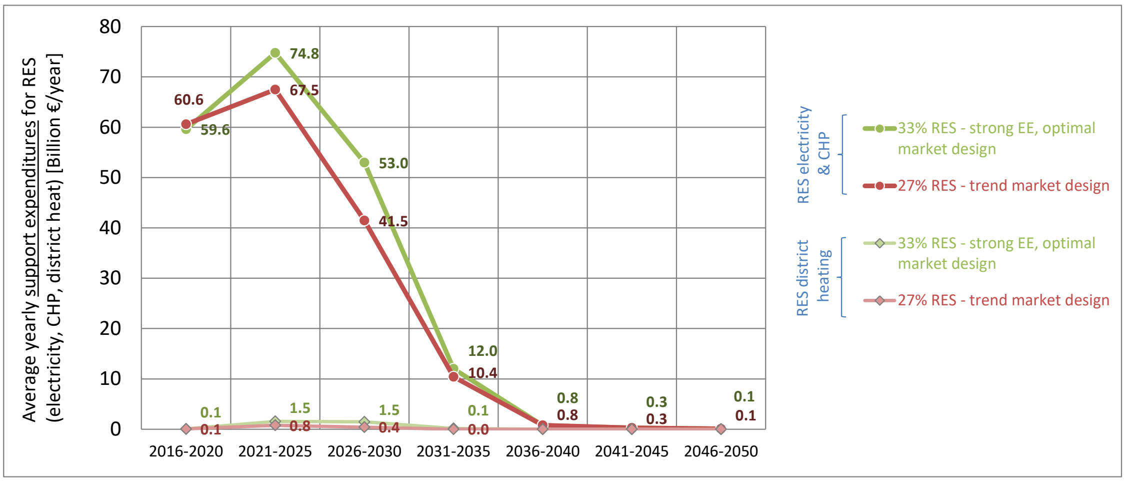


Figure 44: Average yearly support expenditures for RES technologies in the electricity sector and in heating & cooling (grid-connected heat supply) over time in the EU 28 for assessed scenarios

Next a closer look is taken at the need for dedicated financial support for RES in the electricity sector and in heating & cooling, limited to grid-connected heat supply. Figure 44 provides a comparison of the dynamic evolution of the required support expenditures at EU 28 level in the period 2016 to 2050 for assessed RES technologies and sectors. More precisely, the graph displays average yearly expenditures where the averaging is done over 5 year time slides. Support is shown separately at sectorial level, distinguishing between RES in the electricity sector (incl. CHP) and in grid-connected heat supply.

As a general trend, one can see a strong decline of support expenditures over time: Expenditures show a peak in the period 2021 to 2025, and strongly decline in the years thereafter. Post 2030 support expenditures are at a negligibly low level within both sectors and for both assessed policy cases. This is a consequence of, on the one hand, expected cost reductions for RES technologies, and, on the other hand, by the underlying trends concerning prices for fossil fuels and carbon emissions where rising prices are assumed according to PRIMES modelling. This trend also shows that the bulk of support expenditures in the forthcoming decade(s) is dedicated to RES installations that have been erected in the years up to 2020. Another general pattern is that support for RES in the electricity sector (including CHP) is by a factor of around 100 higher compared to heating & cooling, here limited to (heat only) district heating within this comparison.

Differences between assessed policy scenarios are applicable, specifically in the period up to 2035. On average, support expenditures are 11% higher in the ambitious policy scenario (i.e. striving for 33% RES by 2030) compared to the current policy scenario (i.e. where a RES target of 27% is proclaimed for 2030). For comparison, 2030 RES deployment of assessed technologies is 23% larger in the ambitious compared to the current policy scenario.

Thus, one can conclude that there is a need for dedicated RES support in the period post 2020, even if a moderate 2030 RES target of striving for a RES share of 27% is followed. The 2030 policy ambition for RES has an impact on the resulting cost but the increase of policy cost is significantly lower in magnitude than the corresponding increase in RES generation.

