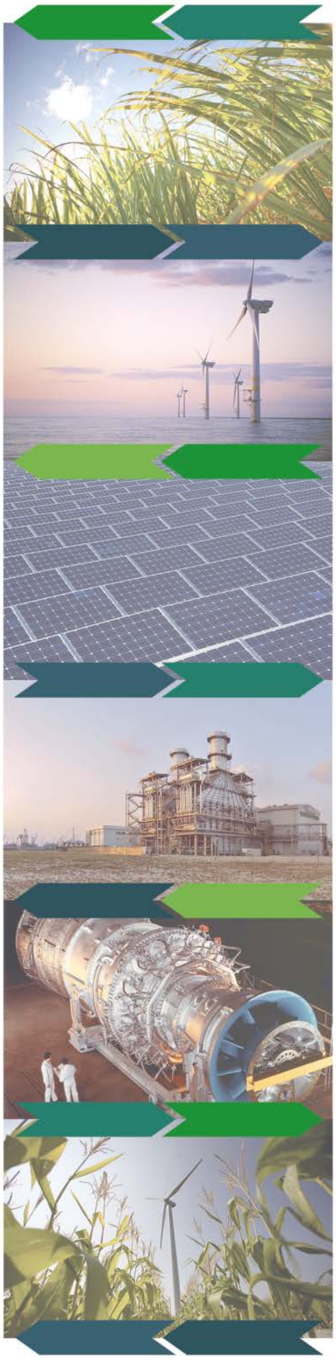
Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation



D.5.3: Summary report on case study: Energy demand and supply in buildings and the role for RES market integration

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SET-Nav
Strategic Energy Roadmap

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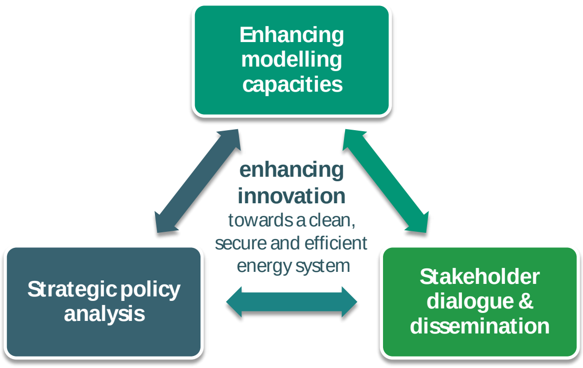
About the project

SET-Nav aims for supporting strategic decision making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.



Who we are?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.

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Executive Summary

This report presents and discusses the main outputs from a modelling **case study within the SET-Nav project** dedicated to the analysis of **energy demand and supply in buildings** and the role for renewable energy market integration in the electricity system. The overall objective of the work package in which this case study was conducted is to provide and apply the modelling capabilities of the project consortium for the analysis of the demand side of energy systems including buildings, industrial processes and transport.

This specific case study aims to analyse the link between energy efficiency improvement in buildings, heating system choice, demand side flexibility options and renewable energy sources (RES) deployment. The goal of the case study is to analyse the role of these elements in different **future energy transition pathways** and in particular to identify measures needed to decarbonize heating and cooling supply of the European building stock. Within this section a concise summary of the main modelling results is presented. Those include the expected final energy demand development for EU28 up to the year 2050 for a current policy and ambitious policy scenario, related costs for heating and cooling from an end user perspective, potentials for district heating as well as an analysis of the impacts on the electricity system and main policy conclusions.

Methodology and scenario definition

Several models were used for the simulations performed within this case study. The **building stock model INVERT/EE-Lab** (see www.invert.at) simulates the development of demand and supply for heating and cooling in the European building sector. The model **eLOAD** was applied to transform the output from INVERT/EE-Lab from annual data into **hourly load** profiles for electrical heating and cooling supply technologies (ACs, heat pumps, direct electric heating). These data were fed into the supply models **Enertile and EMPIRE** to study the relationship between the **electricity sector** and developments in the building sector across the EU in several scenario runs: Model outputs from the model **Green-X** were used to compare biomass use in the building sector with the allocation of biomass across sectors to make sure that the potential for biomass as a source for heating in the building sector is not overestimated. For detailed model description and extensions developed for the main models in WP5 please see deliverable 5.1 of the SET-Nav project on data exchange and model linkages and chapter 2 of this report.

The starting point of the analysis of this case study was the computation of **2 scenarios** calculated with the building stock model INVERT/EE-Lab. For more information on the building stock model and policy impacts in the model please see Müller (2015), Kranzl et al. (2013) or Steinbach (2015). A **current policy scenario** was calculated assuming that all existing policy measures related to the European building stock are implemented in their current form and continue to be valid until the year 2050. In the **ambitious policy scenario** measures already implemented in the current-policy scenario were intensified. Modifications were done by **increasing investment subsidies** and corresponding budgets on country level, tightening the obligations for renewable heating and thermal renovation measures including **intensifying the building codes** by reducing the heat transfer coefficient of the building components after refurbishment and for new buildings.

The results on annual energy demand for heating and cooling from both scenarios are transformed into hourly profiles and fed into the electricity system models for further analyses.

Results on energy demand and renewables in the building stock until 2050

In this section the selected modelling results will be illustrated. First, the **development of heating and cooling demand for the current and ambitious policy scenario** is discussed. Second, **related investment costs and energy expenditures** are illustrated. Finally we further discuss the potentials of **district heating** and the potential connections of heating and cooling with the **electricity system**.

Results on energy demand in the EU28 building stock

Table 1 shows the modelling results from the model Invert/EE-Lab for final energy demand in the EU28 member states for space heating, hot water and cooling from 2012 to 2050. 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 are expected to 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** (see section 3.2), which lead to lower space heating demand. Hot water demand and demand for auxiliary energy to operate heating systems stays rather constant.

Table 1 also 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.

Table 1: Development of final energy demand per end use category for EU28

Final energy demand (TWh)	hot water		space heating		cooling		auxiliary energy demand		TOTAL	
	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	3006
2040	526	538	2187	1943	171	184	57	56	2941	2720
2050	536	554	1953	1651	207	222	58	56	2754	2483

Figure 1 illustrates the development of **final energy demand per energy carrier** in each scenario. It can be clearly seen that fossil energy carriers decrease substantially in both scenarios.

Fuel oil and coal disappear from the heat generation mix and are mainly **substituted by biomass boilers**. Despite a significant decrease **natural gas** still makes up for a **large share of heat supply** until 2050. 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.

Although **district heating is expected to increase its market share** in both scenarios, total energy demand from district heating networks is expected to stay constant or decrease due to higher efficiencies of connected buildings. **Electricity demand** for heating and cooling in European buildings is expected to stay more or less **constant**. However there is a shift from space heating to space cooling. Electricity demand for space heating and hot water supply is expected to decrease despite a significant increase of market shares of heat pumps in particular in new buildings.

Ambient heat exploited by the **use of heat pumps** is also indicated in Figure 1 illustrating the increase of heat pump installations until 2050. In both scenarios the share of biomass doubles from 12% in 2012 to around 23% to 24% in 2050. Total **biomass** use for decentral heating **increases** by +34% in the current policy scenario and +25% in the ambitious policy scenario until 2050. The increased thermal efficiency of the building stock in the ambitious policy scenario thus also helps to conserve limited biomass resources as a valuable renewable energy carrier for higher temperature levels needed in other sectors for ambitious decarbonisation targets calculated in the further course of the SET-Nav project.

Figure 2 illustrates the resulting shares of fossil and renewable energy carriers as well as the secondary energy carriers electricity and district heating in final energy supply for heating and cooling the EU28 building stock. 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. Note that natural gas accounts for more than 90% of fossil energy carriers in 2050. Coal and fuel oil are disappear according to the model results due to the implemented policies and assumptions on energy price developments. **Decentral Renewable energy carriers** (biomass, ambient heat and solar thermal) are expected to increase 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 is expected to decrease. In both scenarios the **share of district heating is increases** from 10% to 15% in the current policy and 14% in the ambitious policy scenario, respectively.

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. Potentials for district heating which can be seen as a substitute for natural gas in urban areas are discussed below. Moreover, additional potentials for efficiency improvement by increased building retrofit will need to be exploited for a more ambitious climate mitigation scenario in line with the COP 21 Paris climate agreement.

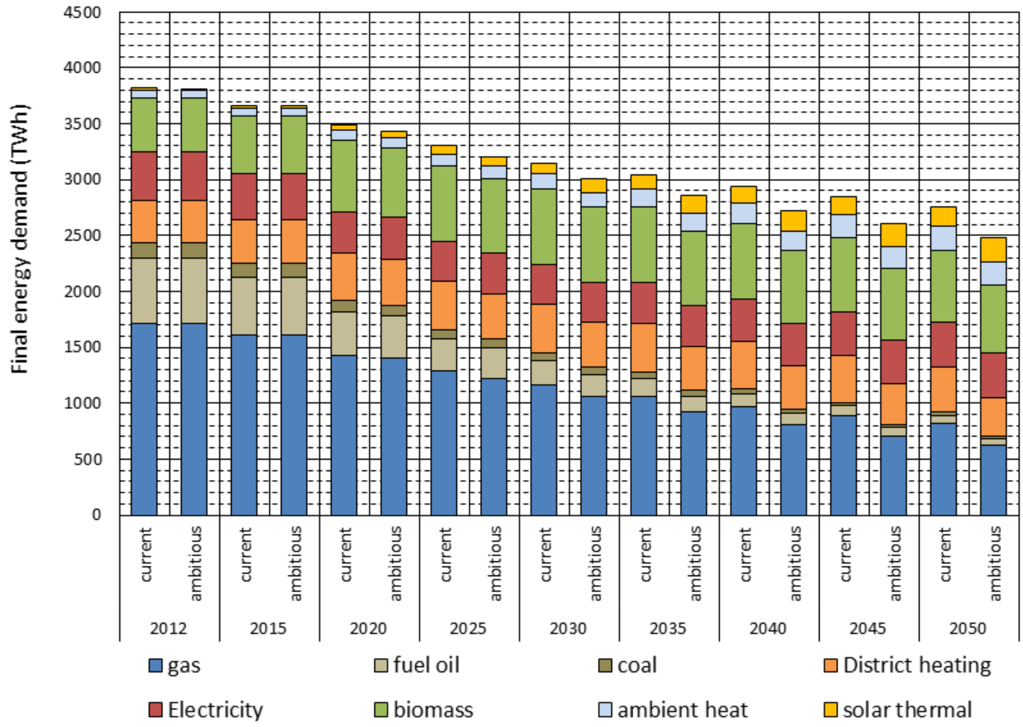

Figure 1: Development of final energy demand for heating and cooling per energy carrier – EU28

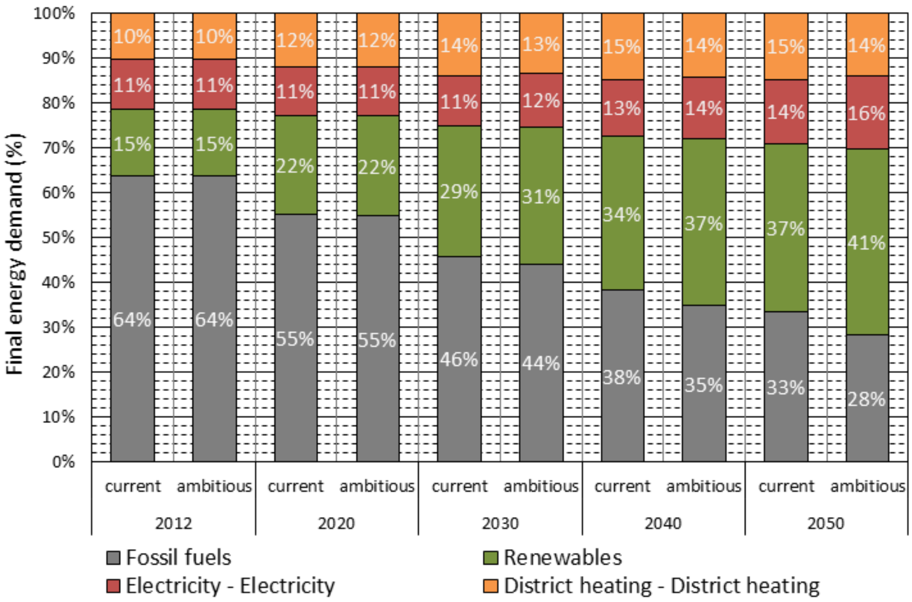

Figure 2: Shares of fossil fuels, renewables, electricity and district heating in final energy demand for space heating, hot water and space cooling supply in EU28 until 2050

Results on investment costs and energy expenditures

Following the reduction of final energy demand for space heating, **energy expenditures** for households and the service sector are expected to **decrease significantly**. Figure 3 shows energy expenditures from an end user perspective on the main energy carriers for heating and cooling in EU28 until 2050. Annual energy expenditures are reduced by around -25% in the current policy scenario and -35% in the ambitious policy scenario respectively. The reduction is mainly a result of **reductions in expenses for fossil energy** carriers while expenses for biomass and district heating slightly increase. Energy expenditures for electricity are expected to increase due to increasing electricity consumption for cooling which increase from around 15 billion € in 2012 to more than 50 billion € in 2050 annually.

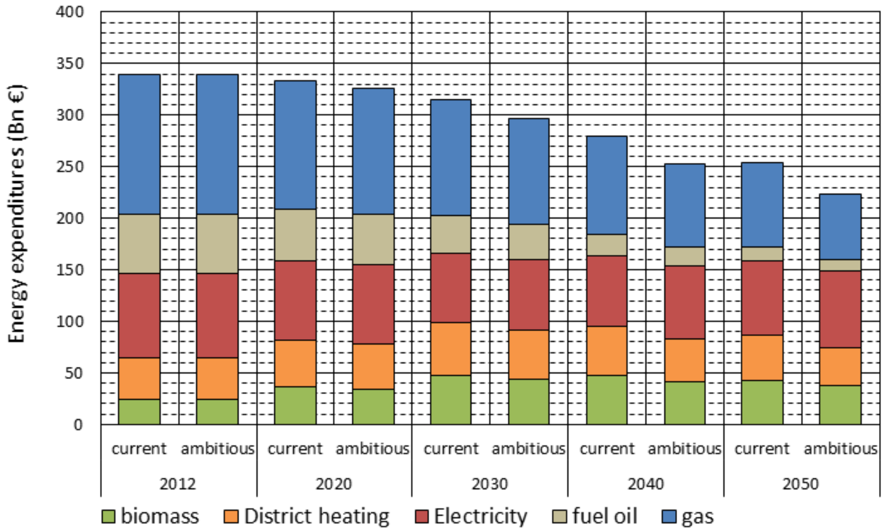

Figure 3: Energy expenditures for space heating, hot water and space cooling by energy carriers in EU28 until 2050

Total annual investments in heating systems and thermal refurbishments which are illustrated in Figure 4 are estimated to be between 100 billion € and 120 billion € in the current policy scenario in the period between 2015 and 2050. The **ambitious policies assumed lead to an increase in annual investments** of around 20 to 25 billion € across EU28 throughout the whole period. The additional investments are mainly a result of higher investments in thermal retrofit measures and (to a lower extent) higher investments in heating systems in particular solar thermal systems as illustrated in Figure 5.

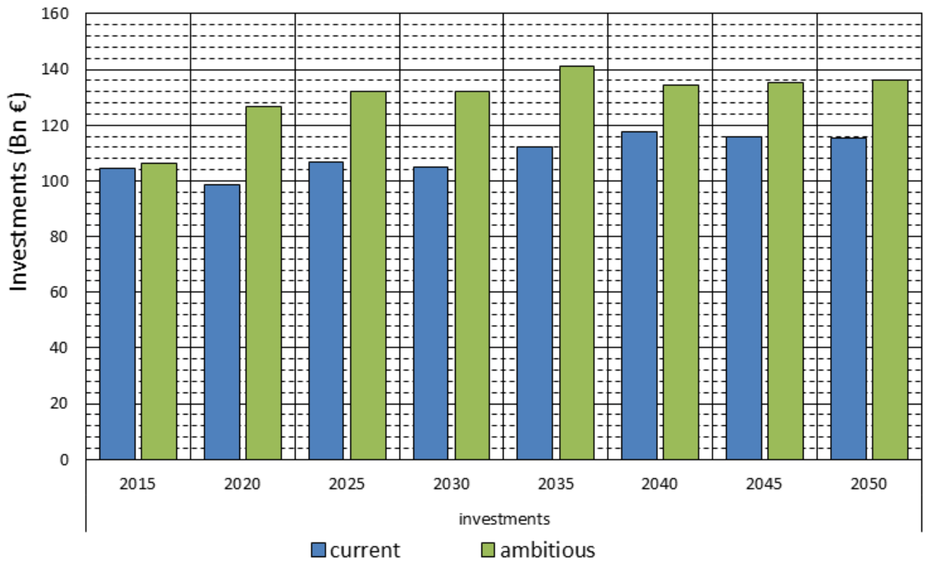

Figure 4: Annual investments in thermal refurbishment and heating systems in EU28 until 2050

Figure 5 shows investments from an end user perspective in heating systems per energy carrier. The scenario results indicate that biomass boilers, heat pumps and solar thermal systems account for the main share of investments in new heating systems while investments in **fossil heating systems** (mainly natural gas boilers) only account for **less than 20% of investments** throughout the period between 2015 and 2050.

Heat pumps are mainly installed in efficient newly constructed buildings with low temperature heat distribution systems in the model. Biomass boilers substitute oil fired boilers in the existing building stock. The investments in solar thermal systems in combination with other heating systems increase substantially in both calculated scenarios.

Note that investments in district heating systems are to a large extend covered by the network operator and are therefore reflected in the energy costs from an end user perspective which is why investments shown in Figure 5 are low although the number of buildings connected to a district heating network increases in both scenarios. Investments in direct electric heaters are low in both scenarios as most installed electrical heating system in the model are more efficient heat pumps.

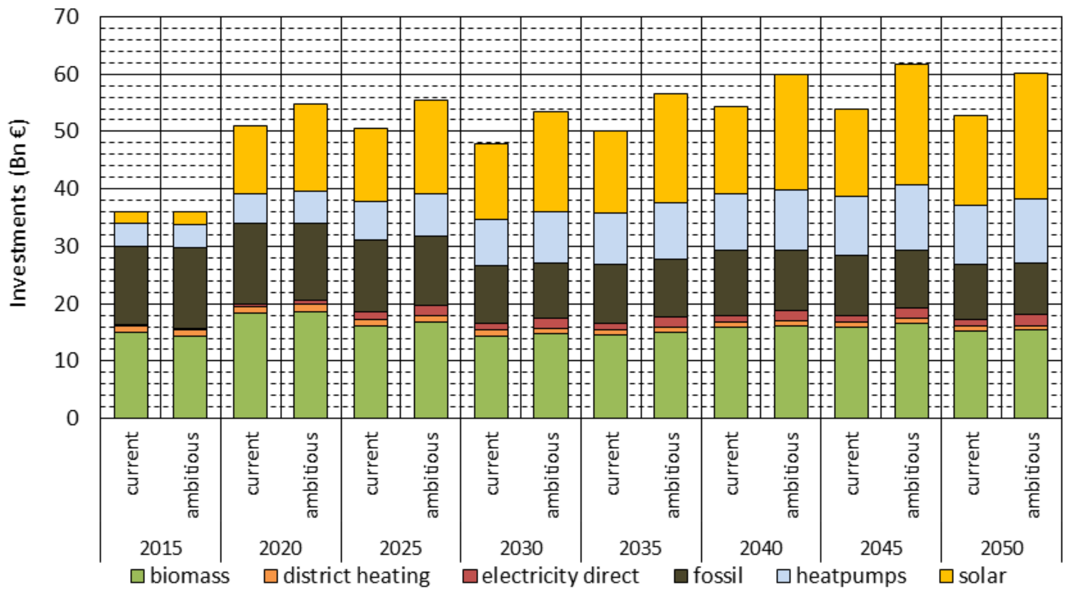

Figure 5: Investments in heating systems per energy carrier from an end user perspective in EU28 until 2050.

Results on district heating potentials

In an additional analysis the **potential of district heating** across EU28 was assessed based on **heat density** maps for Europe which were calculated based on the results modelling results on energy demand development. The resulting heat demands from the INVERT/EE-Lab model runs were disaggregated to 100x100m resolution for EU28 to estimate **spatial distribution of heat demand** which is required to assess district heating potentials and costs. In general, the higher the heat density (defined as heat demand per 100x100m cell) of a region, the lower the distribution costs for district heating will be (see Persson et al. 2017). Apart from the total heat density of an area the **market share of district heating** (share of heat demand connected to the grid) within an area is the main parameter influencing distribution costs. Figure 6 visualizes estimated average **heat distribution costs** in district heating networks in EU 28 member states for the current policy scenario results as cost curves derived from those disaggregated heat demand maps. Heat distribution cost curves for estimated heat densities in the year 2015 and

2050 (dashed line) and market shares of 45% (orange lines) and 90% (blue lines) are illustrated in this figure.

It can be seen that if high shares of buildings within densely populated urban areas are connected to heat networks, up to more than 40% of heat demand in Europe could be supplied with district heat at heat distribution costs below 20 €/MWh which is considered to be a reasonable cost threshold for heat networks to be competitive compared to decentral heating systems.[1] Those low distribution costs levels can also be reached when heat demand reductions up to 2050 are considered. However such high connection rates are hard to achieve in reality due to several barriers including the long lifetime of existing decentral heating systems and preferences from building occupants as well as planners.

Figure 6 also indicates the share of useful energy demand which is currently connected to district heating networks (Actual share 2015) as well as the share of district heating in total useful heat supply in the calculated current policy scenario for the year 2050 (Simulation Results 2050). This analysis indicates that there is **additional potential** for theoretically cost efficient **district heating if high connection rates can be achieved** up to the year 2050. Such high market shares however are not likely to be achieved without regulatory support. Zoning approaches including the identification of **district heating priority areas** can be suitable measure to increase the economic efficiency of district heating networks in the future.

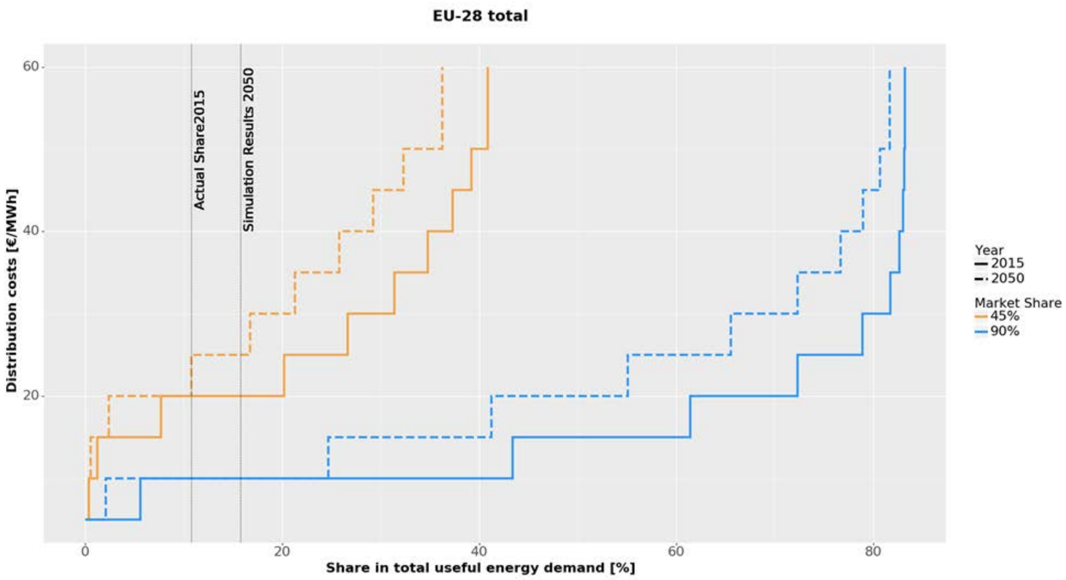

Figure 6: Estimated heat distribution costs for EU 28 in the current policy scenario for heat densities in the year 2015 and 2050 and district heating market shares of 45% and 90%

[1] Note that several other factors like available heat sources, costs of decentral heating options, energy prices etc. also influence the competitiveness of district heating. Distribution costs are therefore only one indicator and heat networks have to be assessed case by case to assess costs on a local level which was not scope of this case study.