3.4 Transport

3.4.1 Scenario description and factsheets

Two scenarios are calculated and described more in detail in the following:

1. A **Current Policy Scenario (CP)**, which reflects the effects of currently implemented policies and serves as a benchmark scenario. The macro-economic development reflects a continuation of past trends.
2. An **Ambitious Policy Scenario (AP)** represents a market situation in which the vehicle stock is fully electrified in the EU28 in the year 2050. In this context, fully electrified means 100% battery electric vehicles (BEVs). Hence plug-in hybrid electric vehicles (PHEVs / EREVs) and fuel cell vehicles (FCVs) play no role in this scenario.

The following fact sheets summarise the two scenarios main assumptions and key results, before the following section describes assumptions in more detail.

Factsheet Scenario “Current policies”. Transport

The current policy scenario assumes that policies adopted in 2014 remain in place and are effectively implemented. National differences in the policy intensity continue to exist. For the CO2 standards for cars and vans, it is assumed, based on current reduction trends, that the 2020/21 CO2 targets for the fleet of new vehicles set out in the Regulations are achieved and remain constant afterwards (for cars 95gCO2/km by 2021).
Complementary, the Directive on alternative fuels infrastructure supports the development of electro-mobility and the uptake of other alternative fuels as long as incentives for the uptake of alternative powertrains/vessels are in place at Member State level.

Results

In the current policy scenario, the vehicle stock of electric vehicles would amount to approximately 3.5 % of the total passenger cars stock and the electricity demand in the passenger transport of average 1.9 TWh, here highest electricity demand is registered in the UK of 11 TWh and lowest in Cyprus and Croatia of 0.1 TWh (Figure 46).

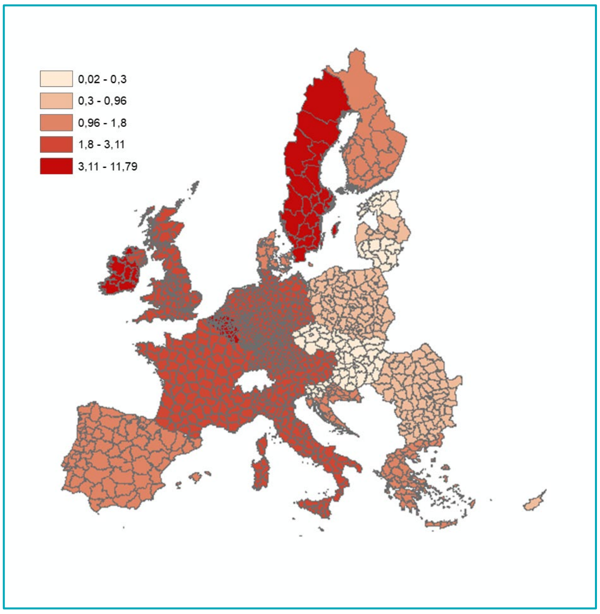


Figure 45 Energy demand from electrified vehicles in 2050 (TWh)

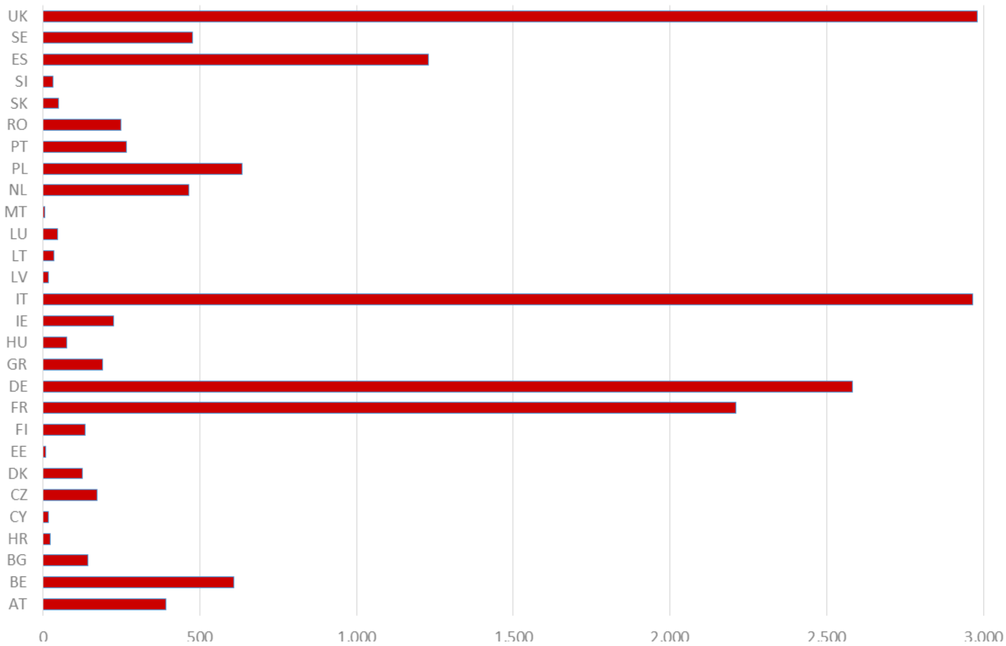


Figure 46 BEV vehicle stock in 2050 under current policies analysis (in thousand units)

Factsheet Scenario “Ambitious policies”. Transport

Present a market situation in which the vehicle stock is fully electrified in the EU28 in the year 2050. In this context, fully electrified means 100% battery electric vehicles (BEVs). Hence plug-in hybrid electric vehicles (PHEVs / EREVs) and fuel cell vehicles (FCVs) play no role in this scenario. The rationale for this is as follows: (i) battery improvements and fast recharging infrastructure remove the key advantage of PHEVs over BEVs (i.e. range), thereby reducing the attractiveness of PHEVs; (ii) uncertainty with regards to FCV model offerings from manufacturers (e.g. there are only three large FCV models in the market today), cost evolution of key FCV components and investment requirements for hydrogen refuelling infrastructure remain significant barriers to the market deployment of this powertrain.

However and as can be seen in Table 1 and Table 3, the electric powertrain is available only for medium-sized PCs in the current version of DIONE. This acts as a limiting factor for the construction of the HOTMAPS ambitious policies scenario.

We assume that the fleet of PCs is fully electrified by assuming small and large cars become medium-sized BEVs. In this case, 88% of the vehicle stock would be electric. A 100% electrified fleet is possible only if LCVs, HDVs and buses are excluded from the modelling exercise. In this analysis, the projected vehicle stock for the EU28 in 2050 is ca. 346 million vehicles. Passenger cars account for over 87% of the stock (see Figure 47).

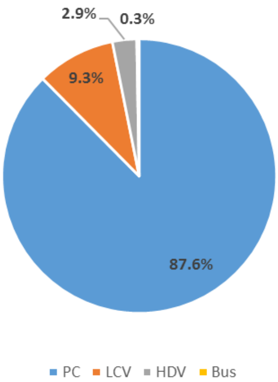


Figure 47 Projected vehicle stock in 2050

Results

In the ambitious policy scenario 100% of BEVs in the passenger fleet would mean the average electricity demand of the 17.4 TWh in EU28 with highest in the UK of 95 TWh and lowest in Malta, following the trend in BEV stock (Figure 49).

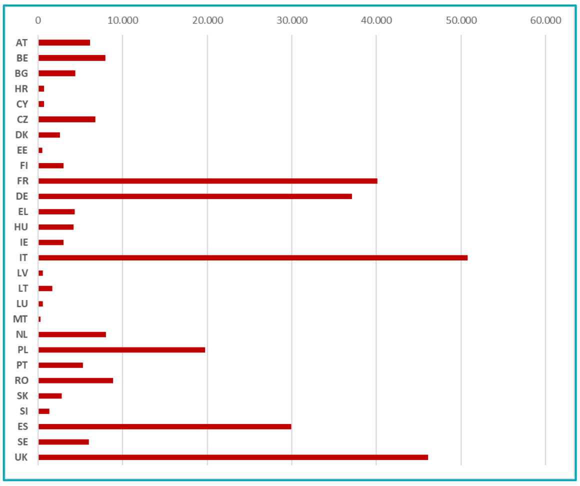


Figure 48 BEV vehicle stock in 2050 under ambitious policies scenario (in thousand units)