Results on the impact of heating and cooling on the electricity sector and flexibility provided by heating and cooling technologies

Based on the scenario results from the building stock model, **hourly loads for heating and cooling** where estimated for all years until 2050. Figure 7 illustrates the changes in the electrical load based on the scenario results in the current policy scenario for EU28. Despite the increase in deployment of electrical heat pumps for decentral heating in Europe the scenario results indicate that electrical load peaks in the **winter season are not expected to increase significantly** due to increased thermal efficiencies of buildings and the substitution of less efficient direct electric heating systems with heat pumps and other non-electric heating systems. **Electrical peak loads in summer** however are expected to increase significantly due to the expected increase in the deployment of air conditioning systems across Europe.

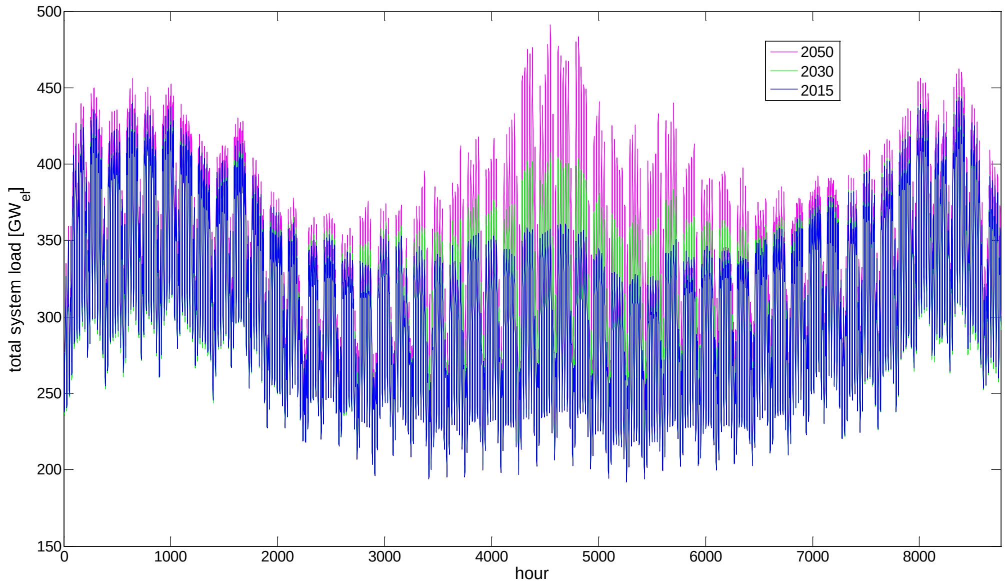

Figure 7: Change of hourly electrical load based on changes in heating and cooling demand from the current policy scenario

The hourly loads modelled in Invert/EE_Lab and e-load were implemented in the **electricity system models** Enertile® and EMPIRE to analyse the impact of changes in heating and cooling demand on the electricity system including the potential value of a **flexible operation of heat pumps and air conditioning systems**.

The electricity system model EMPIRE estimates a significant **uptake of flexible electrical heating and cooling** loads based on cost assumptions for additional investments for controlling heating and cooling systems. Figure 8 indicates that up to the year 2050 more than 50 GW of flexible loads from heating and cooling could be available for shifting electrical loads across EU 28.

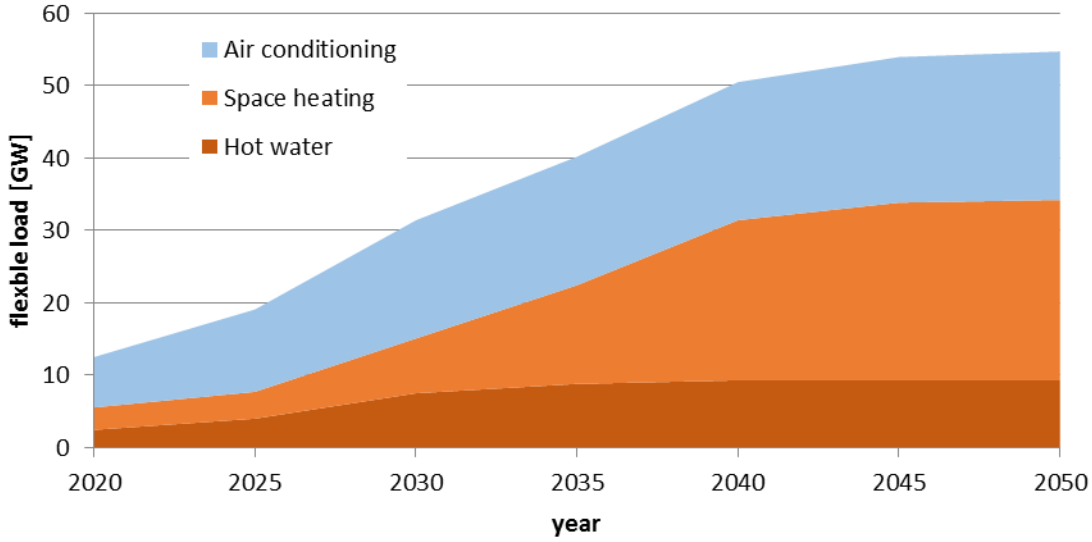

Figure 8: Uptake of flexible loads in buildings in the model EMPIRE based on heating and cooling loads from the current policy scenario

This constitutes a relevant shifting potential to **support the integration of flexible renewable electricity generation** from PV and Wind and can help to reduce the needs for conventional backup capacity. In model runs with the electricity system model Enertile® it was estimated that the flexible operation of heat pumps leads to **cost reductions** of around 1.5 to 1.8 billion € annually compared to inflexible operation of heat pumps. Those savings corresponds to around 0.5% of the overall costs covered by the electricity system model. The main source for those cost reductions is the **reduced demand for gas fired capacity** that has to be installed to cover demand peaks in winter. In both scenarios the flexible operation leads to a reduction of more than 20 GW of gas fired electricity generation capacities.

Potential cost reductions for the electricity system are also reflected in the specific variable heat or cold generation costs of technologies. Figure 9 illustrates the **difference in heat generation costs between flexible and inflexible heat pumps** for the ambitious policy scenario settings in the year 2050. For this analysis it was assumed that flexible heat pumps are equipped with a heat storage tank with a storage capacity of 2 full load hours of the maximum heat demand. By shifting production to hours of lower electricity generation costs the specific heat generation costs are reduced by around 6 €/MWh on average over all countries. The magnitude of specific cost differences mainly depends on electricity demand patterns and the share of variable renewables in each country. The differences in specific costs provide an indication for the **potential cost savings for end users**. It has to be noted that currently end users are typically not exposed to variable electricity prices and therefore have no incentives to invest in additional equipment that allows for shifting loads according to market signals. In order to realize the estimated potentials end users would have to be **exposed to market signals** or have to be provided with other monetary incentives.

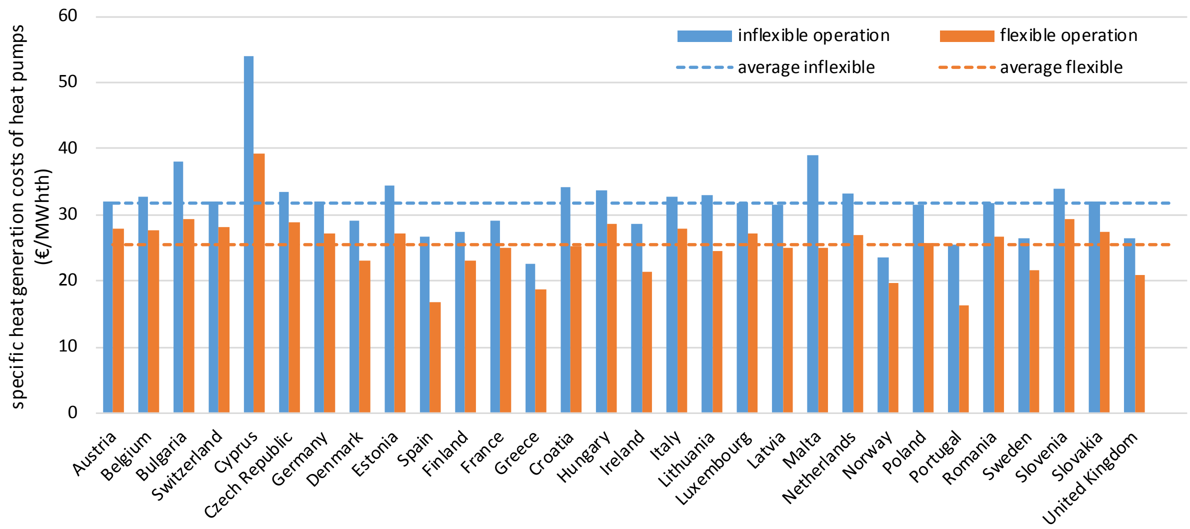

Figure 9: Specific heat generation costs[2] of heat pumps in 2050 in the ambitious policy scenario – comparison of flexible and inflexible operation of heat pumps in the Enertile® model.

Summary and conclusions

From the presented case study analysis the following conclusions can be drawn with regard to the decarbonisation of the European heating and cooling supply:

- 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, in particular if compliance with existing regulation is assumed, more ambitious policies are needed to reach climate targets in line with the Paris agreement. Moreover it has to be noted that both calculated scenarios follow the energy price trends of the Primes reference scenario 2016 where significant energy price increases are assumed.
- The **share of renewables increases** significantly in both scenarios. Biomass heating systems, heat pumps and solar heating systems can substitute the use of fuel oil and coal for decentral heat supply. The main fossil energy carrier left in the heat supply mix by 2050 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 is noted that the 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.
- **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

[2] These values only represent variable generation costs from an electricity generation perspective and do not include investments in the heat pump and storages. Also taxes and other cost components from an end user perspective are not included.

generating heat. It could be shown that substantial **additional potentials** for district heating networks with low distribution costs exist if high connection rates within district heat areas are achieved. Zoning and identification of district heating priority areas can help to increase connection rates and improve economic effectiveness of district heating.

- **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). This will be further analysed within the pathway analysis in the SET-Nav project.
- 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. 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.
- Electricity demand for **space cooling is expected to increase** strongly. Scenario results estimate an increase from around 67 TWh in 2012 to more than 200 TWh in 2050. While final energy demand for heating will still dominate the overall final energy demand for heating and cooling, **electricity demand peaks** from cooling in summer can be significantly higher than electricity demand peaks resulting from space heating in winter. In light of those results policies addressing reductions in cooling demands of buildings (e.g. shading, free cooling) should be enhanced. Those measures were not specifically addressed in the ambitious policy scenario.
- The **flexible operation** of heat pumps and air conditioning systems can provide substantial flexibility for the electricity system and contribute to reducing the need for additional backup capacity in the electricity system. To incentivize investments in demand response ready technologies market signals (e.g. variable electricity prices) or other monetary incentives should be passed on to end users.

1 Introduction

This report describes and discusses the results from case study 5.2 of the SET-Nav projects which is dedicated to the analysis of energy demand and supply development in buildings and the role of renewable energy sources (RES) to decarbonize the European building stock.

The case study is embedded in work package (WP) 5 of the project. The overall objective of WP 5 is to provide scenarios for the demand side of energy systems including buildings, industrial processes and transport. In particular, we deal with specific research and policy questions related to the demand side and flexibility options in form of 3 case studies dedicated to energy demand in buildings, the role of innovative technologies in the industry sector and potential ways to a cleaner transport system. The modelling work in the field of energy demand is covered by the following models: Invert/EE-Lab (buildings), Forecast-Industry (industry), ASTRA (transport) and the load profile and flexibility interface e-load.

Within this report the case study on buildings is presented. This case study aims to analyse the link between energy efficiency improvement in buildings, heating system choice, demand side flexibility options and on-site RES deployment.

The key-questions of addressed in this case study are:

- What are potential contributions of the European building stock to decarbonizing the European energy system?
- How does energy efficiency improvement in buildings, heating system choice, flexibility options (demand response) and on-site RES affect in the building sector and electricity system?
- What is the impact of thermal renovation on energy demand for heating and how might building related energy policies and other framework conditions affect energy savings?
- Which factors trigger heating system choice (including district heating) and the uptake of on-site RES and how might energy policies and other framework conditions affect the energy supply mix of buildings and related generation of on-site RES?
- What is the future role of district heating taking into account reduced heat demand and related heat densities as well as the economic conditions in the electricity sector?
- How will these developments interact with the overall energy system and what is the potential of the building sector for providing flexibility to the electricity system?

The results and findings of the case study are further used to define and calculate future energy transition pathways within work package 9 of the SET-Nav project.

The remainder of this report is structured as follows: Chapter 2 briefly presents the methodology of models applied within the case study work, the main data exchange between models, and the scenario framework of the case study. Within chapter 3 the main results for the potential development of heat demand derived from the building stock model applied in the case study are illustrated. Chapter 4 is dedicated to specific results on the uptake of on-site renewable heating systems derived from the calculated scenarios. In chapter 5 the findings for potentials of district heating are presented. Within chapter 6 the potential impact of developments in heating and cooling on the electricity system are discussed. Chapter 7 concludes this report with a summary of the findings and lessons learned for potential decarbonisation pathways until the year 2050.

2 Methodology, data flows and scenario definition

This chapter provides and overview of the methodologies and models applied within this case study. Furthermore the main data flows between models and the scenario framework is described.

2.1 Overall approach and scenario description

Several models were used for the simulations performed within this case study. The building stock model INVERT/EE-Lab (see www.invert.at) simulates the development of demand and supply for heating and cooling in the European building sector. The model eLOAD was applied to transform the output from INVERT/EE-Lab from annual data into hourly load profiles for electrical heating and cooling supply technologies (ACs, heat pumps, direct electric heating). These data were fed into the supply models Enertile and EMPIRE to study the relationship between the electricity sector and developments in the building sector across the EU in several scenario runs: Model outputs from the model Green-X were used to compare biomass use in the building sector with the allocation of biomass across sectors to make sure that the potentials for biomass as a source for heating in the building sector are not overestimated. For detailed model description and extensions developed for the main models in WP5 please see deliverable 5.1 of the SET-Nav project on data exchange and model linkages. A simplified version of the data exchange concept, involved models for case study 5.2 and the basic scenario design is illustrated in figure 1 below.

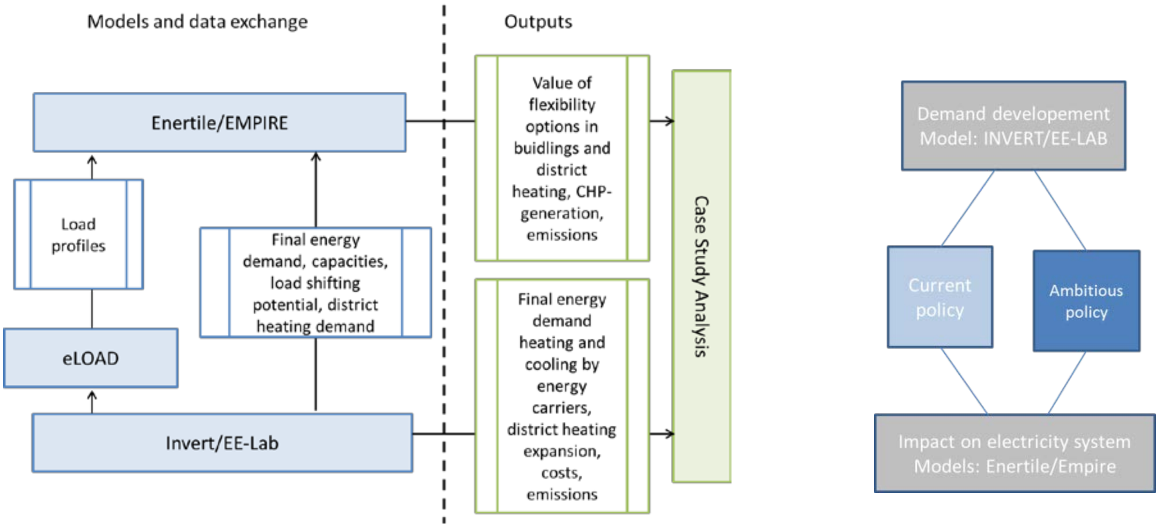

Figure 10: Data exchange concept, model links and general scenario design in case study 5.2

The starting point of the analysis of this case study was the computation of 2 scenarios calculated with the building stock model INVERT/EE-Lab. A current policy scenario was calculated assuming that all existing policy measures related to the European building stock are implemented in their current form and continue to be valid until the year 2050. In the ambitious policy scenario measures already implemented in the current-policy scenario were intensified to reach stronger energy demand reductions and increasing shares of renewables in the building stock.

The results on annual energy demand for heating and cooling from both scenarios were transformed into hourly profiles and fed into the electricity system models for further analyses. The electricity system models followed different scenario approaches within their simulation runs and focused on specific aspects of the link between heating and cooling and the electricity system. Biomass use in all involved models are finally compared with model results from the Green-X model to analyse the feasibility with respect to overall available biomass potentials.

2.2 Modelling heating and cooling demand in the building stock

The following section describes the building stock model applied for the analysis and outlines the scenario assumption for the two policy scenarios calculated within the case study.

2.2.1 Model description Invert/EE-Lab

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 (Kranzl et al., 2013) or (Müller, 2012). The structure and concept is described in Figure 11.

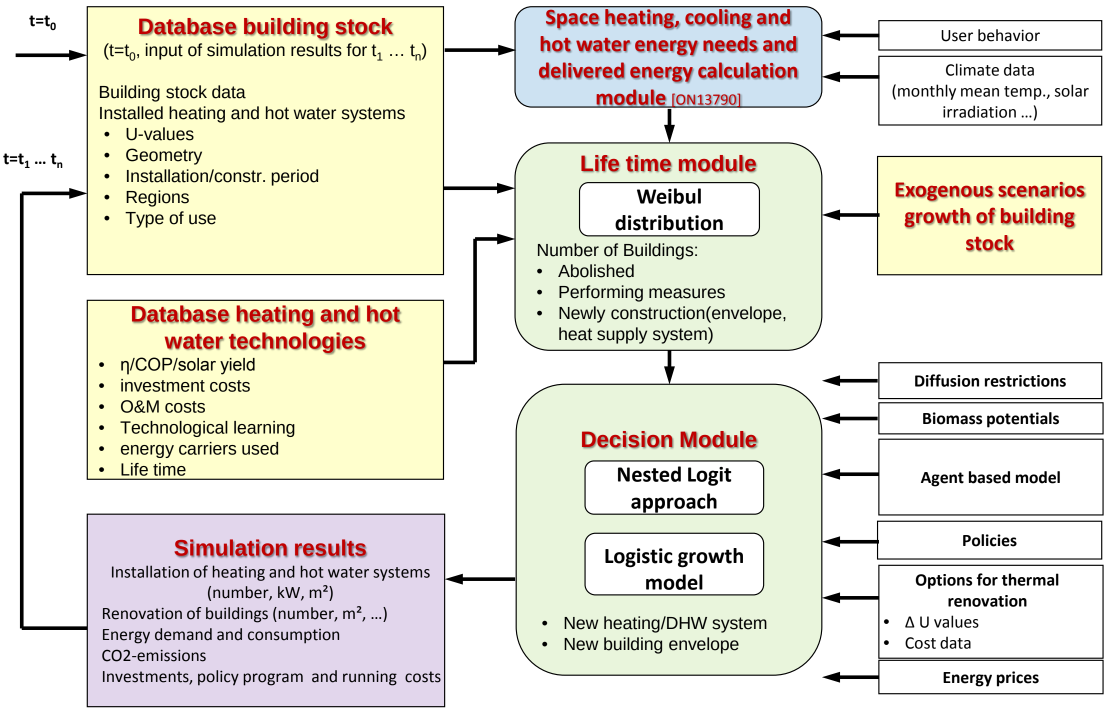

Figure 11: Overview structure of Simulation-Tool Invert/EE-Lab

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, multinominal 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.

2.2.2 Scenario assumptions in building stock model

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),

Building renovation

The Invert-EE-Lab model consists of three renovation options, which are standard renovation and two intensified renovation options, as well as a maintenance option without any improvement of the building envelope. The quality and costs of the different options vary between the designed scenarios.

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.

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 2. (e.g.: favouritism of investment subsidies for renovation actions or mandatory building codes). Also monetary incentive 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), 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 were 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 2.

Table 2: 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
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
Financial policies		
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)

Regulations / Information	EU leg.	Current-policy scenario
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-measures scenario, policy measures 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 low energy buildings subsides were substantially raised, ranging from 30% to 40%.
- 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, as well as reducing costs for energy saving building parts, 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, lower 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.
- 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 and to a lower extent in appropriate conditions fossil powered condensing boilers were increased
- 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 increase to 30% to 50%

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.

2.3 Link to the electricity system

This section describes the process of transforming annual loads from the building stock model into hourly load profiles and the methodology as well as the scenario assumptions for the two different electricity system models Enertile® and EMPIRE.

2.3.1 Transformation of heating and cooling demand into hourly load profiles

The Invert-EE/Lab model has been extended with a link to the model eLoad. This link allows to derive hourly profiles based on the annual heating and cooling demand calculations from Invert-EE/Lab. The annual energy demand for the aggregated building categories “Single Family houses”, “Multi Family houses”, “Private Service buildings” and “Public Service buildings” has been linked with one of the processes for space heating, space cooling or domestic hot water which are already implemented in e-Load. This link is established for each EU28 member state. For the transformation into hourly load profiles climate data across Europe is used. Note that the same climate data is then also used for the simulation runs in Enertile® to make sure that the demand profiles are in line with weather effects (e.g. irradiation and wind speed on renewable generation from Wind and PV) in the electricity system model. This approach allows for a consistent modelling of the impact of developments in the heating and cooling sector on the electricity system.

2.3.2 Model description and scenario assumptions in the electricity system model Enertile®

Enertile® is a model for energy system optimization developed at the Fraunhofer Institute for System and Innovation Research ISI. The model strongly focuses on the power sector but also covers the interdependencies with other sectors such as the heating and transport sector. It is used 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.

Enertile conducts an integrated optimization of investment and dispatch. It optimizes the investments into all major infrastructures of the power sector, including conventional power generation, combined-heat-and-power (CHP), renewable power technologies, cross-border transmission grids, 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 in all hours of each analysed year.

The model currently depicts and optimizes Europe, North Africa and the Middle East. Each country is usually represented by one node, although in some cases it is useful to aggregate smaller countries and split larger ones into several regions. Covering such a large region instead of single countries becomes increasingly necessary with high shares of renewable energy, as exchanging electricity between different weather regions is a central flexibility option. 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.

Enertile includes a detailed picture of renewable energy potential and generation profiles for the optimization. The potential sites for renewable energy are calculated on the basis of several hundred thousand regional data points for wind and solar technologies with consideration of distance regulations and protected areas. The hourly generation profile is based on detailed regional weather data. Figure 12 shows a simplified structure of the input and output of the Enertile optimization model.