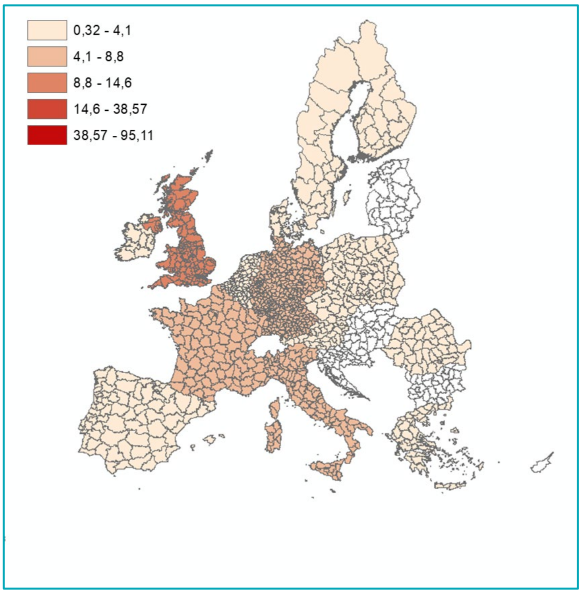


Figure 49. Energy demand in transport with 100% electrified passenger car fleet

3.4.2 Scenario comparison and conclusions

According to the analysed data, the overall final energy consumption fro private passenger fleet decreases significantly in the scenario with 100% BEVs in the fleet in all MS. For example, in Italy the overall annual final electricity consultation currently is accounted for 320 TWh (Terna, 2018). In our Ambitious policy scenario electricity consumption from transport assuming no significant increase in public one, trains and air travel, would mean. Currently in the future scenario the overall energy consumption by private transport would mean 20% of all electricity demand in Italy in 2050 would come from transport sector. However, the overall final energy demand from transport sector according to the scenario B in Italy would mean a decrease by 20% in respect to the BAU scenario should the private transport go 100% electric in 2050.

4 The role of scenarios in the Hotmaps toolbox

Scenarios are an important means to ensure consistency of local, regional, national and EU wide planning. The Hotmaps toolbox will allow the users (energy planners, public authorities) to assess different heating and cooling strategies for the local area regarding their impact on costs, CO_2- emissions, energy demand and energy carrier mix by using calculation modules.

The development of a current policy scenario and an ambitious scenario for local and national scale allows the user to classify the considered and analysed strategies in the context of the national heating and cooling strategies. Thus, the user is able to identify and compare most cost-effective solutions to achieve certain climate mitigation or energy policy targets.

The comparison of individual strategies for the transformation pathways requires predefined indicators. In the Hotmaps project, the main indicators for the comparison are the following:

- Primary energy demand by energy carriers and end-use
- Share of Renewable energy sources
- Final energy demand by energy carriers by end-uses
- Useful energy demand for space heating and hot water, cooling
- CO_2-emissions
- Total costs
- Specific costs

In the Hotmaps toolbox, the comparison functionality serves that purpose. In Figure 45, a potential visualization of the comparison functionality is presented. The user will be able to assess and compare the single indicators of his current work (green and red line) with default data, which can be derived from the generically created scenario data.

Moreover, the predefined, generic scenario data will allow the user to apply e.g. data regarding CO_2-emission factors for electricity in a certain scenario or expected renovation activities and resulting space heating demand, if the user does not have more accurate and tailor made data available on the local level.

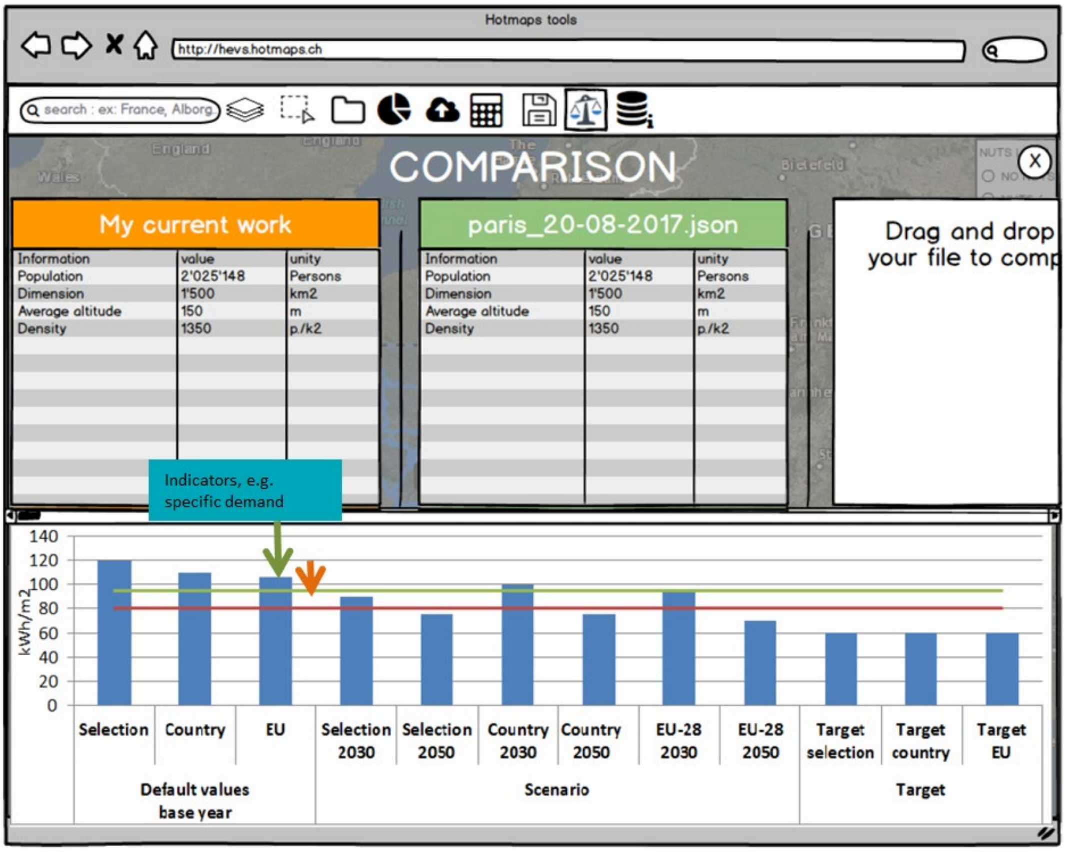


Figure 50: Exemplary Representation on the scenario visualization in the Hotmaps Toolbox

The Hotmaps scenarios are available on GitHub in the Hotmaps project (https://gitlab.com/hotmaps) and can be downloaded. In course of the project (and beyond), we intend to continuously update the scenario database by new scenarios developed in course of several other projects.

More information on how to use the scenarios in the Hotmaps toolbox will be described in the Hotmaps handbook.

References

EMISIA, 2014. Development of a tool for assessing the fleet-level impacts of new road transport technologies, with emphasis in electromobility. Final report.

European Commission, 2016. SWD(2016) 410 final: Impact assessment. Accompanying the documents: COM(2016) 861 final, SWD(2016) 411 final, SWD(2016) 412 final, SWD(2016) 413 final. Available online https://ec.europa.eu/energy/sites/ener/files/documents/mdi_impact_assessment_main_report_for_publication.pdf, accessed on 15.03.2017, Brussels, 30.11.2016.

European Environment Agency (EEA), Corine Land Cover (CLC) 2012, Version 18.5.1., 2012.

Eurostat, Database – Eurostat, Population on 1 January by broad age group, sex and NUTS 3 region, (Code: demo_r_pjanaggr3), 2018. URL http://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-data/database (accessed 5.15.18).

Eurostat, Gross value added at basic prices by NUTS 3 regions [nama_10r_3gva], 2016.

Eurostat, Heating degree-days by NUTS 2 regions – annual data [nrg_esdgr_a], 2013.

Eurostat, CensusHub2, 2011 Census database (Census Hub 2), 2011. URL https://ec.europa.eu/CensusHub2/query.do?step=selectHyperCube&qhc=false (accessed 2.15.18).