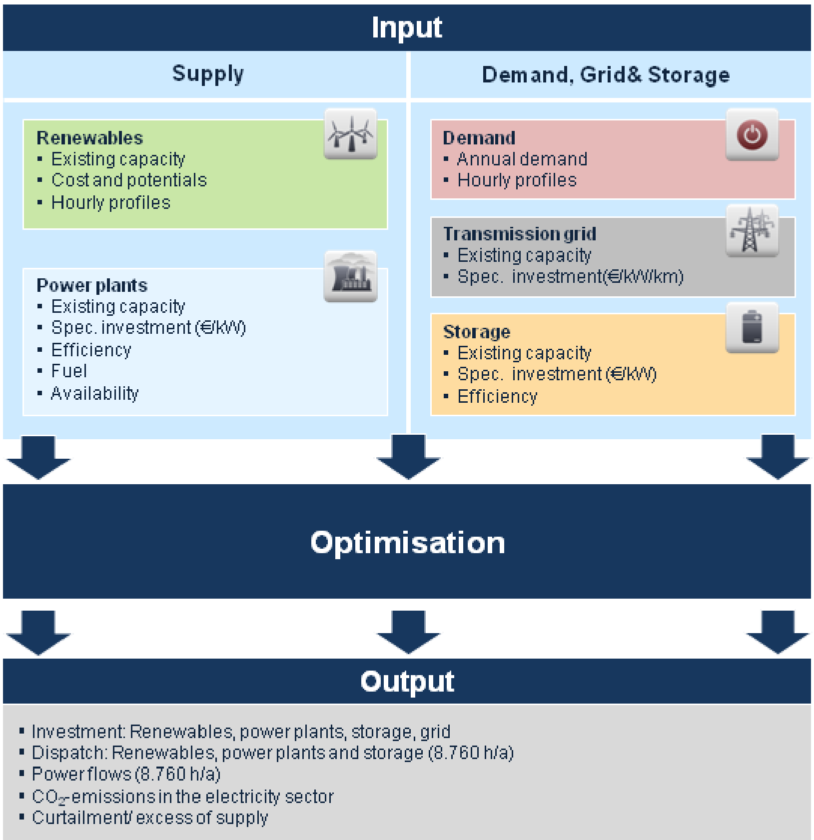

Figure 12: Simplified structure of the Enertile® optimization model

Model extensions

Enertile has a strong focus on the electricity sector in Europe and neighbouring countries. The integration of rising shares of renewable energy in the electricity sector is a crucial task for the next decades. On one hand, this can be addressed by additional flexibility within the electricity sector. On the other hand, a stronger linkage to other sectors could help to integrate renewable electricity. Within the SET-Nav project, Enertile has been expanded by several modules to integrate demand and flexibility from the heating sector.

In the developed flexibility module different flexibilities from the heating sector can be covered. Flexibility options are characterised by an annual demand and a load profile as well as a maximum capacity that can be capped (load shedding) or shifted (load shifting). In the optimisation of the electricity sector these flexibilities can be used within one country as well as other countries taking into account transport capacities. Flexibilities can be covered in higher technical detail for special applications. One important bottleneck in modelling flexibility is data availability on the technical level and computational capacities in the optimisation.

For the building sector two technology specific modules were developed and implemented for all European countries. These options were selected for their high total potential and relatively low costs. Within the heating sector decentralised heat pumps, as well as heat grids can be seen as flexibility options. Within the heat grids combined heat and power plants, electric heater and large heat pumps are connecting the heating and power sector.

Decentralised heat pumps

For decentralised heat pumps and for heat grids an hourly heat demand profile is used as a basis. The flexibility is provided by the use of a heat storage representing storage capacity of the building as well as a hot water storage integrated in the heating system. The hourly operation of the heat pump is integrated in the overall optimization problem. Account is taken of changing efficiencies of the heat pump during the year, heat losses of the heat storages as well as impacts on the electricity system as the possible use of excess renewable electricity generation or costs of electricity generation during high electricity demand and low production of renewable electricity. Bottlenecks for the use of the developed module are mainly calculation time and to some part data availability.

Heat grids

For heat grids, flexibility options can be even higher than for decentralised heat pumps, as often more than one energy carrier covers heat generation in district heating. Depending on heating technologies used in a heat grid, flexibility can be provided by a switch between different heating technologies as well as the use of heat storages. Within the developed module for heat grids, several technology options can be used to cover the heat demand. These are combined heat and power plants, heating boiler based on fossil fuels, electric boilers and large heat pumps based on electricity and ambient heat. In the developed module, heat grids for district heating are considered. District heating grids provide mainly heat for hot water and heating purposes in buildings and have a typical seasonal pattern in their heat demand.

Within the developed flexibility module for heat grids the operation as well as the installation of heating technologies - including power to heat facilities - and heat storages can be integrated in the optimization problem. Depending on the level of detail and the number of regions that are covered, the calculation time for the optimisation problem can increase strongly. Therefore, an important bottleneck for the use of the developed module is calculation time. In case of heat grids data availability on heat grids, heat demand profiles and heating technologies in different countries is a crucial limitation.

Scenario assumptions

The scenarios for this case study calculated with Enertile are based on the Primes Reference Scenario. This concerns the assumptions on the development of electricity demand in the European countries and the prices of fossil fuels and CO_2. However, for the ambitious policy scenario a higher development path of the CO_2-price is assumed. The CO_2-price in the ambitious policy runs is assumed to be 150 €/t in the year 2050 in contrast to 88 €/t in the current policy scenario (based on Primes Reference Scenario). Table 3 shows the fuel and CO_2-prices used in the Enertile scenarios.

Table 3: Fuel and CO_2-prices in the Enertile® scenarios (based on Primes Reference Scenario)

Fuel prices in €/MWh_{th}			CO_2-price in €/t	
gas	coal	oil	Current	Ambitious
38,2	14,2	63,8	88,0	150

The model optimizes endogenously the expansion and deployment of conventional and renewable technologies. Nevertheless, the capacity and generation of hydro, biomass and nuclear is fixed according to the values in the Primes Reference Scenario. Furthermore, the status of offshore wind energy for the year 2020 in the Primes Reference Scenario is integrated within the optimization as a minimum restriction for the calculated scenario years. In this case study, the optimization covers the year 2050. The optimal portfolio of technologies for electricity generation in the EU 28 member states plus Norway and Switzerland is determined. Simultaneously the heat generation of decentralised heat pumps and the heat production in heat grids is optimized.

As flexibility options from the heating sector decentralised heat pumps and heat grids are taken into account. The resulting heat demand for these two respective options from the building stock model was integrated in the electricity system model Enertile. This applies to both the current and ambitious policy scenario. For both scenarios, we considered two alternative operation modes for the decentralised heat pump system. In the inflexible scenarios, there is no heat storage available to allow for load shifting of heat pumps. In contrast to his, in the flexible scenario a heat storage system equivalent to two full load hours of heat demand can be used to ensure a flexible operation of the heat pumps. Table 4 gives an overview of the calculated scenarios and the different properties concerning heat demand and flexibilities.

Table 4: Overview of scenarios calculated with the Enertile® optimization model

Scenario	time scope	heat demand	decentralised heat pumps	heat storage	heat grids
Current_flex	2050	current policy scenario	✓	✓	✓
Current_inflex	2050		✓		✓
Ambitious_flex	2050	ambitous policy scenario	✓	✓	✓
Ambitious_inflex	2050		✓		✓

2.3.3 Model description and scenario assumptions in the electricity system model EMPIRE

EMPIRE is the European Model for Power Investment (with high shares of) Renewable Energy [Skar 2016]. It is used for assessing the mid-term and long-term generation capacity and transmission expansion in the European power system.

The model includes short-term uncertainty from load and RES and short-term dynamics for operational constraints. Long-term system dynamics is also present for carbon emission price, fuel prices, technology efficiencies, technology costs and RES share targets.

The number of technologies present in the system is exhaustive: from fossil fuel plants to biomass, geothermal, hydro storage and battery storage. In the RES side, off-shore wind, on-shore wind and solar are represented with data from the EMHIRES dataset as source [SETIS 2017].

Electricity demand is represented by hourly country profiles through the ENTSOe data for EU28 countries plus Switzerland, Norway and Balcan countries [OPSD 2017]. The annual electricity demand comes from EU reference case which is based on the outputs from the PRIMES model [EC 2016].

The historical data is used to create short-term stochastic scenarios which take into account the statistical properties of the inputs and their correlations.

Flexibility is represented in the model through 10 Demand Responsive (DR) loads. Seven of them concern the building sector, one represents industry and two represent transport. The seven flexible load groups from the building sector are represented in Table 5. The DR groups aggregate different types of loads according to potential, hourly profile and "Supertype".

Table 5 Flexible loads represented in EMPIRE.

DR_group	Sector	Supertype	Type	Initial Capacity (MW)	Initial investment cost (€/MW)
1	Residential	Cooling	Air Conditioning	958	250
2	Residential	Hot Water	Heat Pumps	179	20
2	Residential	Hot Water	Electric Direct Heaters	564	
2	Residential	Hot Water	Storage Heating	238	
3	Residential	Space Heating	Heat Pumps	1150	250
4	Residential	Space Heating	Electric Direct Heaters	704	20
4	Residential	Space Heating	Storage Heating	52	
5	Non-residen.	Cooling	Air Conditioning	888	10
6	Non-residen.	Hot Water	Heat Pumps	11	5
6	Non-residen.	Hot Water	Electric Direct Heaters	31	
6	Non-residen.	Hot Water	Storage Heating	38	
7	Non-residen.	Space Heating	Heat Pumps	171	20
7	Non-residen.	Space Heating	Electric Direct Heaters	602	
7	Non-residen.	Space Heating	Storage Heating	33	
8	Industry	Industry Processes	Aluminium, Chemical,…	1008	0
9	Transport	Electric Vehicle	Freight transport	13	500
10	Transport	Electric Vehicle	Private cars	102	500

The number of flexible load groups is the maximum affordable for the current problem size and computational available option.

The profile loads are obtained from ENERTILE and the annual energy demand from the Invert/EE-Lab model.

Shiftable loads are modelled through three constraints. The balance constraint fixes the energy consumption of the flexible load to the original demand value in each day interval. In second place, the country load-generation balance constraints incorporate the changes by flexible loads [1]. Third, the flexible loads are constrained to take values within an interval defined by its load profile.

Generation + Imports – Exports + Discharge – Charge = Load + Flexible load – Lost load [1]

The flexible loads are allowed to time shift their demand at a given cost. From the prosumers perspective, these are the reservation prices, the minimum price at which they sell its flexibility. From the supplier's perspective it is the maximum that would pay to consumers in order to change their demand. If the reservation price is lower than the price differential between two short-run marginal hourly costs, or inter-hour price differential, then it is optimal for the system to execute the load shifting.

Flexible loads expansion is modelled through strategic decision variables with investment costs given in Table 5. The difference with conventional generation expansion decisions is that flexible loads are limited by their corresponding energy demands, given by the Invert model. Reference and ambitious scenario, differing in building energy demand allow different amounts of flexible potential.

3 Results on energy demand development and related costs in the building stock until 2050

This chapter provides the modelling results on energy demand developments in buildings. First, the development of heating and cooling demand for the current and ambitious policy scenario is discussed. Second, related investment costs and energy expenditures are illustrated. The scope of the simulations covers the EU 28 member states from 2012 to 2050. In chapter 0 we will further discuss the potentials of district heating and the potential connections of heating and cooling with the electricity system in chapter 0.

Quantitative results are presented which provide the basis for the evaluation of policy effects and potential decarbonisation scenarios. The main indicators for heating and cooling are comparatively discussed for a current and an ambitious scenario and subsequently addressed separately for residential and service buildings.

The presented results are derived from the INVERT/EE-Lab model (section 2.2.1). The model calculations provide projections for the development of the final energy demand on country level including the development of energy carrier deployment, based on modelling consumer decisions within the building stock. The underlying assumptions for the current and the ambitious policy scenario reflecting different economic and regulatory conditions are described in section 2.2.2.

3.1 Development of final energy demand for heating and cooling in the EU28 building stock until 2050

This section initially outlines the aggregated results for total final energy demand. Results are shown for the EU28 building stock, however, model runs have been performed for each member state separately. Subsequently results on sector level will be discussed.

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

Figure 13 and Table 6 show the modelling results for total final energy demand in the EU28 member states from 2012 to 2050 for a current and an 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 are expected to 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 (see section 0), 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).

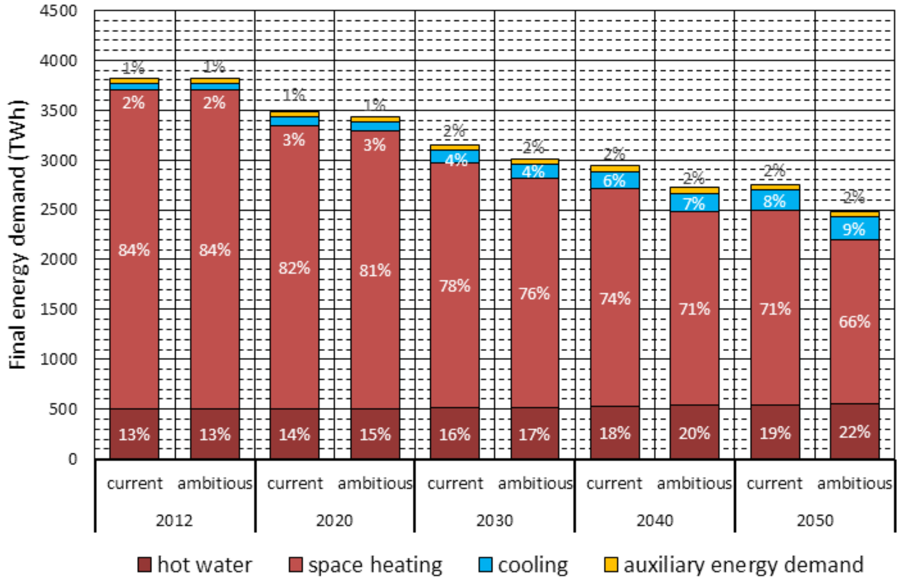

Figure 13: Total final energy demand by usage types for *current and ambitious* scenario for EU28 in TWh

Table 6: 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 expected 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) respectively 11% (ambitious scenario) due to population growth and increase of total floor area. 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 demand for auxiliary energy to operate heating systems is expected to increase but is expected to amount to only around 2% by 2050. 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 6 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 14 and Table 7 illustrate the development of final energy demand per energy carrier. Figure 15 shows the corresponding shares for each scenario. It can be clearly seen that fossil energy carriers are decreased 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 demand decrease 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.

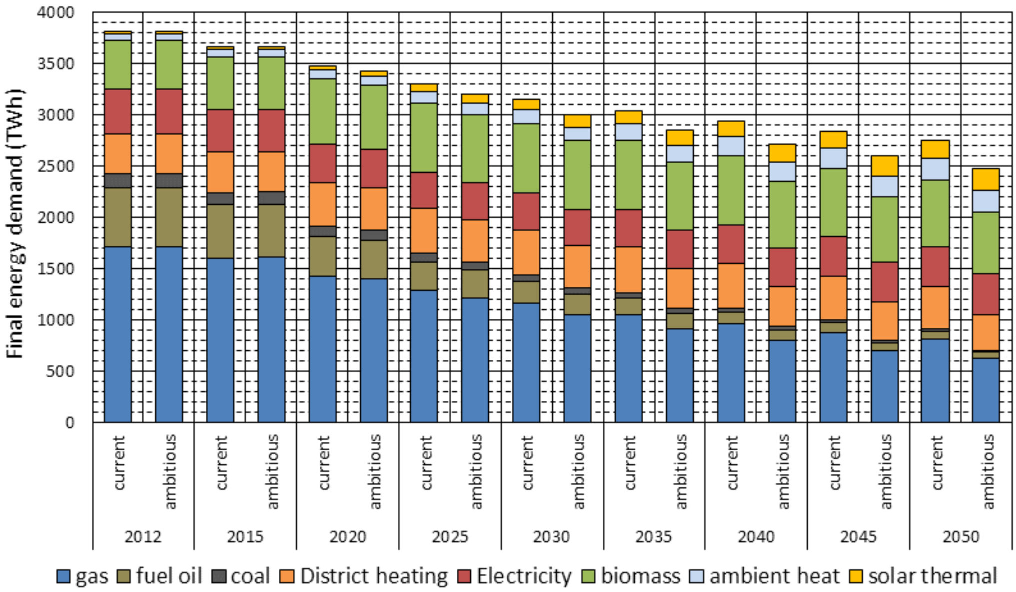

Figure 14: Total final energy demand by energy carrier for current and ambitious scenario for EU28 in TWh

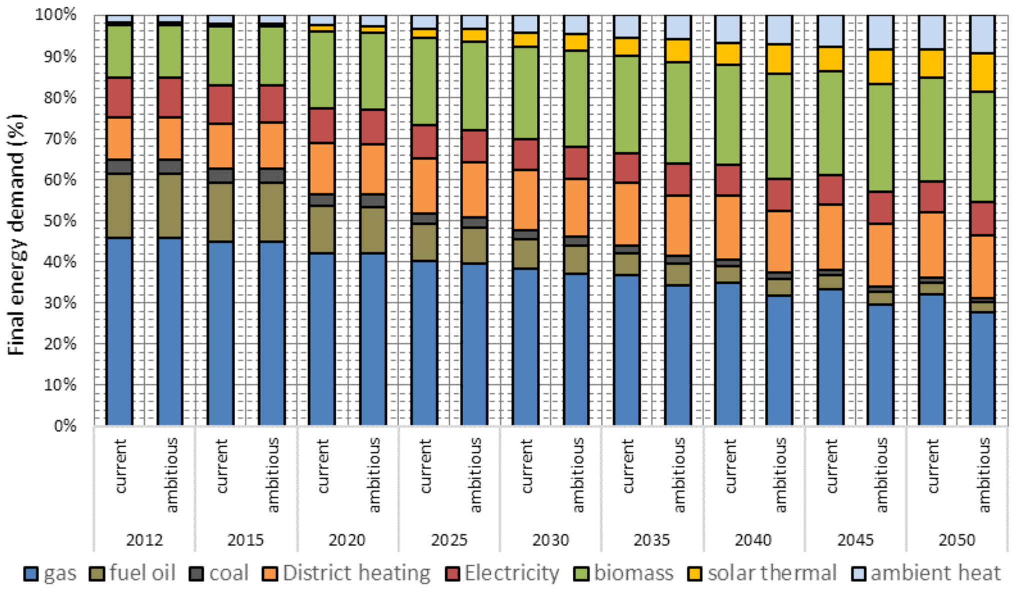

Figure 15: Share on total final energy demand per energy carrier for *current and ambitious* scenario for EU28 in %

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

Table 7: 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 stays more or less constant, or slightly decrease (-7% to -8%) in both scenarios. However there is a noticeable shift from space heating to space cooling, which can be seen in Figure 16. Electricity demand for space heating and hot water supply is expected to decrease by around -60%, 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. It can be estimated, that cooling will account for about 61%-64% of the electricity demand for heating and cooling.

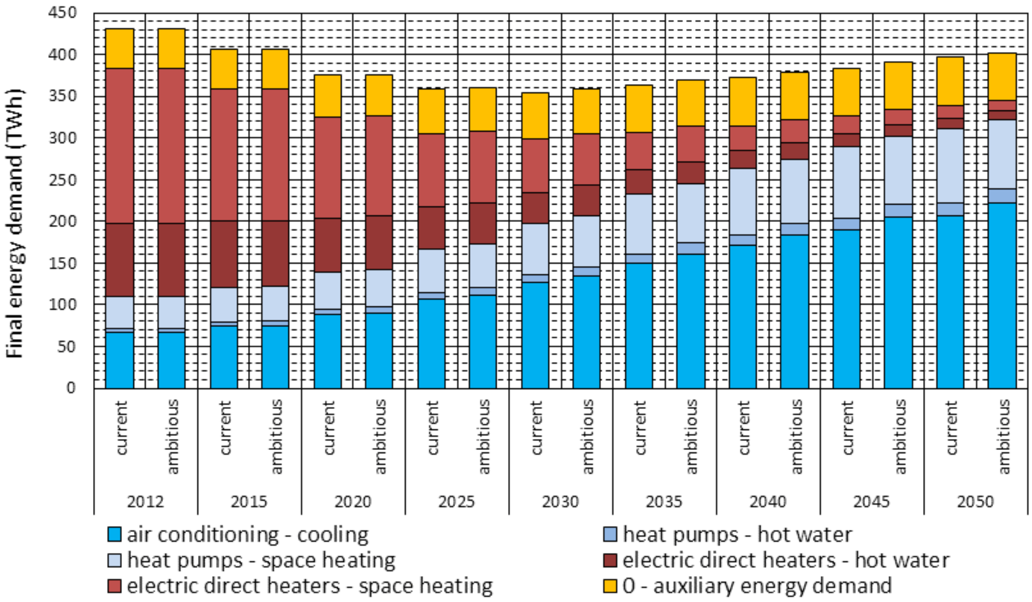

Figure 16: Total electricity demand heating and cooling for current and ambitious scenario for EU28 in TWh

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 calculated in the further course of the SET-Nav project. It is therefore crucial to use other options for heat demand at lower temperature levels such as space heating in combination with low temperature heat distribution systems.

Figure 17 shows the results for total final energy for space heating and Figure 18 for domestic hot water. It can be seen, that increase in supply from renewables for water heating is covered by solar thermal systems to a large extend which are assumed to be installed in combination with other heating systems. Figure 18 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. For more details on the uptake of PV and solar thermal systems please see section 4.3 of this report.

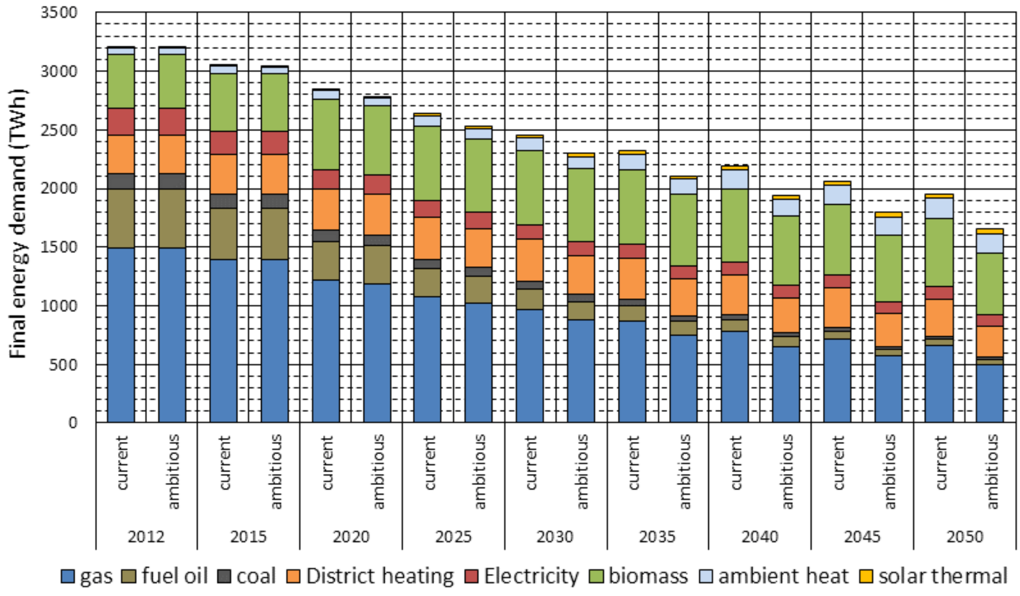

Figure 17: Total final energy demand for space heating by energy carrier for current and ambitious scenario for EU28 in TWh

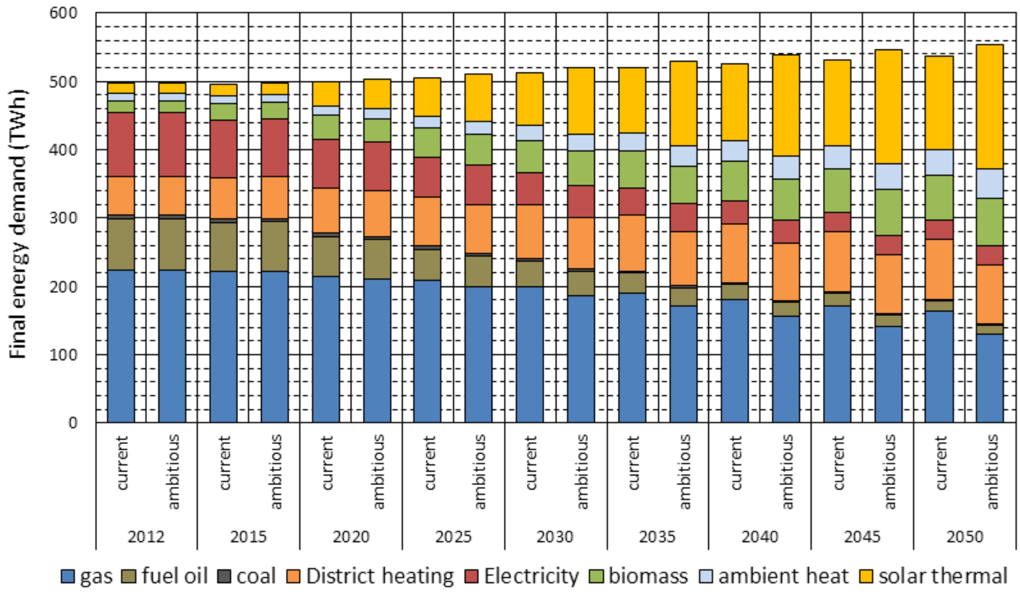

Figure 18: Total final energy demand for water heating by energy carrier for current and ambitious scenario for EU28 in TWh

Figure 19 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 are expected to disappear 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 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 is expected to decrease. The share of district heating is expected to increase from 10% to 15% in the current policy and 14% in the ambitious policy scenario respectively.