Fleiter, T.; Steinbach, J.; Ragwitz, M. (projekt coordination) et al. (2016): Mapping and analyses for the current and future (2020 - 2030) heating/cooling fuel development (fossil/renewables). Fraunhofer ISI, Frauhofer ISE, TU Wien, TEP Energy, IREES, Observer:

Fleiter, Tobias; Fehrenbach, Daniel; Worrell, Ernst; Eichhammer, Wolfgang (2012): Energy efficiency in the German pulp and paper industry - A model-based assessment of saving potentials. In: Energy 40 (1), S. 84–99. Online verfügbar unter http://www.sciencedirect.com/science/article/pii/S036054421200120X.

Fleiter, Tobias; Schlomann, Barbara; Eichhammer, Wolfgang (Hg.) (2013): Energieverbrauch und CO2 Emissionen industrieller Prozesstechniken - Einsparpotenziale, Hemmnisse und Instrumente. Fraunhofer Institut für System- und Innovationsforschung. Stuttgart: Fraunhofer Verlag.

Haylock, M.R., van den Besselaar, E. J. M., van der Schrier, G., Klein Tank, A. M. G., A European daily high - resolution observational gridded data set of sea level pressure. JOURNAL OF GEOPHYSICAL RESEARCH 116, 2011.

Kranzl, L., Hummel, M., Müller, A., Steinbach, J., Renewable heating: Perspectives and the impact of policy instruments. Energy Policy, 59 (2013), pp.44-58. https://doi.org/10.1016/j.enpol.2013.03.050

Müller, A., Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock (PhD-Thesis). Technische Universität Wien, Wien, 2015.

Müller, A., Büchele, R., Kranzl, L., Totschnig, G., Mauthner, F., Heimrath, R., Halmdienst, C., 2014. Solarenergie und Wärmenetze: Optionen und Barrieren in einer langfristigen, integrativen Sichtweise (Solargrids), Neue Energien 2020. Technische Universität Wien, Institut für Energiesysteme und elektrische Antriebe, Energy Economics Group, Wien.

Müller, A., Stochastic Building Simulation, working paper. Available at http://www.marshallplan.at/images/papers_scholarship/2012/Mueller.pdf., Berkely, 2012.

Rehfeldt, Matthias; Fleiter, Tobias; Worrell, Ernst (2018): Inter-fuel substitution in European industry. A random utility approach on industrial heat demand. In: Journal of Cleaner Production 187, S. 98–110. DOI: 10.1016/j.jclepro.2018.03.179.

Resch G., L. Liebmann, A. Ortner, J. Geipel, M. Welisch, A. Hiesl, C. Zehetner, S. Busch, M. Ragwitz, A. Held, S. Steinhilber, M. Magosch, C. Klessmann, L. Janeiro, L. Tesniere, A. Behrens, A. Hassel, F. Genoese, C. Karakosta, A. Papapostolou, H. Doukas, J. Jansen, K. Veum, J.M. Glachant, A. Henriot, H. Gil, L. Szabo; 2017. Final report of the project towards2030-dialogue. A European research project led by TU Wien, supported by the EASME of the European Commission within the "Intelligent Energy Europe" programme. TU Wien, Energy Economics Group, Vienna, Austria, July 2017. Accessible at www.towards2030.eu.

Schremmer, C., Derszniak-Noirjean, M., Keringer, Florian, Raffael Koscher, Michael Leiner, Ursula Mollay, Edith Stifter, Joanne Tordy, Lukas Kranzl, Mostafa Fallahnejad, Lukas Liebmann, Andreas Müller, Gustav Resch, Jan Steinbach, Rainer Elsland, André Kühn, Frederik Mayer, Martin Pudlik, Gerda Schubert, Simin Davoudi, Paul Cowie, Paola Gazzola, Territories and low-carbon economy (ESPON Locate), Annex to the Final Report (Scientific Report). ÖIR GmbH, Vienna, 2017.

Thiel, C., Drossinos, Y., Krause, J., Harrison, G., Gkatzoflias, D., Donati, A.V., 2016. Modelling Electro-mobility: An Integrated Modelling Platform for Assessing European Policies. Transp. Res. Procedia, Transport Research Arena TRA2016 14, 2544–2553. https://doi.org/10.1016/j.trpro.2016.05.341