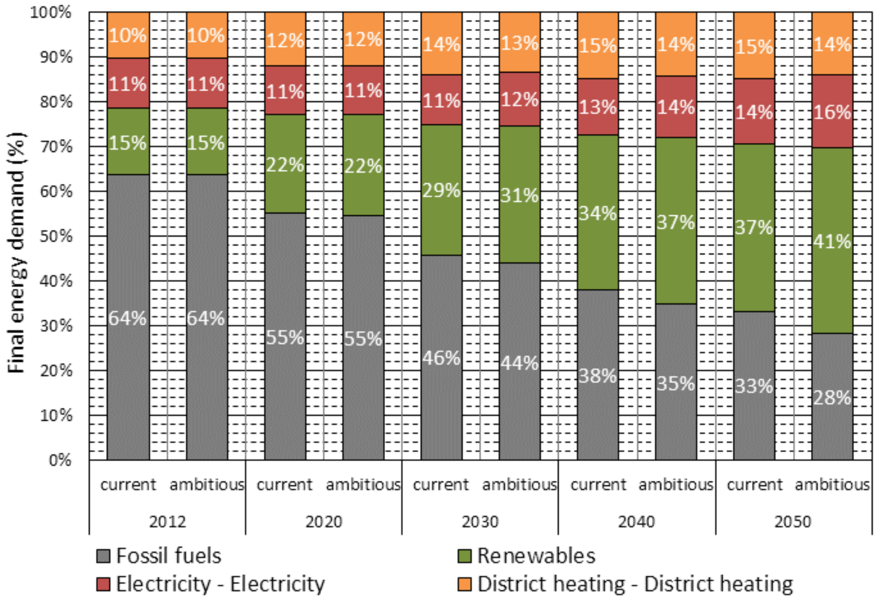

Figure 19: Shares of fossil fuels, renewables, electricity and district heating on final energy demand for space heating, hot water and space cooling supply in EU28 until 2050

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 CO2 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. Potentials for district heating which can be seen as a substitute for natural gas in urban areas are discussed in chapter 5 of this report.

At the end of this section Figure 20, Figure 21 and Figure 22 exemplary results on country level are shown.

Figure 20 provides modelling results for total final energy demand on country level differentiated by end use categories.

Figure 21 shows the expected shares of energy carriers on the total final energy demand for the ambitious scenario in the year 2050. As we discussed before on EU28 level, the share of fossil energy carriers is expected to decrease substantially, there are significant differences between countries concerning remaining fossil energy carriers within the modelling results.

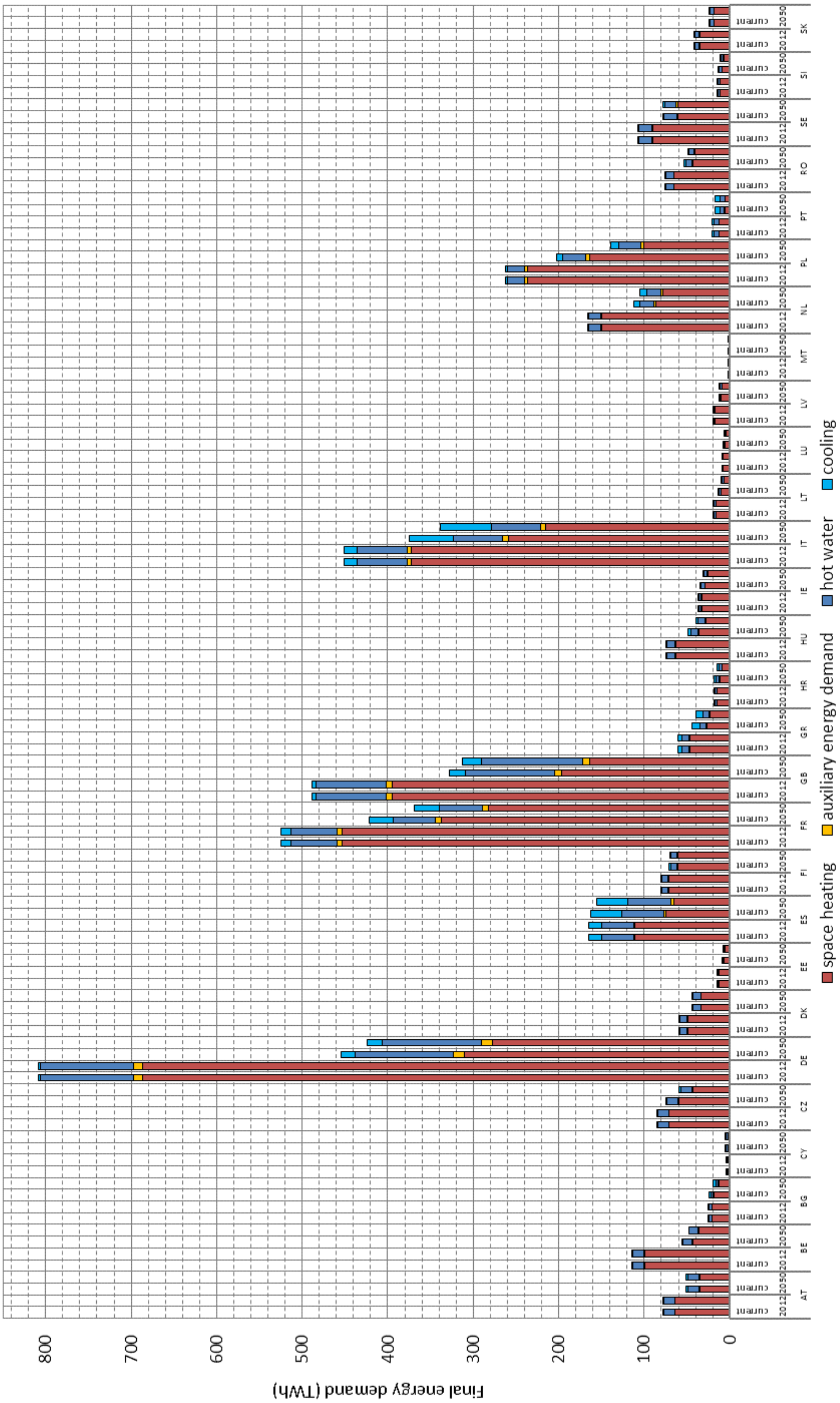

Figure 20: Total final energy demand by end use for *current and ambitious* scenario on country level for EU28 in TWh

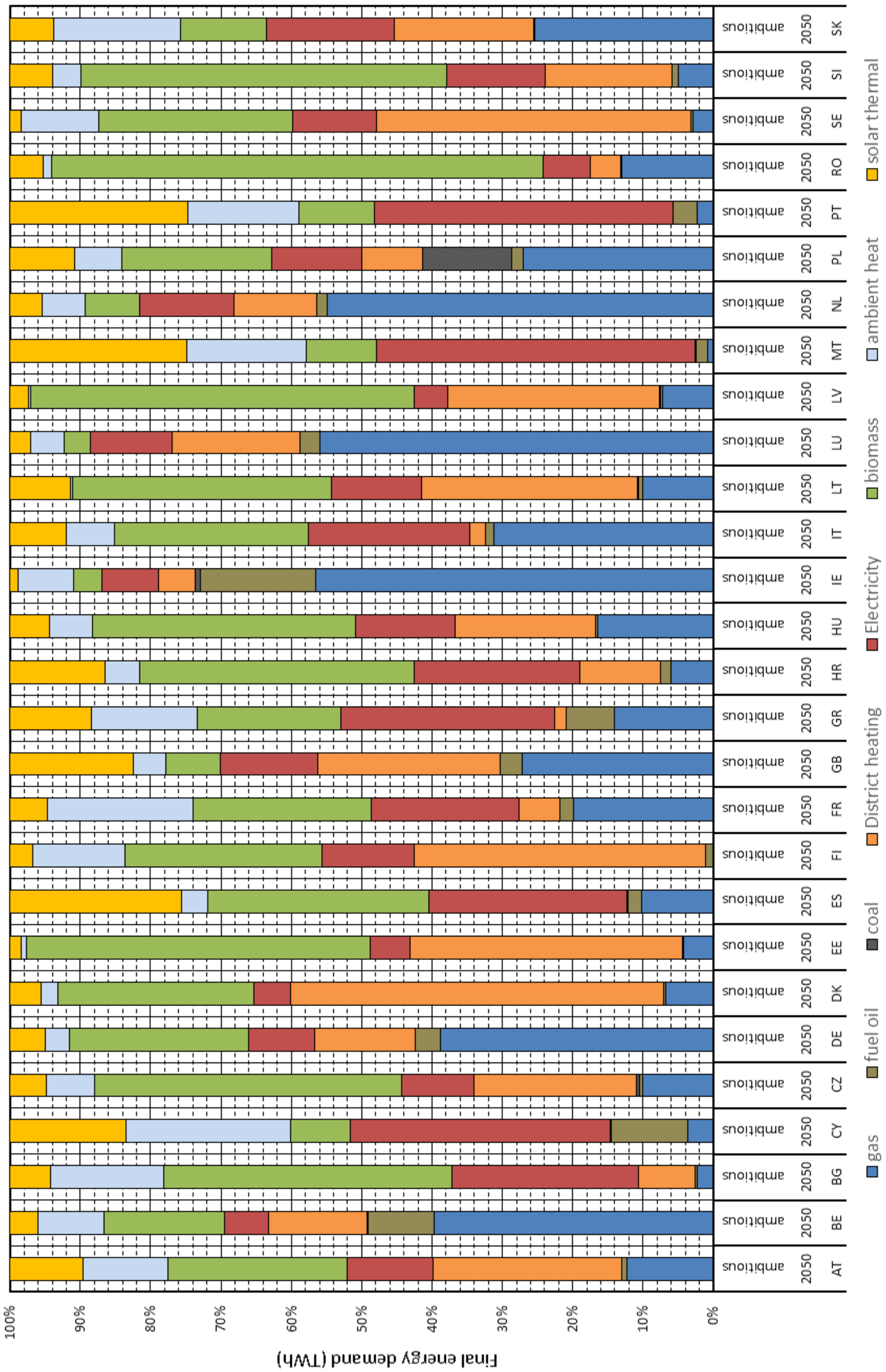

Figure 21: Total final energy demand by energy carriers for *the ambitious* scenario on country level for EU28 in TWh

Figure 22 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.

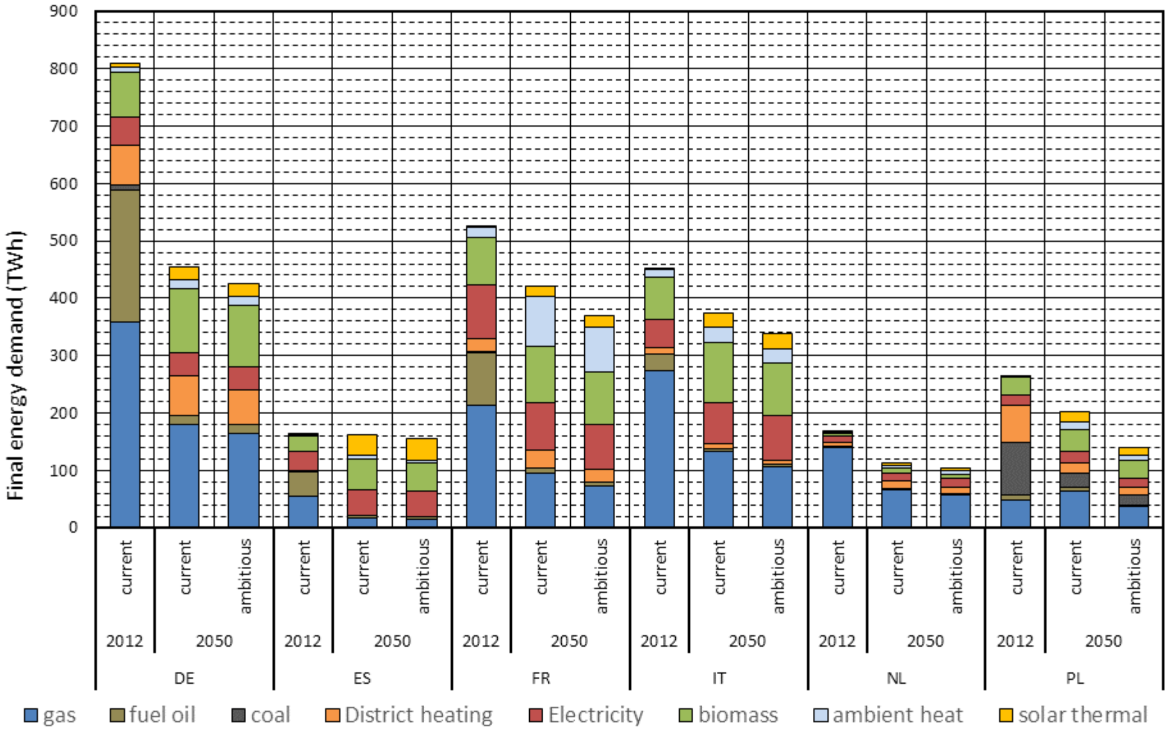

Figure 22: Total final energy demand by energy carrier for selected countries for current and ambitious scenario for EU28 in TWh

3.1.2 Development of the final energy demand for heating and cooling in the residential sector

The building stock model Invert/EE-Lab distinguishes between several building categories on country level. Within the SET-Nav project the results were aggregated to the categories "Residential buildings", "Non residential private building" and "Non residential public buildings". Figure 23 provides a sector specific illustration of final energy demand for heating and cooling for the residential and the service sector. It can be seen that currently around 72% of the energy demand is caused by the residential sector, whereas the service sector accounts for about 28%. In the scenarios these ratios do not change significantly until 2050 with the residential sector still accounting for around 69% of final energy demand for heating and cooling in the building stock. The slightly increasing share of buildings in the service sector is mainly a results of a stronger increase of cooling demands in the service sectors compared to the residential sector.

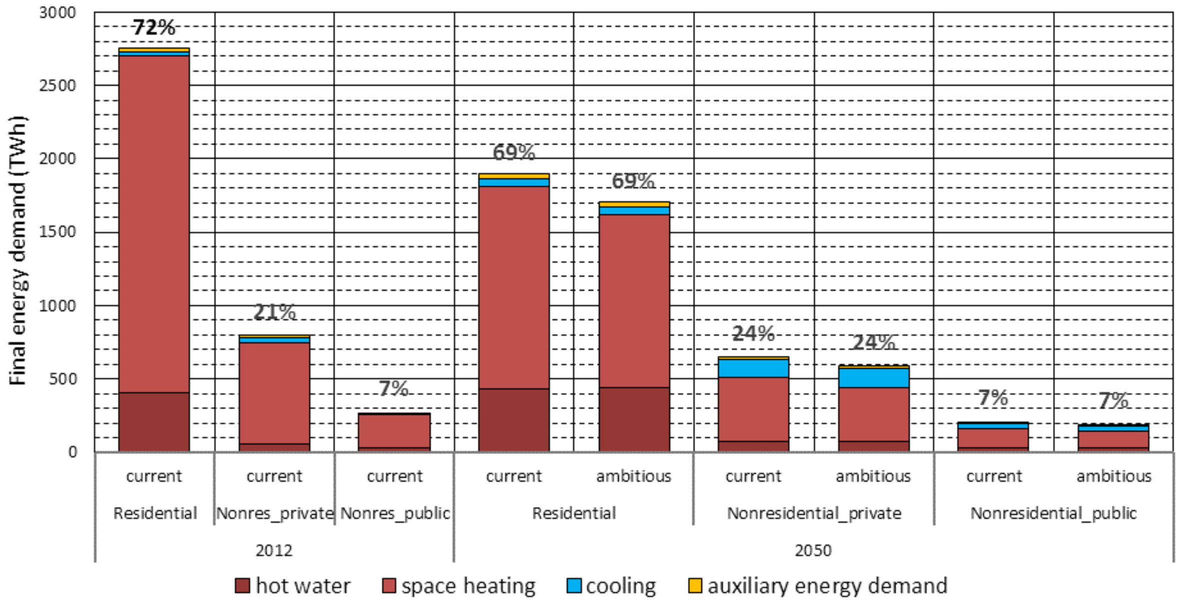

Figure 23: Total final energy demand by usage types for residential and service sector for current and ambitious scenario for EU28 in TWh

Within this section, the results for residential buildings will be presented while the following section will illustrate the results for private and public non-residential buildings which are summarized under the term service sector

Figure 24 shows final energy demand in the residential sector per end use category. The residential sector, which covers different types of single family houses as well as multifamily buildings, amounts to about 2754 TWh in 2012. 83% of final energy demand for heating and cooling is caused by space heating, 15% by water heating, 1% by space cooling and 1% by auxiliary energy demand for heating. According to the simulation results final energy demand is expected to decrease by around -31% (current scenario) to -38% (ambitious scenario). This is caused by a significant reduction of the space heating demand of about -40% (current) to -49% (ambitious), mainly due to thermal renovation measures and to a lower extent due to more efficient heating systems. The share of space heating on the final energy demand therefore shifts from 83% in 2012 to about 70% in 2050. Energy demand for domestic hot water is expected to increase by 5% to 9%, which is mainly a result of increased population and increasing number of dwellings. Energy demand for space cooling increases by around 150%. However the share in final energy demand only increases from 1% to 3% indicating that in terms of energy needs heat demand is still dominating the energy demand of buildings across Europe by the year 2050.

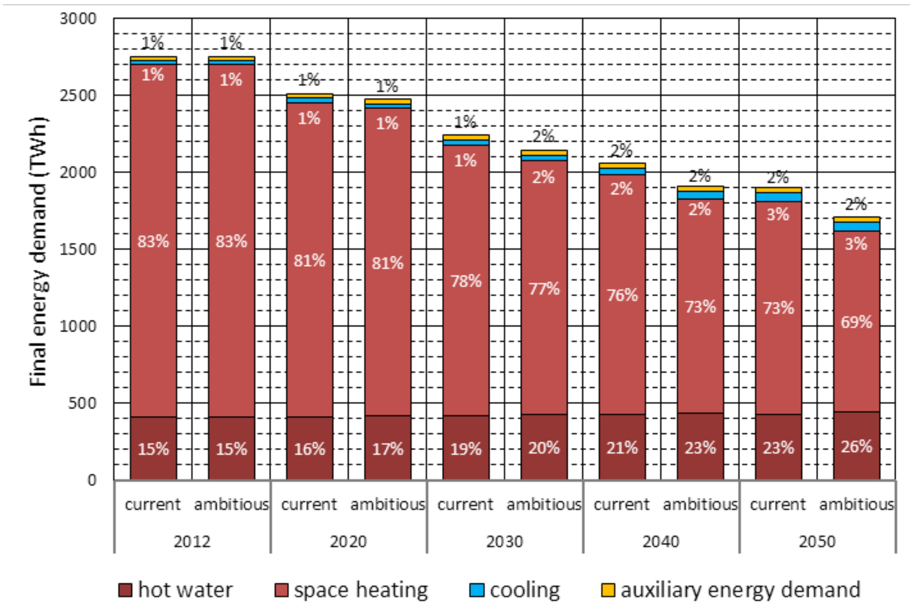

Figure 24: Final energy demand by end use for the *residential* sector for *current and ambitious* scenario for EU28 in TWh

Under the given scenario assumptions, the energy carrier mix for the residential sector is expected to change as shown in Figure 25, Figure 26 and Table 8.

The results clearly reveal that the share of renewables in the residential sector is expected to increase significantly. While in 2012 fossil energy carriers were accounting for approximately 62%, their share is expected to decline to about 37% in the current and 32% in the ambitious scenario. The remaining fossil share is dominated by natural gas. While the demand for district heating and electricity stays rather constant in relative terms, based on the underlying scenario assumptions, the share of renewable energy carriers will be doubled from 19% to 42% in the current scenario and 47% in the ambitious scenario.

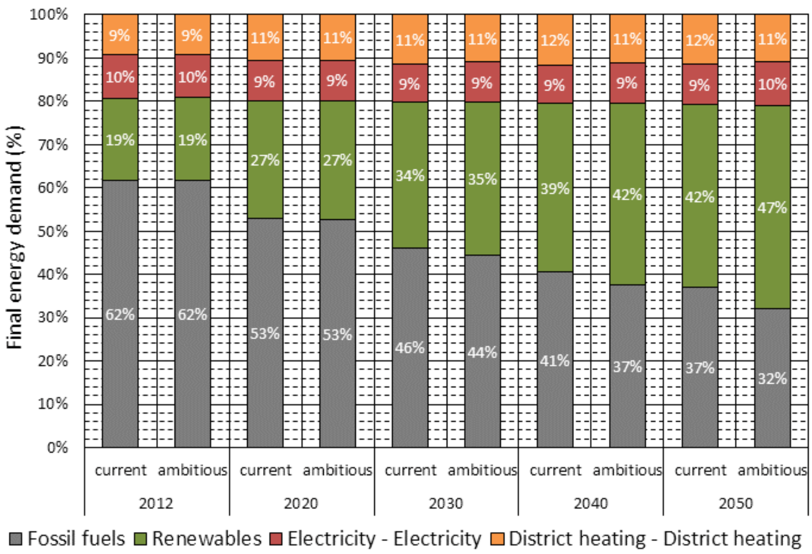

Figure 25: Shares of fossil fuels, renewables, electricity and district heating on the final energy demand for space heating, hot water and space cooling supply in EU28 *residential* sector until 2050

Figure 26 illustrates the development of final energy demand by energy carriers. As mentioned above, the demand of fossil energy carriers is expected to decline. In the case of natural gas the decrease amounts to around -48% to -59% from about 1170 TWh to 612 TWh (current scenario) and 477 TWh (ambitious) respectively. Oil and coal demand is expected to decrease by 80% to 90%.

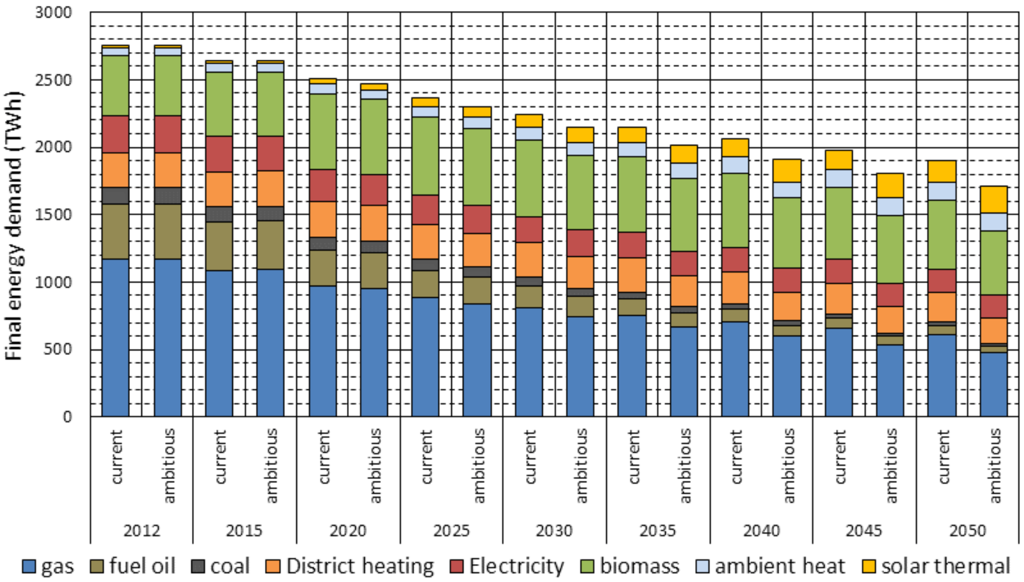

Figure 26: Final energy demand by energy carriers for the *residential* sector for the *current and ambitious* scenario for EU28 in TWh

Despite increasing shares in total final energy demand, energy demand for district heating is expected to moderately decrease, because of decreasing useful energy demand due to thermal renovation. Despite the expected uptake of heat pumps and a significant increase of space cooling, the results suggest that electricity demand for heating and cooling in 2050 will be around 37% lower than in 2012. (see Figure 27). The results imply a strong reduction of electricity demand for direct electric heaters due to better thermal quality of buildings and a substitution direct electric heating systems in favour of heat pumps and other decentral heating systems. Biomass demand will in both scenarios does not increase significantly. The current scenario shows an increase in biomass use of about 14% in 2050 (5% increase in ambitious scenario). The use of ambient energy for heating is expected to increase by around 130% compared to the base year, accounting for 7% (current policy) to 8% (ambitious policy) of final energy demand for heating and cooling. Both scenarios suggest a strong uptake of solar thermal systems. Solar thermal systems are expected to deliver 8% (current scenario) to 12% (ambitious scenario) of final energy demand for heating and cooling in the year 2050.

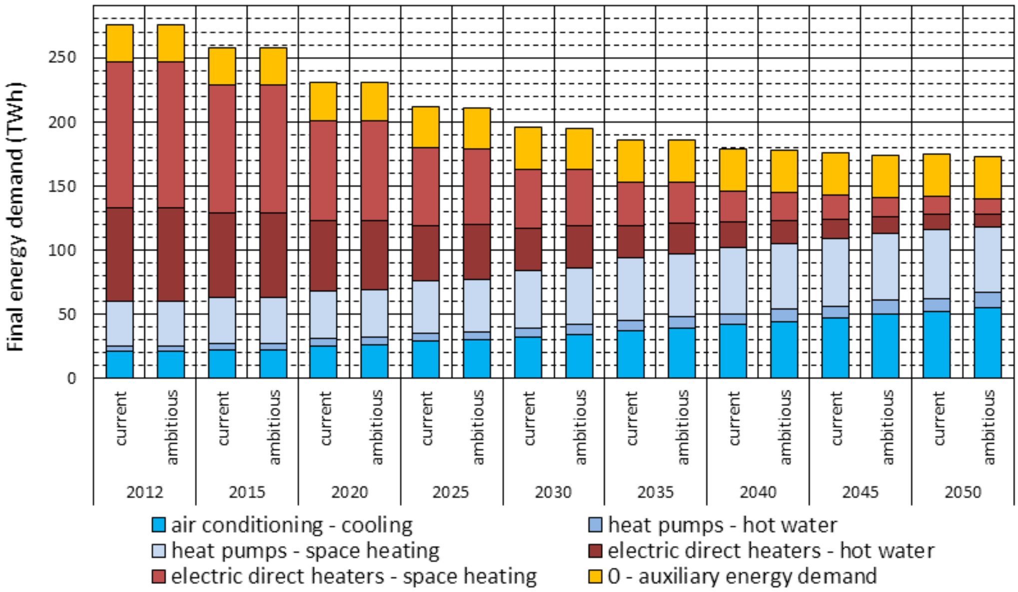

Figure 27: Total final energy demand for electricity for the residential sector for current and ambitious scenario for EU28 in TWh

Table 8: Final energy demand by energy carrier for the *residential* sector for *current and ambitious* scenario for EU28 in TWh and corresponding shares in %

Final energy demand	2012		2050				2012/ 2050	2012/ 2050
Scenario			curr.	amb.	curr.	amb.	curr.	amb.
	(TWh)	(%)	(TWh)	(TWh)	(%)	(%)	(+/- %)	(+/- %)
gas	**1170**	42%	**612**	**477**	32%	28%	-48%	-59%
fuel oil	**410**	15%	**65**	**52**	3%	3%	-84%	-87%
coal	**120**	4%	**24**	**17**	1%	1%	-80%	-86%
District heating	**254**	9%	**219**	**184**	12%	11%	-14%	-28%
Electricity	**276**	10%	**175**	**173**	9%	10%	-37%	-37%
biomass	**450**	16%	**514**	**473**	27%	28%	14%	5%
ambient heat	**58**	2%	**134**	**132**	7%	8%	133%	130%
solar thermal	**17**	1%	**155**	**198**	8%	12%	800%	1054%
TOTAL	***2754***	100%	***1898***	***1707***	100%	100%	-31%	-38%

3.1.3 Development of the energy demand for heating and cooling in the service sector

Figure 28 shows the model results for the final energy demand in the service sector. The service sector in the applied building stock model Invert/EE-Lab covers office buildings, wholesale and retail market buildings, restaurants and hotels, healthcare and education buildings and buildings summed up as other buildings. The final energy demand of those building categories amounts to about 1062 TWh in 2012. 86% is cause by space heating, 8% by sanitary hot water, 4% by space cooling and 2% by auxiliary energy demand for heating systems. According to the simulation results the final energy demand in the service sector is expected to decrease by around -19% (current scenario) to -27% (ambitious scenario). This is caused by a significant reduction of space heating demand of about -37% (current) to -47% (ambitious), mainly due to thermal renovation measures and to a lower extent to more efficient heating systems. The share of space heating on the final energy demand shifts from 86% to about 62% to 66%. The share of sanitary hot water demand is expected to increase to 13% to 14%, which is mainly due to changes in user behaviour related to the modernisation of the building stock. Energy demand for space cooling increases by around 250%, correspondingly the share on the final energy demand will increase from 4% to around 20%. Also a slight increase of the needs of auxiliary energy demand for heating is expected.

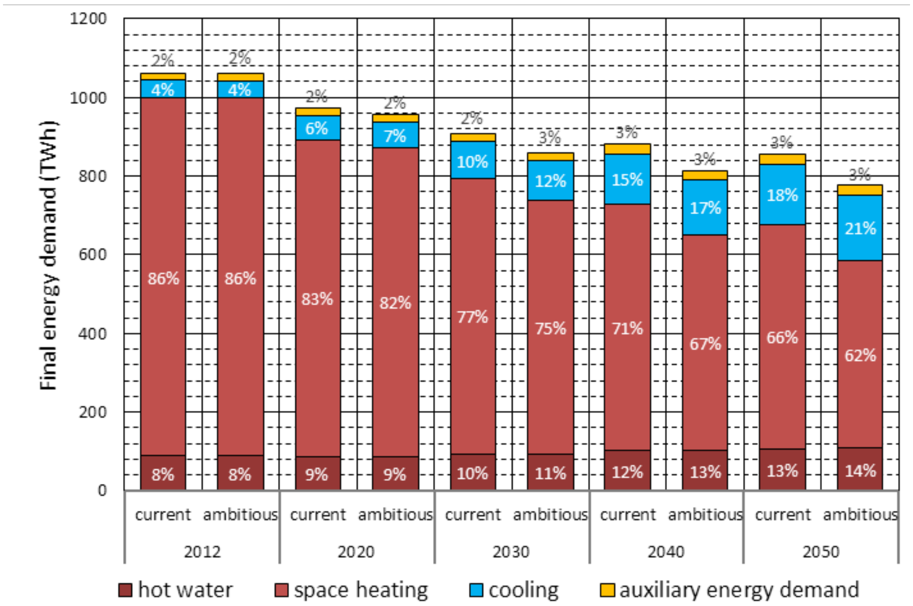

Figure 28: Final energy demand by usage types for the *service* sector for *current and ambitious* scenario for EU28 in TWh

Due to the underlying scenario conditions, the energy carrier mx for the residential sector is expected to change as shown in Figure 29, Figure 30 and Table 9.

The results indicate that the majority of the fossil energy carrier share will be substituted by renewables and the secondary energy carriers district heating and electricity. The share of fossils is expected to decrease from 69% to 25% in the current policy scenario and 20% in the ambitious policy scenario respectively. By 2050 95% of fossil energy demand stems from the use of natural gas. While in 2012 renewables account for only 4% of the energy demand their share is expected to rise to approximately 30%. Final energy demand for district heating is expected to increase from 13% to around 20%. Due to renovation actions, the uptake of heat pumps as a substitution for electricity direct heaters, and more efficient heating systems the energy demand for space heating and sanitary hot water is reduced. Electricity demand for space cooling however is expected to increase dramatically in both scenarios (see Figure 31). Electricity demand is expected to increase by around 30%, which leads to a share of nearly 30% in the 2050 energy carrier mix. Renewable energy carriers are expected to increase strongly from a 4% share in 2012 to around 29% in the ambitious policy scenario.

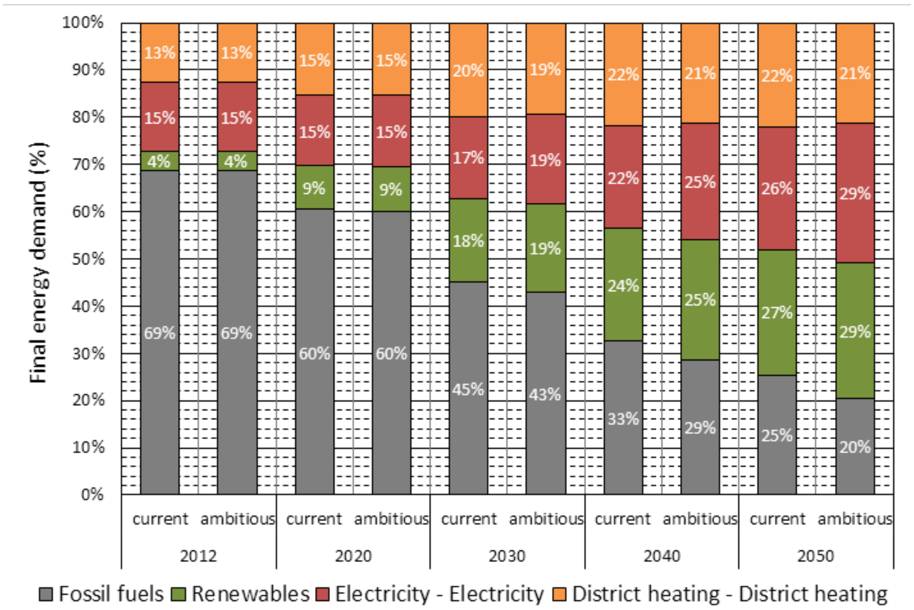

Figure 29: Shares of fossil fuels, renewables, electricity and district heating on the final energy demand for space heating, hot water and space cooling supply in EU28 *service* sector until 2050

Figure 30 illustrates the development of final energy demand by energy carriers in the service sector. As mentioned above, the demand of fossil energy carriers is expected to decline significantly. In the case of natural gas the decrease amounts to around -60% to -70% from about 547 TWh to 206 TWh (current policy) and 150 TWh (ambitious policy). Oil and coal decreases by -90% or more and account for only around 1% of the future energy carrier mix for heating and cooling in the scenarios.

Biomass usage for space heating in the service sector is expected to significantly more than in the residential sector and is expected to account for around 15% of final energy demand for heating and cooling in the service sector by 2050. The use of ambient energy for heating is expected to increase drastically as well. The model results suggest an increase from 1% in 2012 to 10% in 2050. The deployment of solar thermal systems is also expected to increase. However by 2050 the share in final energy demand of the service sector is expected to be only around 2%.

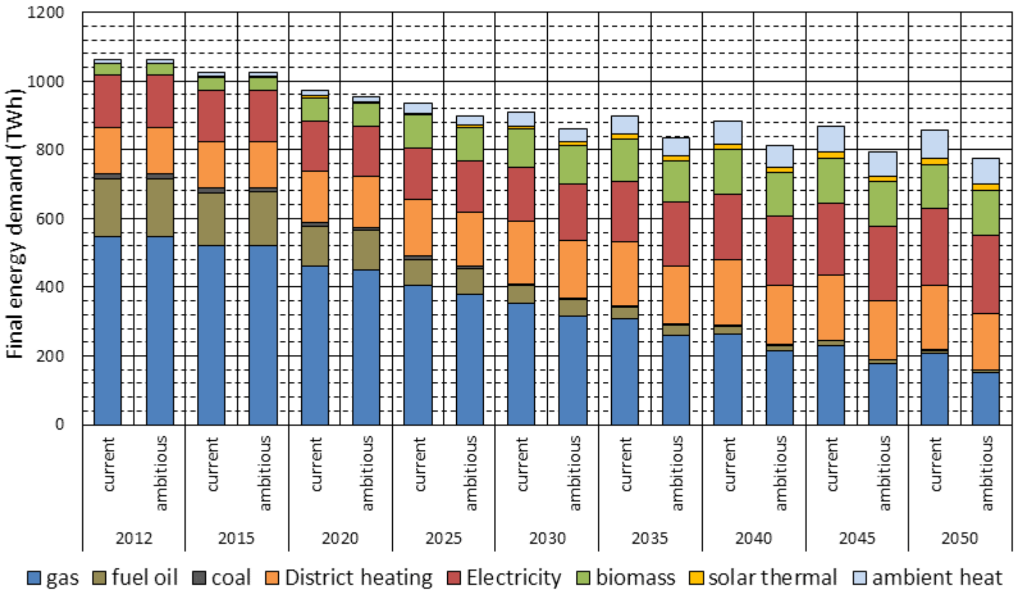

Figure 30: Final energy demand by energy carriers for the *service* sector for *current and ambitious* scenario for EU28 in TWh

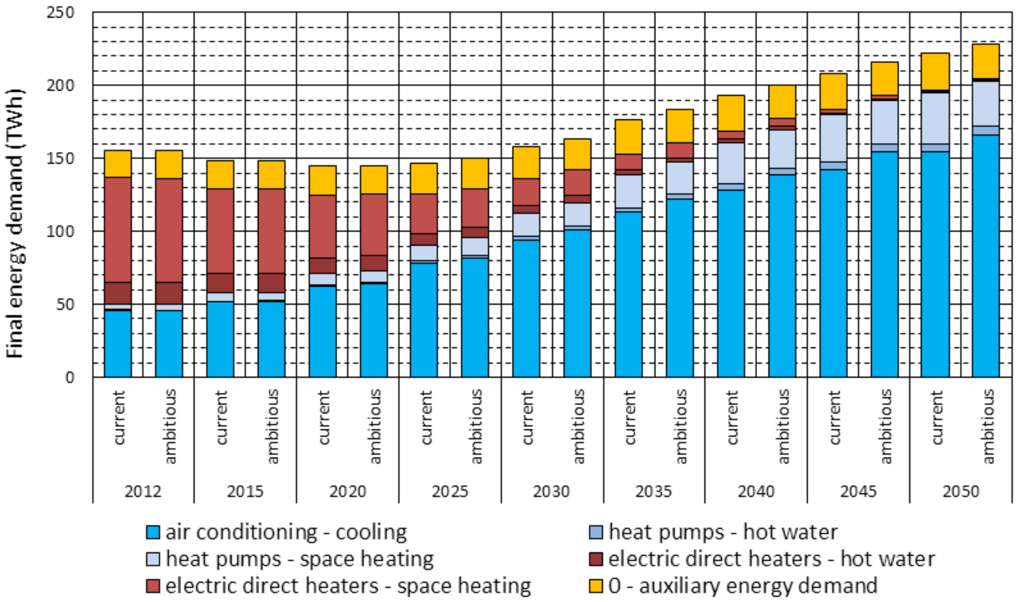

Figure 31: Total final energy demand for electricity for the service sector for current and ambitious scenario for EU28 in TWh

Table 9: Final energy demand by energy carrier for the *service* sector for *current and ambitious* scenario for EU28 in TWh and corresponding shares in %

Final energy demand	2012		2050				2012/ 2050	2012/ 2050
Scenario			curr.	amb.	curr.	amb.	curr.	amb.
	(TWh)	(%)	(TWh)	(TWh)	(%)	(%)	(+/- %)	(+/-)
gas	**547**	52%	**206**	**150**	24%	19%	-62%	-73%
fuel oil	**169**	16%	**9**	**7**	1%	1%	-95%	-96%
coal	**13**	1%	**2**	**1**	0%	0%	-87%	-91%
District heating	**134**	13%	**189**	**165**	22%	21%	41%	23%
Electricity	**155**	15%	**222**	**229**	26%	29%	43%	47%
biomass	**31**	3%	**129**	**130**	15%	17%	320%	324%
ambient heat	9	1%	82	76	10%	10%	811%	745%
solar thermal	3	0%	17	18	2%	2%	550%	566%
TOTAL	***1062***	100%	***856***	***776***	100%	100%	-19%	-27%

3.2 Development of costs related to heating and cooling until 2050

This section is dedicated to the underlying costs for heating and cooling from an end user perspective. The costs are directly derived from the underlying assumptions on energy prices and investments costs implemented in the building stock model Invert/EE-Lab. Those include investment costs and granted subsidies for thermal renovations (excluding maintenance measures) and heating systems as well as the energy expenditures corresponding to the annual final energy demand until 2050. All values including the public subsidies represent annual values.

3.2.1 Development of energy expenditures and investments in energy efficiency and heating systems until in the overall building stock

Energy expenditures

Following the reduction of final energy for space heating, energy expenditures for households and the service sector are expected to decrease significantly. Figure 32 and Table 10 show energy expenditures from an end user perspective for space heating, hot water, space cooling and auxiliary energy in the EU28 until 2050.

Annual Energy expenditures amount to about 340 billion € in 2012 and are reduced by around -25% in the current policy scenario and -35% in the ambitious policy scenario respectively. That amounts to around 250 billion € and 220 billion € respectively in the year 2050. Model results indicate that the expenditures for space heating will be strongly reduced by about -40% to -50%, mainly as a result of thermal renovation measures in the building stock. On the contrary a growing demand for space cooling and therefore increasing energy expenses for electricity for air conditioning from about 15 billion € in 2012 to more than 50 billion € in 2050 annually are estimated in the scenarios. Space heating expenses will still account for the biggest share (around 55% to 60% of the total energy expenses) while cooling will cover around 25%. The energy expenses for water heating are expected to decrease despite an increase in total energy demand, mainly because of the increased deployment of solar thermal systems.

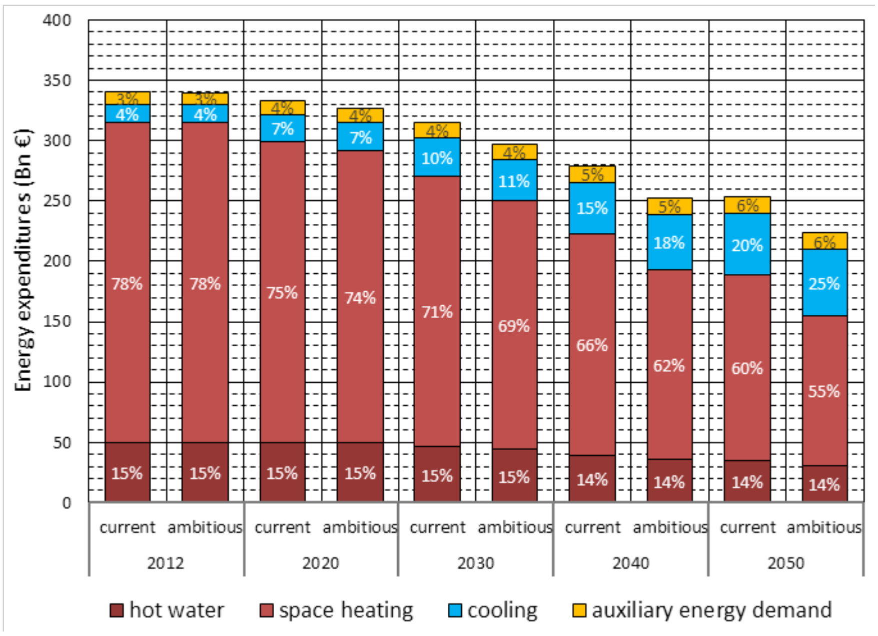

Figure 32: Energy expenditures by usage types for current and ambitious scenario for EU28 in Bn €

Table 10: Energy expenditures by usage types for *current and ambitious* scenario for EU28 in TWh and change energy expenditures by usage types for *current and ambitious* scenario for EU28 in %

Energy expenditures (Bn €)	hot water		space heating		cooling		auxiliary energy demand		TOTAL	
Scenario	current	ambitious	current	ambitious	current	ambitious	current	ambitious	current	ambitious
2012	49.7	49.7	265.2	265.2	14.8	14.8	10.2	10.2	***339.9***	***339.9***
2020	50.2	49.7	249.1	242.3	22.0	22.6	12.0	12.0	*333.4*	*326.6*
2030	46.4	44.4	224.2	205.8	31.4	33.7	13.2	13.0	*315.1*	*296.9*
2040	39.5	36.1	183.7	156.9	42.4	45.9	13.8	13.5	*279.4*	*252.3*
2050	35.3	30.8	153.2	123.7	51.3	55.1	14.1	13.7	***253.9***	***223.3***
Share 2012	15%	15%	78%	78%	4%	4%	3%	3%	100%	100%
Share 2050	14%	14%	60%	55%	20%	25%	6%	6%	100%	100%
Change 2012/2050	-29%	-38%	-42%	-53%	246%	272%	38%	34%	***-25%***	***-34%***

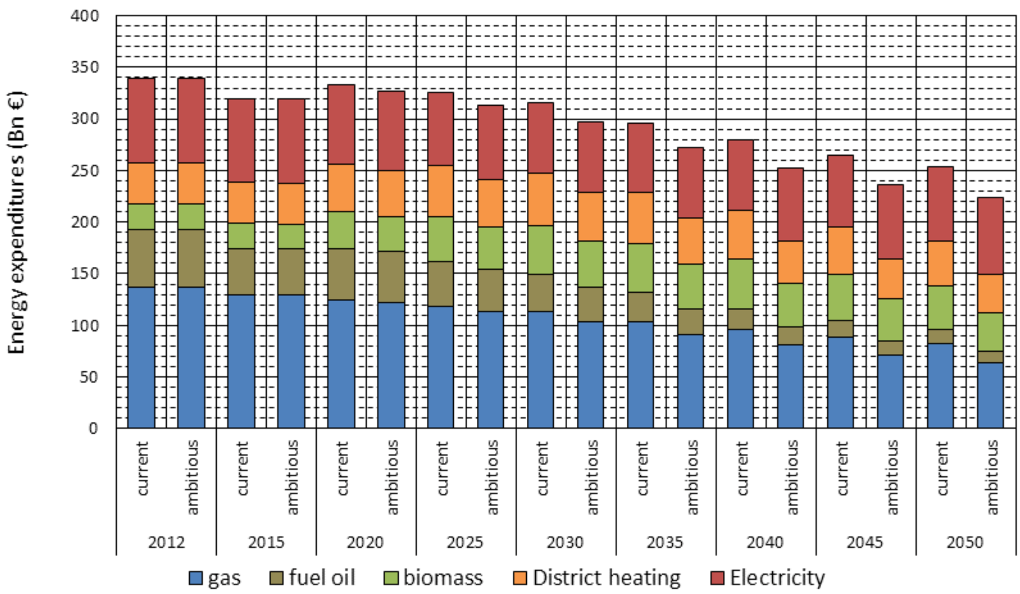

Figure 33: Energy expenditures by energy carriers for *current and ambitious* scenario for EU28 in Bn €

Figure 33 shows energy expenditures from an end user perspective on the main energy carriers for heating and cooling in EU28 until 2050. The reductions are mainly stem from a decrease in expenses for fossil energy carriers while expenses for biomass and district heating slightly increase.

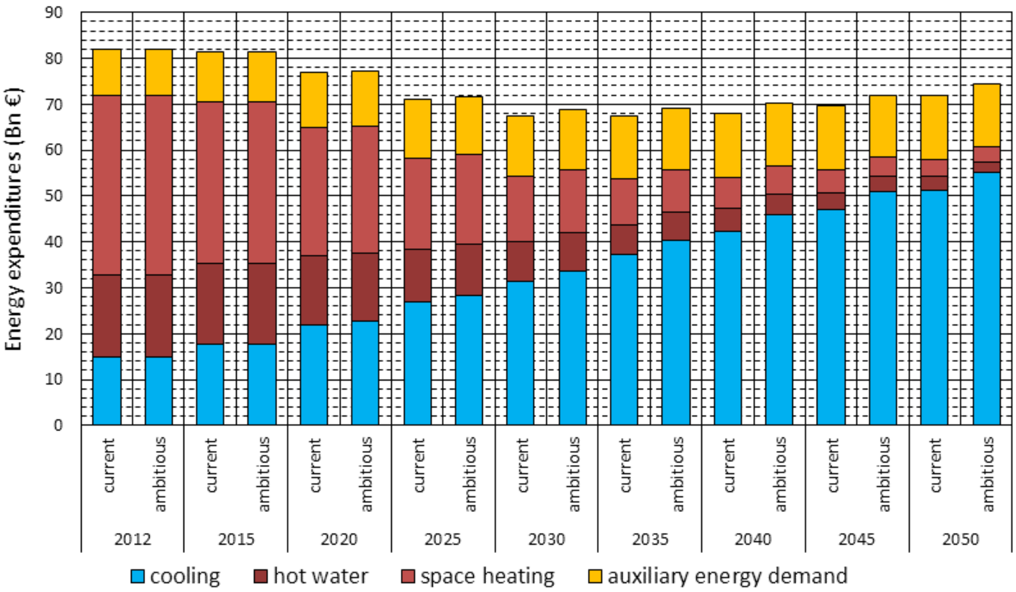

Figure 34: Energy expenditures for electricity for *current and ambitious* scenario for EU28 in Bn €

Energy expenditures for electricity (Figure 34) are expected to remain rather constant. However a significant shift in the end use categories from space heating and water heating to cooling, which accounts for around 70% of the electricity expenses for heating and space cooling in 2050, can be observed.

Investments

Total annual investments in heating systems and thermal refurbishments are estimated to be between 100 billion € and 120 billion € in the current policy scenario in the period between 2015 and 2050. Investments in retrofit measures, illustrated in Figure 35, amount to about 50 billion € to 70 billion € annually, whereas investments for heating systems, illustrated in Figure 36, amount to about 40 billion € to 50 billion €. Table 11 presents an overview of the investments in all measures, while Table 12 reveals the granted subsidies.

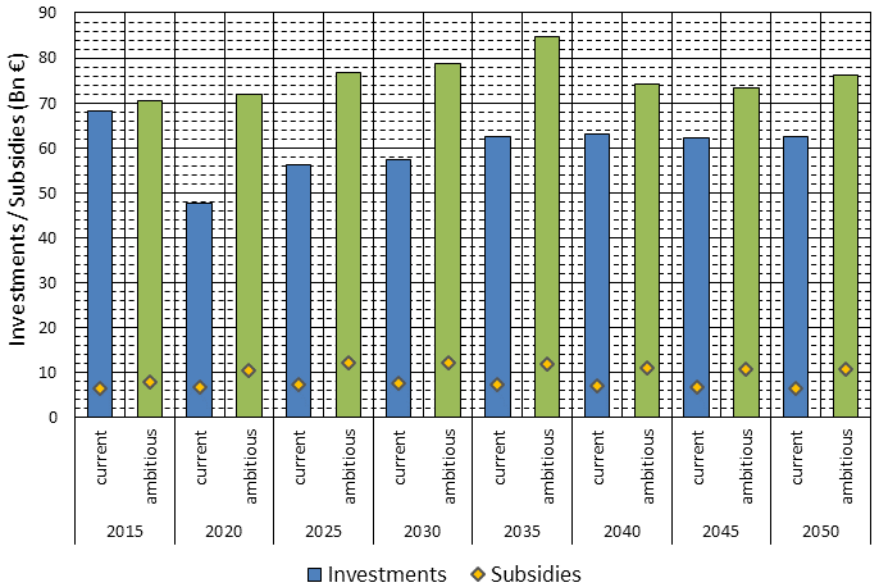

Figure 35: Investments and subsidies for building renovation for current and ambitious scenario for EU28 in Bn €

The additional measures applied in the ambitious policies result in an increase in annual investments of around 20 billion € to 25 billion € resulting in about 120 billion € to 135 billion € in total annual investments across the EU28 throughout the whole period. The additional investments are mainly a result of higher investments in thermal retrofit measures and (to a lower extent) higher investments in heating systems in particular solar thermal systems.

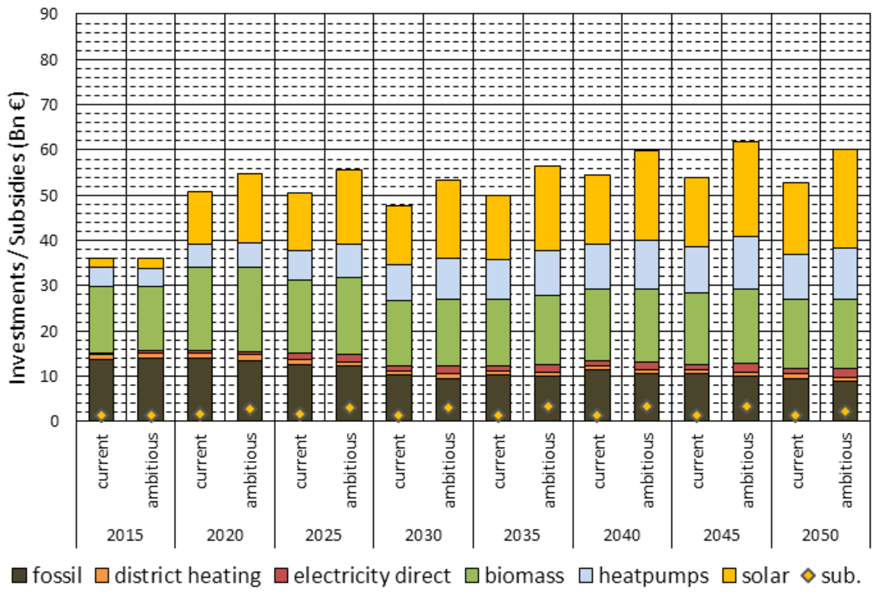

Figure 36: Investments and subsidies for heating systems by energy carriers for current and ambitious scenario for EU28 in Bn €

The subsidies granted for renovation actions according to the assumed subsidy regimes in each member state account for about 7 billion € to 12 billion € annually, whereas subsidies for heating system investments amount to about 1,3 billion € to 3,2 billion €.

The main parameters influencing the investments in thermal renovation are the age of building parts, , building performance standards, energy prices as well as underlying investment costs and public subsidies. Although the amount of annual subsidies in each scenario remains rather stable, investments in thermal renovation increases during the simulation period, due to stricter building performance standards expected to be in place after 2020 on the one hand and higher prices for energy carriers. Note that both scenarios assume increasing fuel prices derived from the EU reference scenario 2016.

Figure 36 differentiates investments in heating systems from an end user perspective per energy carrier. The scenario results indicate that biomass boilers, heat pumps and solar thermal systems account for the main share of investments in new heating systems. Investments in fossil heating systems (mainly natural gas boilers) only account for less than 20% of investments throughout the period between 2015 and 2050. Investments in space heating and water heating technologies are mainly driven by their lifetime, annual subsidies, renewable heat obligations and energy prices.

Heat pumps are mainly installed in efficient newly constructed buildings with low temperature heat distribution systems in the model. Biomass boilers substitute oil fired boilers in the existing building stock. The investments in solar thermal systems in combination with other heating systems increase substantially in both calculated scenarios.

Note that investments in district heating systems are to a large extend covered by the network operator and are therefore reflected in the energy costs from an end user perspective which is why investments shown in Figure 36 are low although the number of buildings connected to a district heating network increases in both scenarios. Investments in direct electric heaters are low in both scenarios as most installed electrical heating system in the model are more efficient heat pumps.

Table 11: Investment costs by usage types for current and ambitious scenario for EU28 in TWh and change energy expenditures by usage types for current and ambitious scenario for EU28 in %

Inv. (Bn €)	building envelope			HVAC technologies			TOTAL		
Scenario	Current	ambitious	diff.	current	ambitious	diff.	current	ambitious	diff.
2015	68.2	70.4	*2.2*	36.1	36.0	*-0.1*	***104.3***	***106.4***	*2.1*
2020	47.7	71.9	*24.1*	50.9	54.9	*4.0*	*98.6*	*126.7*	*28.1*
2030	57.4	78.8	*21.4*	47.8	53.4	*5.7*	*105.2*	*132.2*	*27.0*
2040	63.2	74.3	*11.1*	54.4	60.0	*5.5*	*117.6*	*134.2*	*16.6*
2050	62.4	76.2	*13.8*	52.8	60.1	*7.3*	***115.2***	***136.3***	*21.1*
Share on inv.	55%	59%		45%	41%		100%	100%	

Table 12: Subsidies by usage types for current and ambitious scenario for EU28 in TWh and change energy expenditures by usage types for current and ambitious scenario for EU28 in %

Sub. (Bn €)	building envelope			HVAC technologies			TOTAL		
Scenario	Current	ambitious	diff.	current	ambitious	diff.	current	ambitious	diff.
2015	6.6	7.9	*1.3*	1.3	1.3	*0.0*	***7.9***	***9.2***	*1.3*
2020	6.7	10.6	*3.9*	1.6	2.9	*1.2*	*8.3*	*13.5*	*5.1*
2030	7.6	12.3	*4.6*	1.4	3.2	*1.8*	*9.0*	*15.5*	*6.4*
2040	7.1	11.1	*4.0*	1.5	3.2	*1.8*	*8.5*	*14.3*	*5.8*
2050	6.7	10.8	*4.2*	1.4	2.2	*0.8*	***8.1***	***13.0***	*4.9*
Share on sub	83%	81%		17%	19%		100%	100%	

3.2.2 Development of energy expenditures and investments in energy efficiency and heating systems until in the residential sector

This section highlights investments and expenditures of the residential sector. Total annual investments in thermal refurbishment and heating systems amount to about 95 billion € in a current policy scenario and 110 billion € under ambitious scenario conditions. Figure 37 shows that about 50 billion € to 60 billion € are expected to stem from building renovation, about 45 billion € to 50 billion € are expected to be invested into new heating systems, shown in Figure 38.

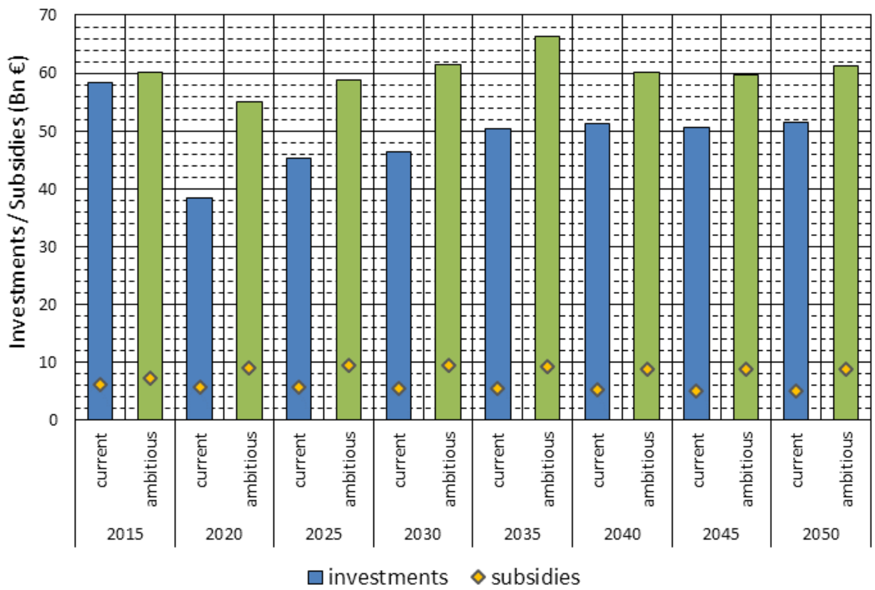

Figure 37: Investments and subsidies for building renovation for the residential sector for current and ambitious scenario for EU28 in Bn €

Subsidies for thermal renovation are assumed to account for about 5 to 10 billion € and about 2 to 4 billion heating systems.

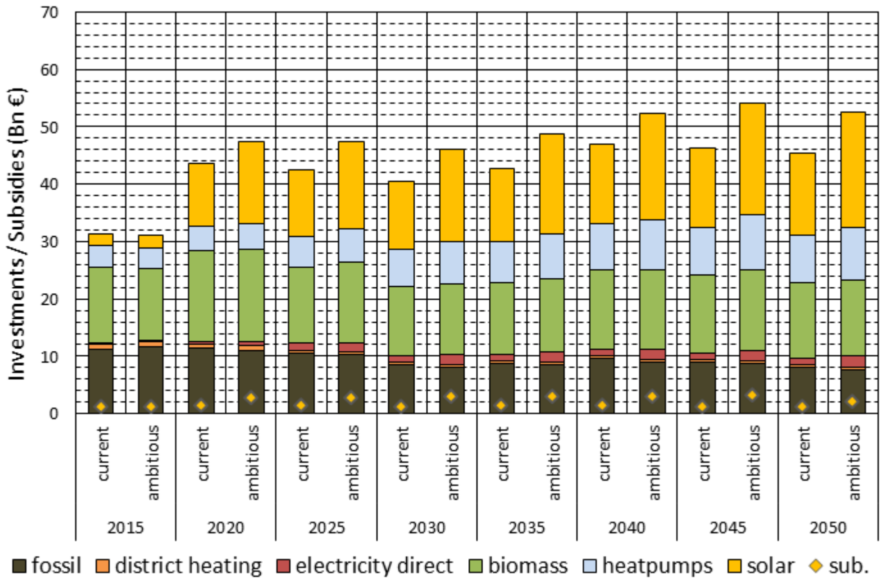

Figure 38: Investments and subsidies for heating systems in residential buildings by energy carriers for current and ambitious scenario for EU28 in Bn €

The results illustrated in Figure 38 the high share of investments in renewable heating systems. New buildings and buildings with a high renovation standard are mainly equipped with heat pumps. Solar thermal systems are deployed as secondary heating systems providing domestic hot water.

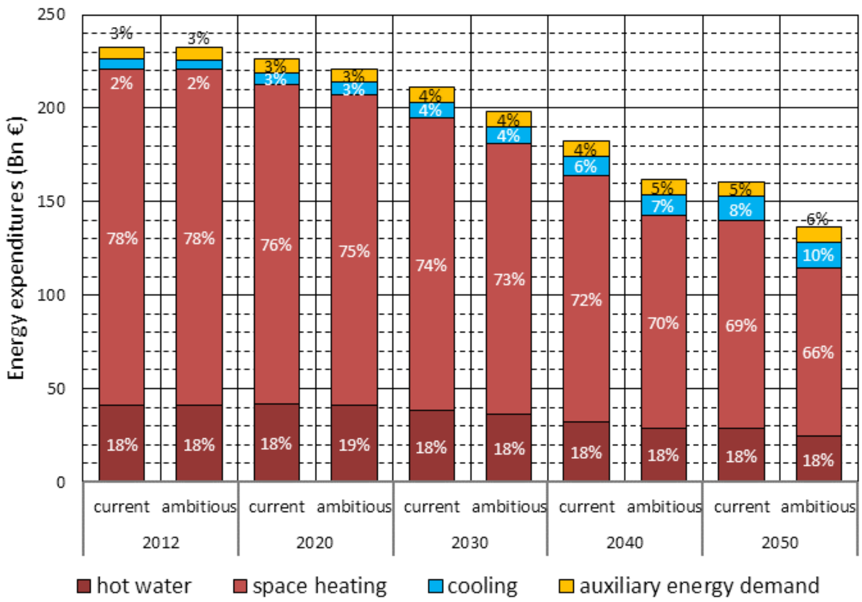

Figure 39: Energy expenditures by usage types for the *residential* sector for *current and ambitious* scenario for EU28 in Bn €

Figure 39 and Figure 40 reveal the annual energy expenditures for space heating, hot water, space cooling and auxiliary energy, reflecting the results for the final energy demand. A substantial reduction of energy expenses of about -31% to -41% can be expected. The majority of savings is induced by lower energy demands in thermally refurbished buildings. Moderately lower water heating expenditures due to the use of efficient heat pumps and high shares of solar thermal energy for water heating in 2050 can be expected, as well as higher expenditures for air conditioning. The share of space heating on the energy expenditures decrease from 78% to 69%

in the current policy scenario and 66% in the ambitious policy scenario. Space cooling accounts for about 8% to 10% of energy expenditures in the year 2050. It should also to be noted that electricity demand for auxiliary energy of heating systems accounts for about 6 % of total energy expenditures in 2050.

Figure 40 presents the energy expenditures by energy carrier. Besides the previously discussed reduction, it can be seen that natural gas accounts for the main share of expenditures on fossil energy carriers. Total expenditures for natural gas however decrease by about -40% to -50% indicating a significant reduction of revenues of natural gas providers in ambitious decarbonisation scenarios.

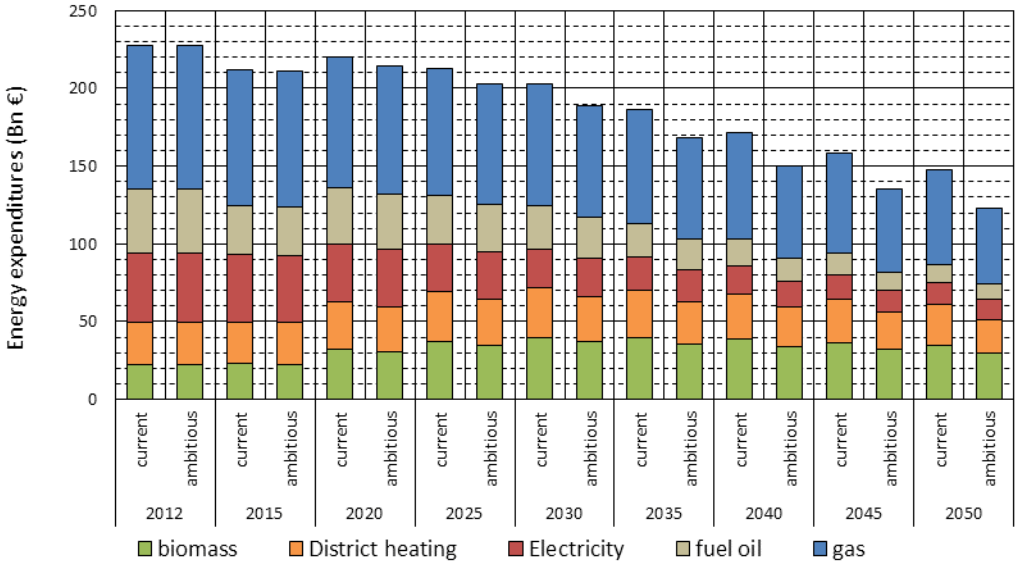

Figure 40: Energy expenditures by energy carriers for the *residential* sector for *current and ambitious* scenario for EU28 in Bn €

3.2.3 Development of energy expenditures and investments in energy efficiency and heating systems until in the service sector

This section highlights investments and expenditures of the service sector. Total annual investments in thermal refurbishment and heating systems amount to about 18 billion € in the current policy scenario and 23 billion € under ambitious scenario conditions. Figure 41 shows that about 11 billion € to 16 billion € is expected to origin from building renovation, about 7 billion € to 8 billion € are expected to be invested into new heating systems (see Figure 42).

Public subsidies for thermal renovation are assumed to be around 1 billion € to 2 billion € and about 0,2 billion € to 0,3 billion € for heating systems.

The results shown in Figure 42 reveal a strong focus on renewable sources. However, fossil fuel powered heating systems still show a market share of about 16 to 20% in the year 2050.

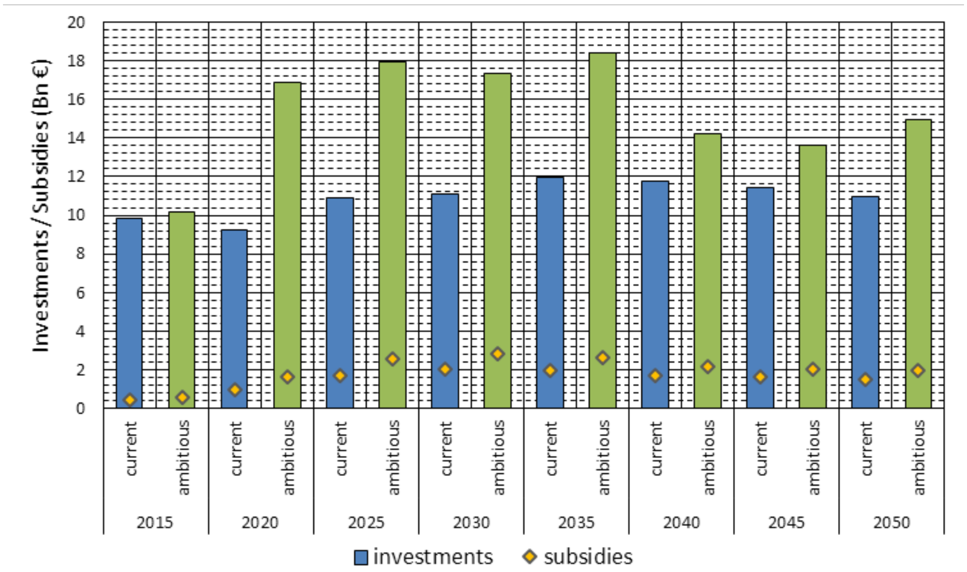

Figure 41: Investments and subsidies for building renovation for the service sector for current and ambitious scenario for EU28 in Bn €

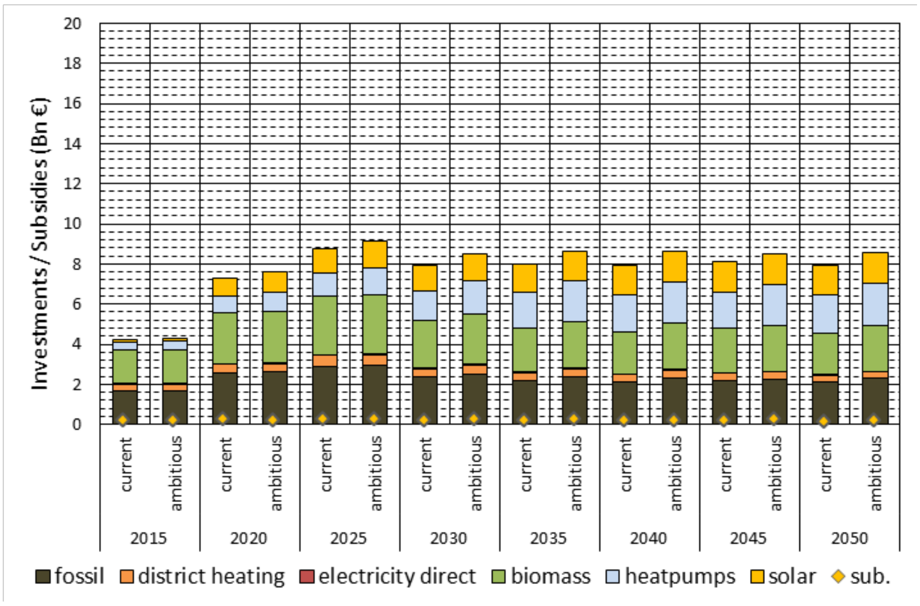

Figure 42: Investments and subsidies for heating systems in *service* buildings by energy carriers for *current and ambitious* scenario for EU28 in Bn €

Figure 43 illustrates the annual energy expenditures for space heating, hot water, space cooling and auxiliary energy, reflecting the results on final energy demand shown in the previous section. A reduction of energy expenses of about -13% to -19% can be expected for the service sector. A substantial increase in energy expenditures for air conditioning can be observed. The share of space heating in energy expenditures decreases from 79% to 45% in the current policy scenario and 38% in the ambitious policy scenario. The share of hot water remains constant, while expenditures for space cooling will account for about 41% to 47% of the energy expenditures in 2050 according to the scenario results. Figure 44 presents the energy expenditures by energy carriers. Expenditures for natural gas will be around 40% to 50% lower than in 2012, whereas the share of biomass slightly increases. The share of district heating is rather constant throughout the whole period.

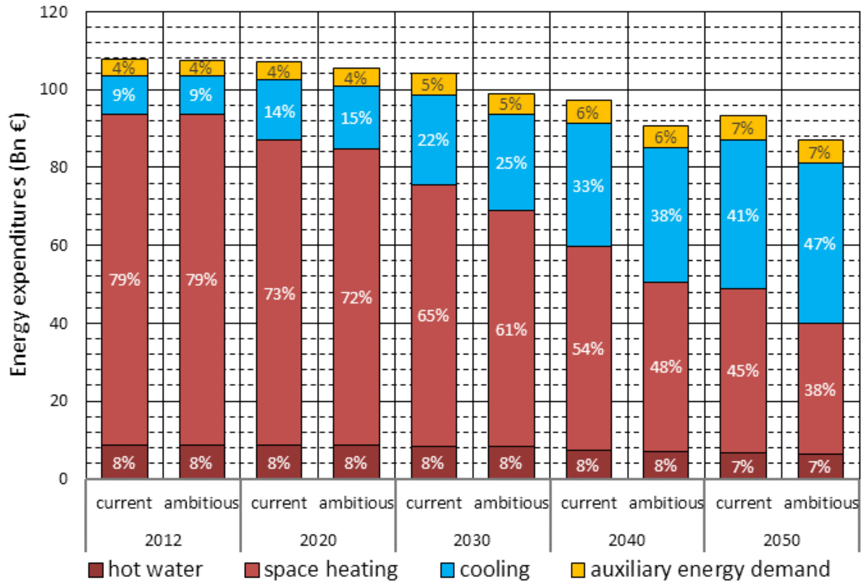

Figure 43: Energy expenditures by usage types for the *service* sector for current and ambitious scenario for EU28 in Bn €

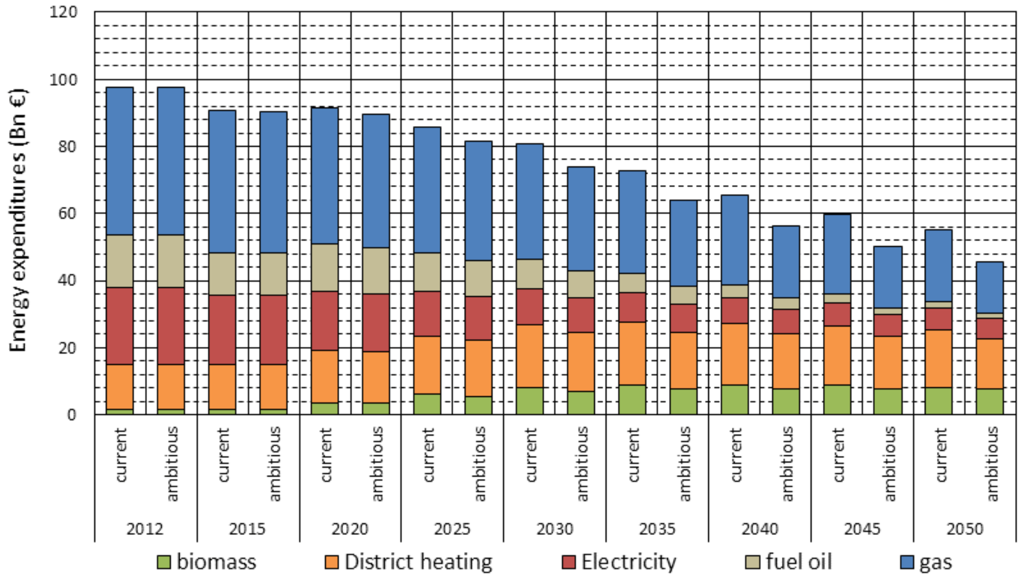

Figure 44: Energy expenditures by energy carriers for the *residential* sector for *current and ambitious* scenario for EU28 in Bn €

4 Uptake of renewable vs. fossil heating systems in the building stock

In this chapter an overview of the diffusion of renewable heating technologies until the year 2050 is provided. The main renewable technologies in the European heating sector are decentral biomass boilers, heat pumps and solar thermal systems. Also electricity production from decentral Photovoltaic systems (PV) can be seen as renewable technologies to support decentral generation of heat. While the uptake of photovoltaic is mainly analysed within other case studies and work packages in the SET-Nav project also the model INVERT/EE-Lab simulates the use of PV. Modelling results are presented in combination with the uptake of solar thermal systems to analyse the exploitation of potential building roof areas for heat and electricity generation within the scenarios.

4.1 Biomass

As discussed in section 3.1 the use of biomass increases substantially in both calculated scenarios. In the current policy scenario biomass (wood log, pellets and wood chips) use in decentral heating systems increases from 480 TWh in the calibration year 2012 to around 643 TWh in 2050. Due to increased thermal insulation the biomass use in the ambitious scenario increases to only 603 TWh. Less biomass is used in the ambitious scenario although in total more buildings are heated with biomass compared to the current policy scenario. This is illustrated in Figure 45 which shows the total gross floor area heated by decentral biomass boilers in the current and ambitious policy scenario for EU 28. In both scenarios the gross floor area heated by biomass more than doubles to around 8000 million m^2 in the year 2050 with slightly more in the ambitious policy scenario. The share of gross floor areas heated by biomass increases from around 13% in 2015 to 22% in the current policy and 23% in the ambitious policy scenario. This illustrates the importance of thermal efficiency not only for the reduction of fossil energy carriers but also for the conservation of limited biomass potentials.

Due to higher thermal efficiencies the installed capacity (Figure 46) of biomass boilers is estimated to increase by around 66% from 340 GW_{th} to 555 GW_{th} in the current policy and 561 GW_{th} in the ambitious policy scenario respectively.

Gross floor area:

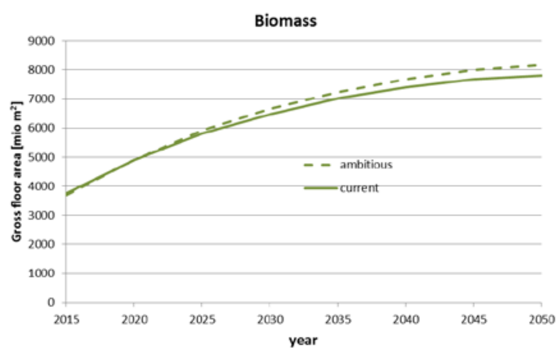

Figure 45: Gross floor area heated by biomass boilers in EU28

Installed capacity:

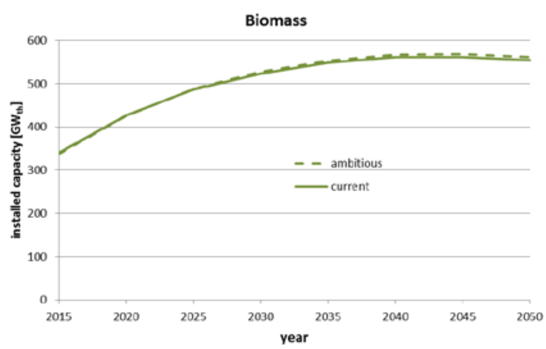

Figure 46: Installed capacity of biomass boilers in EU28

It can also be seen that the diffusion of biomass boilers in the building stock slows down. Within the model Invert/EE-Lab biomass potential restrictions in the form of cost curves for biomass resources have been implemented. This leads to higher fuel costs for biomass boilers and therefore higher expected heat generation costs compared to other technology options for higher exploitation rates of biomass potentials. In comparison with biomass potentials derived in the Bio Sustain project ("Sustainable and optimal use of biomass for energy in the EU beyond 2020 - Energy - European Commission") biomass use for decentral heating corresponds to an exploitation of around 45% of bioenergy potentials from forestry in a reference scenario for potentials available in the year 2030. While the results for biomass use in both scenarios are therefore considered to be feasible with respect to available biomass potentials, it has to be noted that biomass from forestry is also a valuable resource for industrial heat generation and heat generation in district heating networks which are not included in those figures. In comparison with scenarios up to the year 2030 calculated in the Bio Sustain project where all sectors are included, biomass use for decentral heating in the presented current and ambitious policy scenario lies within the scenario results of the Bio Sustain project which support the assumption that the scenario calculation result in a biomass exploitation within resource potentials. The trade-off between competing uses of biomass for energy supply in other sectors in particular for very ambitious scenarios with CO_2 reduction targets of around -85% will be further analysed in the pathway analysis (WP9) of the SET-Nav project.

4.2 Heat pumps

In both scenarios the use of heat pumps increases substantially. The applied building stock model takes into account the temperature levels of heat distribution systems and the dependency of the coefficient of performance (COP) of heat pumps on temperature levels of heat sources (ground and air source heat pumps are implemented in the model).

Total final energy for heating covered by heat pumps consists of the electricity consumption of heat pumps and ambient heat extracted from the heat source on a lower temperature level. Both components are illustrated in Figure 47 for the current and ambitious policy scenario for all EU28 member states. In both scenarios the use of heat pumps increases substantially. In 2015 it is estimated that around 120 TWh of final energy demand is covered by decentral heat pumps. The electricity demand of those heat pumps corresponds to around 47 TWh while around 73 TWh of heat are attributed to exploitation of ambient heat. This corresponds to an average COP of around 2.55 in the year 2015. Up to 2050 heat pumps account for more than 300 TWh in both scenarios. Electricity demand from heat pumps increases to around 100 TWh across all EU28 member states. It has to be noted that within the model heat pumps are mainly installed in newly constructed buildings and in to a smaller extend in well refurbished existing buildings in combination with low temperature heat distribution systems. This increases the average COP of all heat pumps to around 3 until the year 2050. If heat pumps would also be installed in combination with higher temperature heat distribution systems (e.g. above 50°C) those high COPs cannot be reached and electricity demand for heat pumps would be significantly higher than in the calculated scenarios.

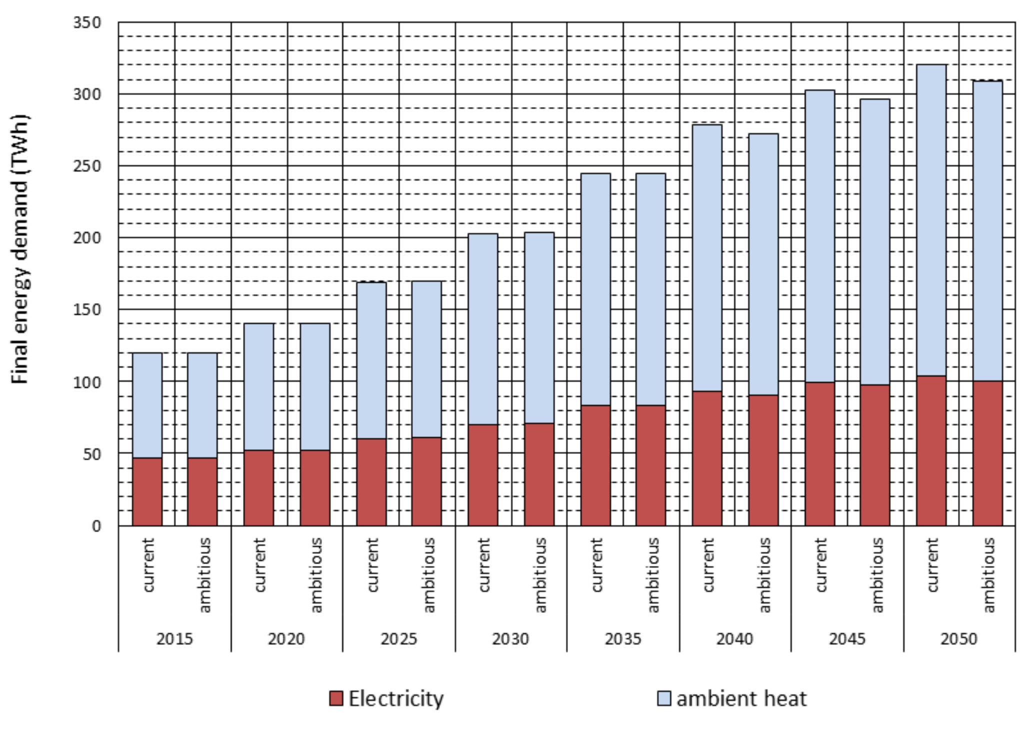

Figure 47: Total final energy demand delivered by heat pumps split up into the share of electricity and ambient heat

The result that heat pumps are expected to be mainly installed in buildings with relatively low heat demand is also reflected in the fact that the increase in gross floor area heated by heat pumps increase significantly faster than electricity demand for heat pumps. Figure 48 shows the development of gross floor areas covered by heat pumps. In the current policy scenario it is estimated that heat pumps in the year 2050 will deliver heat for around 5000 million m^2 of gross floor area. This corresponds to around 14% of the total gross floor area. In the ambitious scenario heat pumps are expected to increase further to around 5500 million m^2 delivering heat for around 15% of the EU28 living space. Figure 48 illustrates that the increase in installed capacities is lower, which is also an effect of the restricted use of heat pumps in thermally efficient buildings. Installed capacity of heat pumps only increases from around 100 GW_{th} in 2015 to around 300 GW_{th} in both scenarios.

Gross floor area:

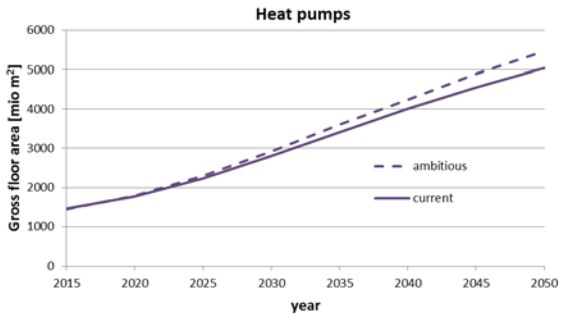

Figure 48: Gross floor area heated by biomass boilers in EU28

Installed capacity:

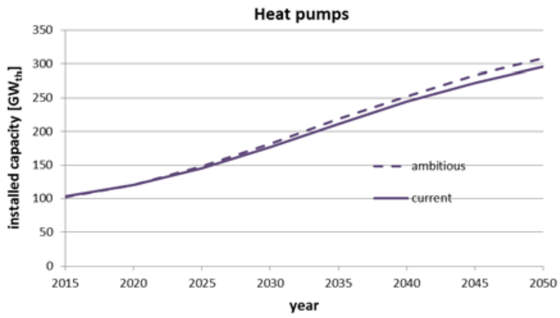

Figure 49: Installed capacity of heat pumps in EU28

4.3 Solar thermal systems and electricity generation from decentral PV

The Invert/EE-Lab model also simulates the exploitation of available building roof areas through solar thermal collectors and photovoltaic systems. The potential roof area is derived from the gross floor area of buildings which is one of the main inputs for the model. Assuming restrictions on the full exploitation of those areas including the assumption that roof areas facing north are excluded from the potential it is estimated that by 2050 more than 6000 million m^2 would be available for solar thermal collectors and or PV modules. Figure 50 shows the model development for the current and ambitious scenario runs. Following the current trend it is estimated that the diffusion of PV modules will be stronger than the increase of solar thermal collector areas. Figure 50 also indicates that the monetary subsidies which have been assumed to increase in the ambitious policy scenario significantly increase the number of solar thermal systems across the EU. The results estimate that 27% more solar thermal collector area would be exploited in the ambitious policy scenario than in the current policy scenario.

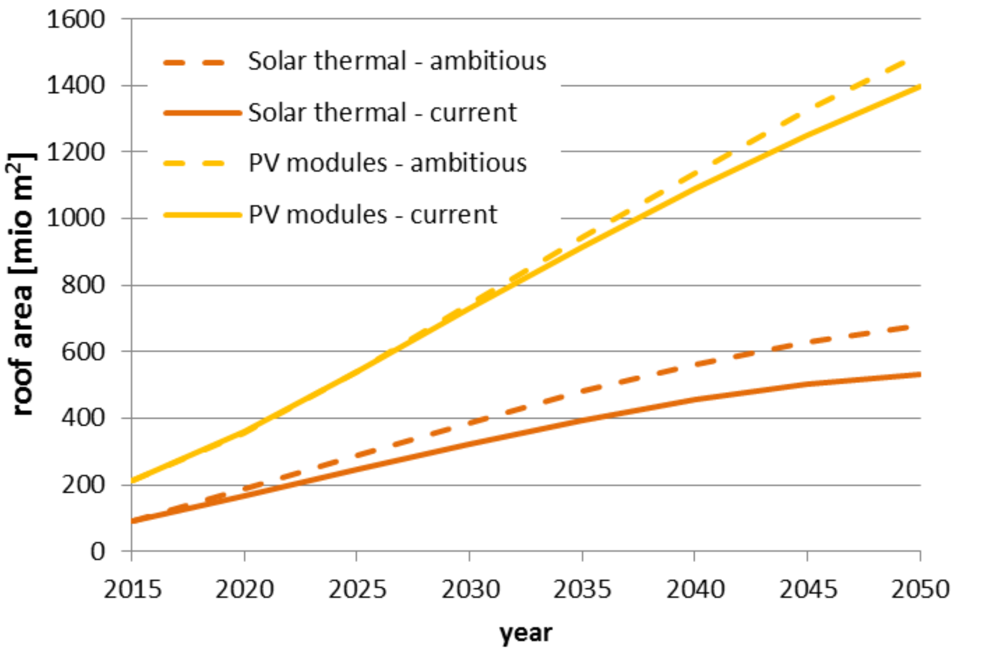

Figure 50: Roof area covered by solar thermal collectors and PV in EU28.

Figure 51 illustrates the comparison of areas covered by PV and solar thermal collectors with available roof potentials from 2015 to 2050 in the ambitious policy scenario. While in the year 2015 it is estimated that only 4% of potential roof areas are exploited this share rises to 33% in the year 2050. While this comparison suggests that there is additional potential available it could also be argued that using around 1/3 of available roof area until the year 2050 already constitutes a major challenge and would also significantly impact the appearance of the European building stock.

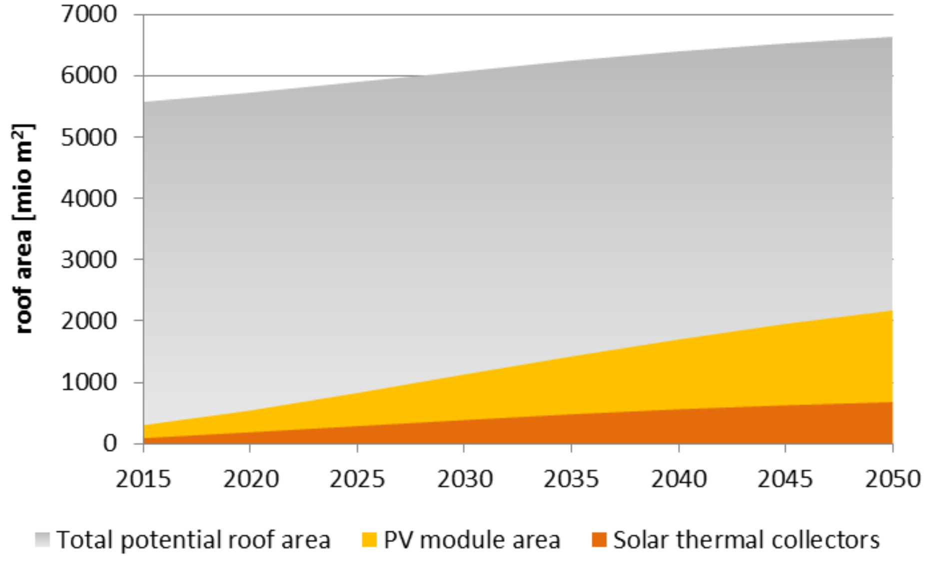

Figure 51: potential roof area for solar thermal collectors and PV and exploitation of those potentials in the ambitious policy scenario.

The applied building stock model also allows to estimate to which extent onsite electricity generation from PV would contribute to heat generation for space heating and domestic hot water. It was assumed that electricity from PV would first be used to cover the electricity demand for appliances in a building. If there is excess electricity generation available and savings from onsite use are higher than the feed-in tariffs provided for feeding electricity back into the grid it is assumed that the excess electricity is used for the generation of hot water and space heating. The results which are illustrated for the ambitious policy scenario in Figure 52 indicate that a significant share of (around 15%) of electricity generation from PV would contribute to local heat generation. Due to the negative correlation between space heating demand and solar radiation the contribution is however limited and cannot substitute connections to the electricity grid or the use of other energy carriers as a primary source for heating without unreasonably high investments in decentral storage and oversized PV systems.

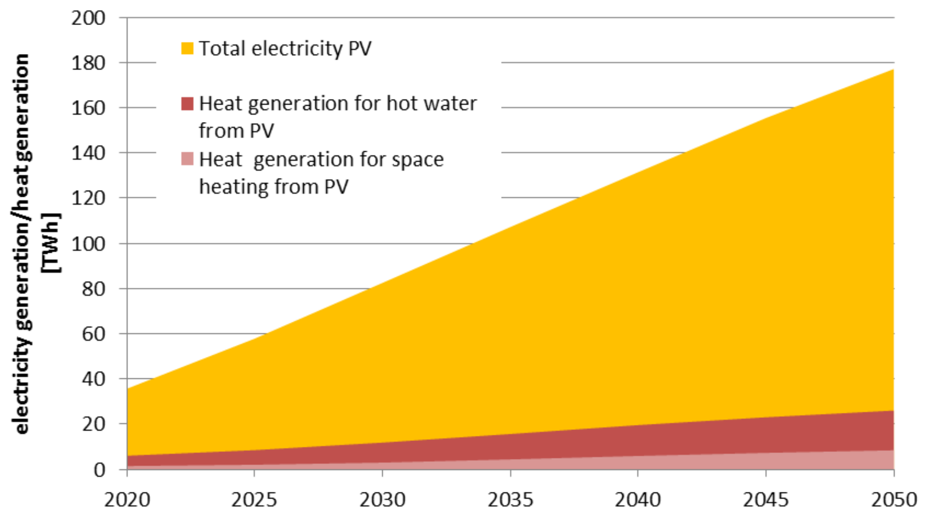

Figure 52: Share of electricity generation from PV used for heat generation for EU28

4.4 Fossil fuel systems

Despite the implemented policy measures fossil fuel systems still account for a substantial share of heat supply in both scenarios. The gross floor area heated by fossil fuel systems (Figure 53) only decreases by -8% in the current policy scenario and –13% in the ambitious policy scenario. While the share of oil and coal boilers is reduced significantly natural gas alone accounts for around 37% of gross floor areas by the year 2050 across the EU28 member states. The decrease in installed capacities is estimated to be more significant due to the increased thermal efficiency of the building stock by 2050 (see Figure 54). Those results indicate that a substantial share of reductions in fossil fuel use stems from thermal efficiency measures. Under the assumptions for both scenarios including financial support for renewable heating systems it is estimated that natural gas boilers will still be one of the main heat supply technologies by 2050. To reach even more ambitious CO_2 reduction targets either further measures to substitute gas boilers have to be implemented or a significant share of natural gas has to be substituted by other renewable gaseous energy carriers like biogas or power to gas in combination with renewable electricity generation. The role and potentials of district heating which can be seen as a substitute for natural gas in densely populated areas will be discussed in the following chapter.

Gross floor area

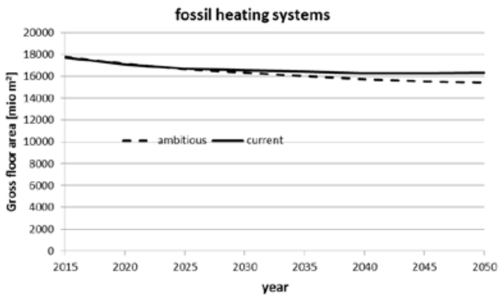

Figure 53: Gross floor area heated by fossil fuel systems in EU28

Installed capacities

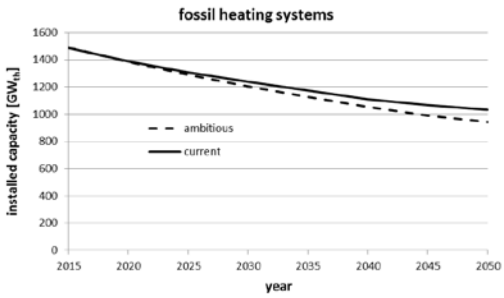

Figure 54: Installed capacity of fossil fuel systems in EU28

5 The role of district heating

Figure 55 and Figure 56 illustrate that both the gross floor area heated by district heating networks as well as the installed capacity of district heating in buildings within the calculated scenarios increases. It was already discussed in the previous section that district heating could be an option to substitute the use of natural gas in densely populated areas across the EU 28 member states. If district heat is generated by a combination renewable or efficient energy sources (including excess heat from industrial processes, municipal waste, large scale heat pumps and biomass) CO_2 from space heating and hot water supply could be further reduced. However for district heating to be competitive the distribution costs of centrally generated heat have to be below certain thresholds. Within this section an additional analysis in which potentials low cost heat distribution costs is presented to provide more insights on the potential role of district heating in Europe.

Gross floor area

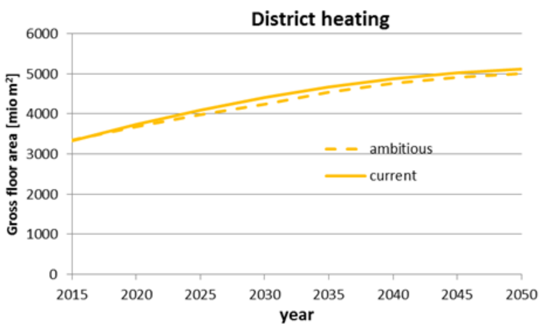

Figure 55: Gross floor area heated by district heating in EU28

Installed capacities

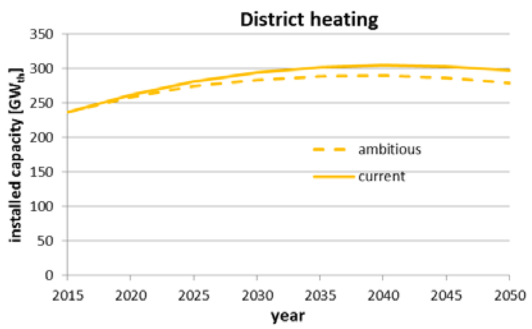

Figure 56: Installed capacity of district heating in EU28

The analysis is based on a regional disaggregation of heat demand on 100mx100m resolution for the results on energy demand for space heating and domestic hot water described in chapter 3.1. For this purpose, the distribution costs for district heating are calculated based on a function of heat densities for each raster cell. In general, the higher the heat density (defined as heat demand per 100x100m cell) of a region is the lower the distribution costs for district heating will be (see Persson et al. 2017). In order to prevent high average distribution costs for areas within regions due to not populated or less populated areas with lower heat demand, coherent heat demand areas are identified and the average distribution costs for these areas are pointed out.

Apart from the total heat density of an area the market share of district heating (share of heat demand connected to the grid) within an area is the main parameter influencing distribution costs. Thus, the analysis is conducted for two market share scenarios for district heating. The first one assumes a market share of 45 %, the second one of 90 %. The whole analysis is conducted for the current policies scenario.

5.1 Estimation of district heating potentials

The calculation of district heating distribution costs is based on the approach proposed by (Persson and Werner, 2011) and follows the adaption conducted in (Müller et al., 2014). As main input parameter, a spatial highly resolved heat density map of EU28 is used (see also section 5.2.1 for further details). The authors (Persson and Werner, 2011) showed for the Swedish case, that annual district heating distribution C_d, which consider the annuity α, the Investments for distribution I [€] and the heat annually sold Q_s [GJ/a], can bet written as function of two cost components C_1 [€/m] and C_2 [€/m], the required pipe diameter d_a and the linear Heat density $\frac{Q_s}{L}$ [GJ/m a]. This relation is written in equation 1.

$$C_d = \frac{\alpha * I}{Q_s} = \frac{\alpha * (C_1 + C_2 * d_a)}{\frac{Q_s}{L}} \quad [€/GJ]$$ **Eq. 1**

The cost components C_1 and C_2 are dependent from the plot ratio of the area, and can be assumed as displayed in Table 13. The plot ratio represents the density of buildings in a specified area of land and the applied distinction is park areas, outer city areas and inner city areas.

Table 13: Used cost parameters for district heating distribution capital costs (Source: (Persson and Werner, 2011))

Area characteristics	Plot ratio (e)	C_1 (€/m)	C_2 (€/m^2)
Inner city areas	$e \geq 0.5$	286	2022
Outer city areas	$0.3 \leq e < 0.5$	214	1725
Park areas	$0 \leq e < 0.3$	151	1378

The authors showed that equation 2 is a suitable approximation for the determination of the required pipe diameter d_a.

$$d_a = 0.0486 * \ln\left(\frac{Q_s}{L}\right) + 0.0007 \; [m]$$ **Eq. 2**

Cost calculation assuming decreasing heat demand and initial market shares

In (Müller et al., 2014), the authors adapted the calculation of the district heating distribution costs C_d as displayed in equation 3 where decreasing heat demand Q_{T+t} within the depreciation time τ [a] is considered. This allows the consideration of the effects of thermal refurbishments in the building stock on district heating distribution costs. The decreasing heat demand is an endogenous result within this case study, which is based on the scenario results for the development of the building stocks heat demand in section 3.1.

$$C_d = \frac{C_1 + C_2 * (0.004586 * \ln\left(\frac{Q_T}{L}\right) + 0.0007}{\sum_{t=1}^{\tau} \frac{\frac{Q_{T+t}}{(1+r)^t}}{L}} \left[\frac{€}{GJ}\right]$$ Eq. 3

A further assumption in this analysis concerns the initial market share of district heating, which directly affects the district heat demand and thus the distribution costs. We define the market share as the share of heat demand that can be connected to the grid in the first year. The lower the market share and thus the lower the heat demand within a potential grid is, the higher the distribution costs will be. In order to consider the market share explicitly, the Heat Density map is multiplied by the expected market share and the distribution costs reflect the costs for the various market shares.

Identification of coherent areas based on energetic thresholds

Based on the district heating distribution costs, which can be calculated for each raster cell separately, coherent areas are identified. Following the approach in (Persson et al., 2017), coherent areas are defined as such areas, where “the demand is sufficiently high and the heat densities are concentrated”. The concentrated heat densities (MWh/ha) guarantee reasonable distribution costs, and the high demand can be identified as minimum required demand (MWh) to allow an economic viable district heating supply. Thus, for all regions within Europe, the coherent areas for adjacent cells are identified based on the energetic thresholds. For this purpose, the NUTS3 boundaries of all EU-28 countries serve as boundaries for the identification of coherent areas. This approach can result in multiple independent coherent areas per region. Single pixels within each area, where the density is too low (and thus the distribution costs are too high) are excluded, if surrounding pixels fulfil the requirements. Finally, the average distribution costs for all coherent areas within this region are calculated for the considered pixels.

District heating distribution costs for regions considering energetic and economic threshold

The application of the energetic threshold for the heat densities (GWh/km^2) has a strong impact on (1) the district heating potential and (2) the resulting average distribution costs to exploit this potential. An example is given in Figure 57 for one exemplary NUTS3 region.

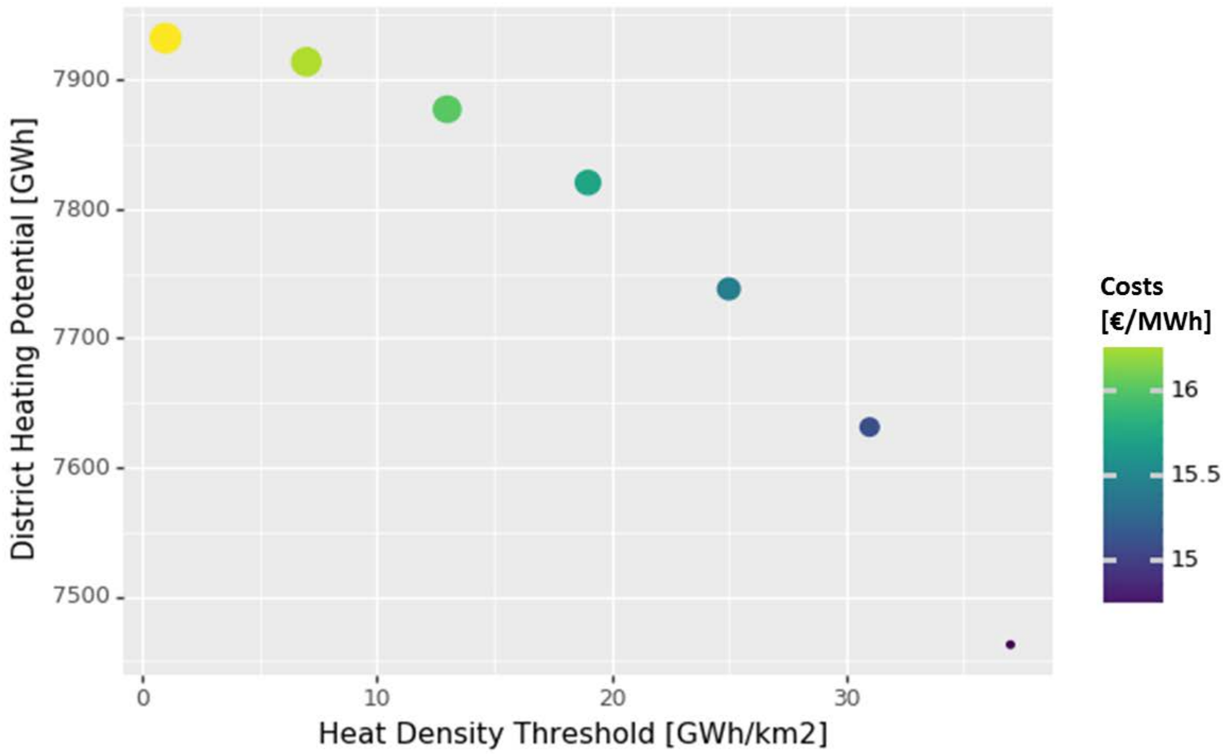

Figure 57: The impact of the heat density threshold on District Heating Potential and the resulting distribution costs for the example of Vienna (NUTS3-region) and the current policies scenario in the year 2015. The initial market share of district heating is assumed to be 45 %.

In order to consider these effects explicitly, multiple variants are calculated by defining various energetic thresholds for heat densities and demand in the coherent areas. On top, the average distribution costs for the region with all coherent areas within the region are calculated. The resulting costs can be appended to each variant of heat density and required demand in the area. Subsequently, cost categories (€/MWh) are introduced in order to aggregate the results for all regions within a country on country level (aggregation from NUTS3 to NUTS0 level). The derivation of district heating potential for EU-28 requires an aggregation of the results from country level. Figure 58 summarizes the used data, it's spatial resolution as well as the methodological approach.

Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]	Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]	Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]	Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]
AUT	83120	894	ESP	116455	2446	HUN	60124	691	NLD	138041	1221
BEL	81715	856	EST	11726	121	IRL	34021	345	POL	229719	2336
BGR	21896	294	FIN	66775	512	ITA	312211	5182	PRT	28429	639
CYP	1913	64	FRA	447988	3999	LTU	13158	188	ROU	53973	817
CZE	69557	620	GBR	460191	5031	LUX	5598	62	SVK	33245	310
DEU	592920	6947	GRC	45695	880	LVA	13322	109	SVN	10462	155
DNK	43094	601	HRV	12504	196	MLT	5286	21	SWE	83510	1078

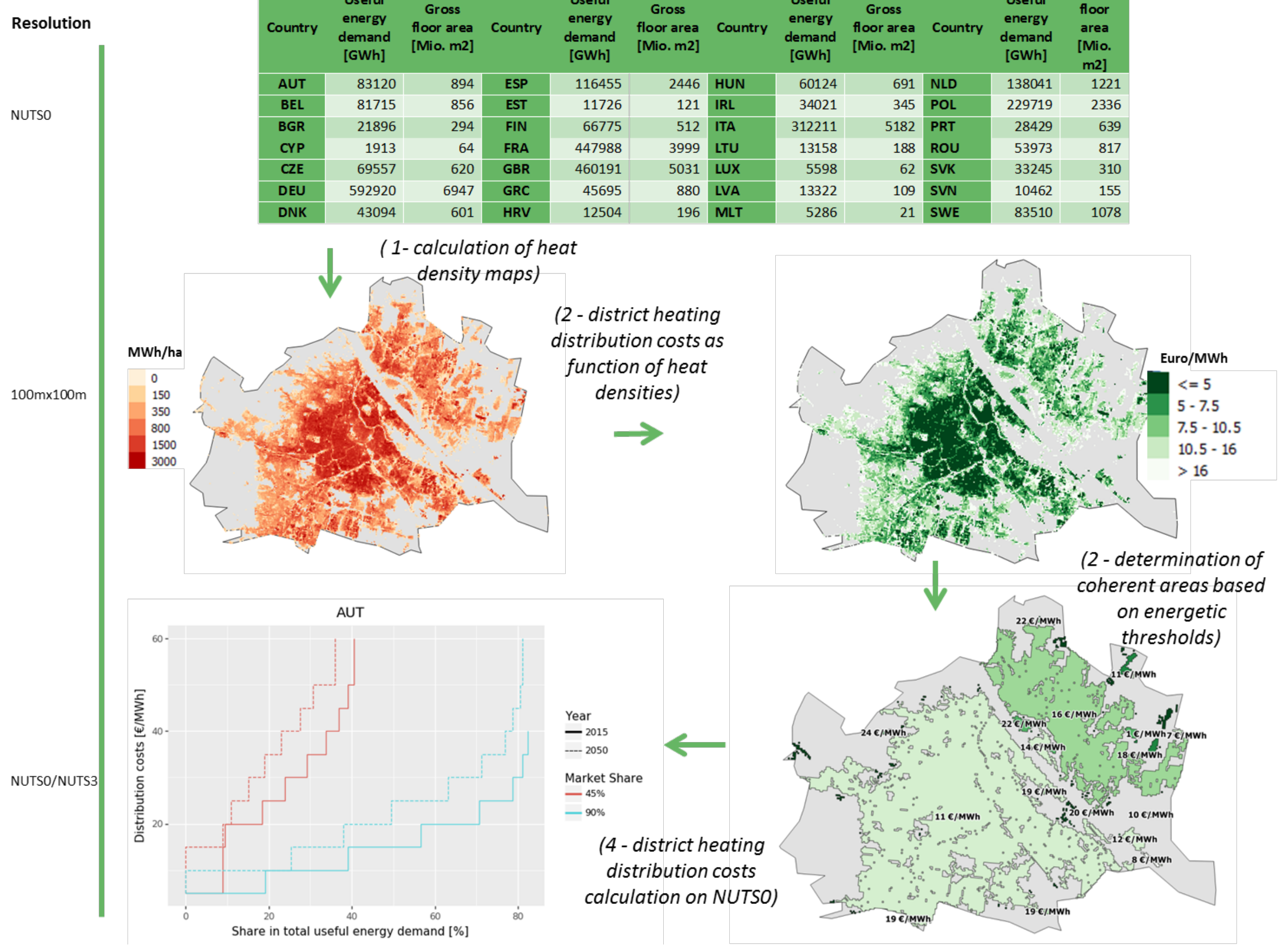

Figure 58 Overview of methodology, used data and it's spatial resolution as well as on how to derive district heating potentials for EU-28

5.2 Input data and assumptions

5.2.1 Heat demand and Heat Density Map

The analysis to derive district heating potentials is based on the heat density map that is derived within the project. The heat density map uses the useful energy demand as a result of Invert/EE-Lab. These values are available on Country level and are disaggregated to 100m x 100m raster based on data for population, Corine land cover data and the areas soil sealing. A full description of the methodology can be found in (Pezzutto et al, 2018). Detailed information about the underlying useful energy demand and gross floor area per member state for the year 2015 as a result of the SET-Nav current policies scenarios can be found in Table 14.

Table 14: Useful energy demand on NUTS0 level for all EU-28 countries as input data for the calculation of the district heating potentials for the year 2015.

Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]	Country	Useful energy demand [GWh]	Gross floor area [Mio. m2]
AUT	83120	894	HUN	60124	691
BEL	81715	856	IRL	34021	345
BGR	21896	294	ITA	312211	5182
CYP	1913	64	LTU	13158	188
CZE	69557	620	LUX	5598	62
DEU	592920	6947	LVA	13322	109
DNK	43094	601	MLT	5286	21
ESP	116455	2446	NLD	138041	1221
EST	11726	121	POL	229719	2336
FIN	66775	512	PRT	28429	639
FRA	447988	3999	ROU	53973	817
GBR	460191	5031	SVK	33245	310
GRC	45695	880	SVN	10462	155
HRV	12504	196	SWE	83510	1078

The spatial distribution of the heat densities also varies from Country to Country. Figure 59 displays the distribution of heat densities per member states for the year 2015. For example, Austria and Beglium has almost the same useful energy demand (83 TWh for Austria and 82 TWh for Belgium), however a higher share of demand can be attributed to densely populated areas in Austria. Also the differences in the useful energy demand between Czech Republic and Finland are minor, but the distribution of the heat densities shows major differences.

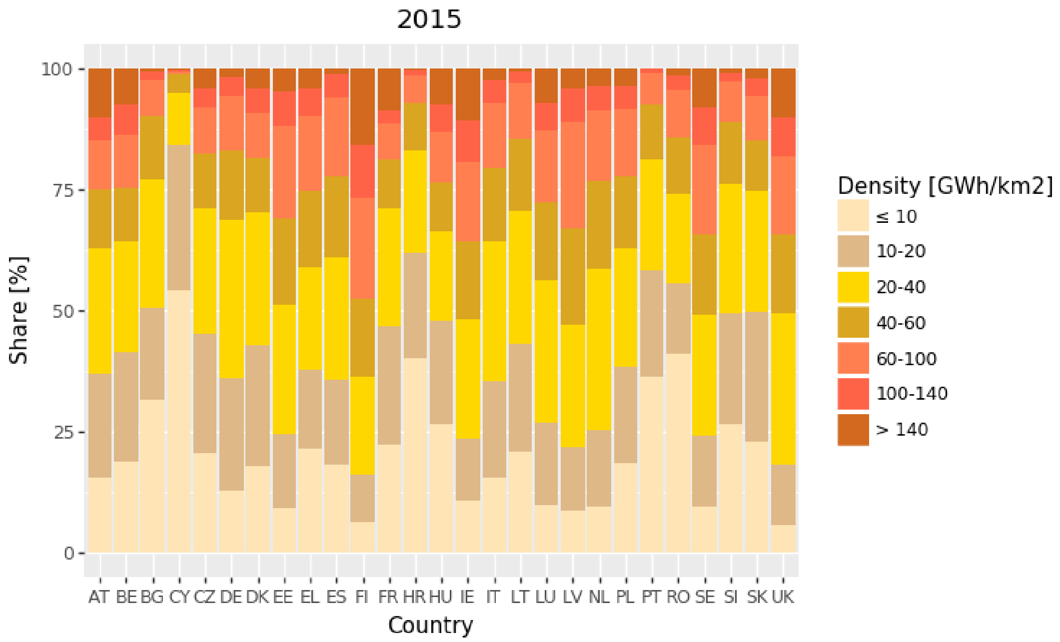

Figure 59: Distribution of heat densities per member state (except Malta) for different density classes in the year 2050

As the analysis of the district heating potentials also considers the development of the buildings' heat demand in course of time due to thermal refurbishments. Energy efficiency measures generally lead to lower heat densities, which is illustrated in Figure 60.

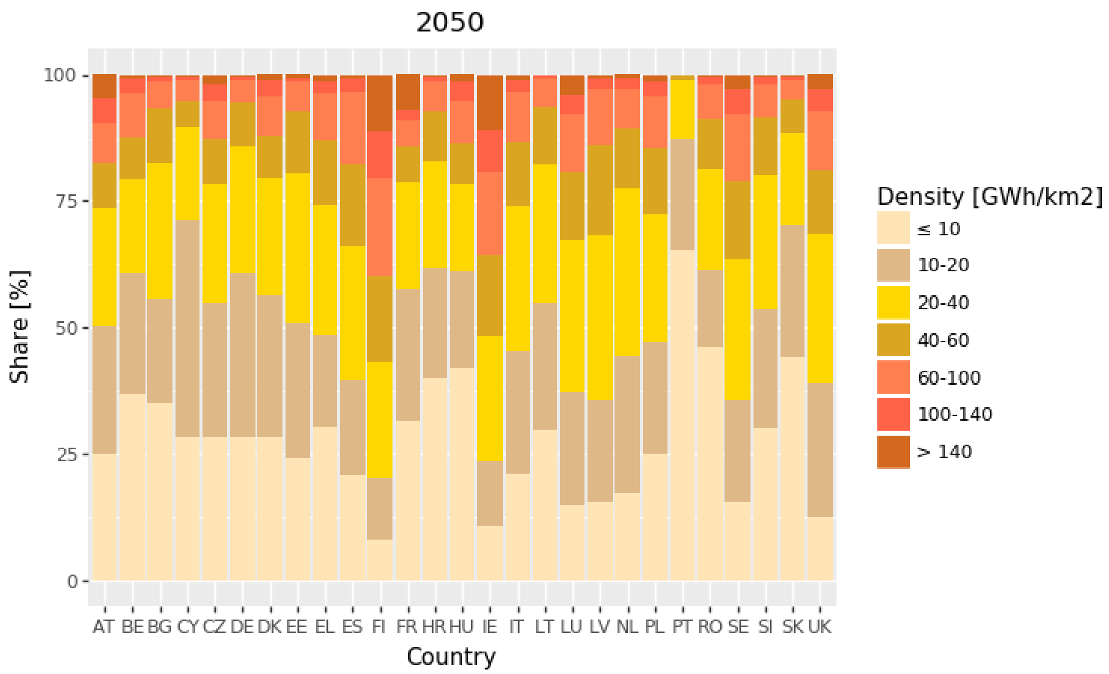

Figure 60: Distribution of heat densities per member states (except Malta) for different density classes in the year 2015

5.3 Results on District heating potentials for EU-28

Figure 61 illustrates heat distribution cost curves for estimated heat densities in the year 2015 and 2050 (dashed line) and market shares of 45% (orange lines) and 90% (blue lines).

It can be seen that if high shares of buildings (90% initial market share) within densely populated urban areas are connected to heat networks up to more than 50% of heat demand in Europe could be supplied with district heat at heat distribution costs below 20 €/MWh which is considered to be a reasonable cost threshold for heat networks to be competitive compared to decentral heating systems. Those low distribution costs levels can also be achieved when heat demand reductions up to 2050 are considered, visualized as dashed line. However those high connection rates can only be achieved if additional regulatory measures are implemented. Even for less ambitious scenarios regarding the initial market share, the share of heat demand that could be supplied by district heating form an economic point of view (with distribution costs around 20 €/MWh) could be increased to 20 %. Figure 61 also indicates the share of useful energy demand which is currently connected to district heating networks (Actual share 2015) as well as the share of district heating in total useful heat supply in the calculated current policy scenario for the year 2050 (Simulation Results 2050).

This analysis indicates that there is additional potential for theoretically cost efficient district heating if high connection rates can be achieved up to the year 2050. Such high market shares however are not likely to be achieved without regulatory support. Zoning approaches including the identification of district heating priority areas can be suitable measure to increase the economic efficiency of district heating networks in the future.

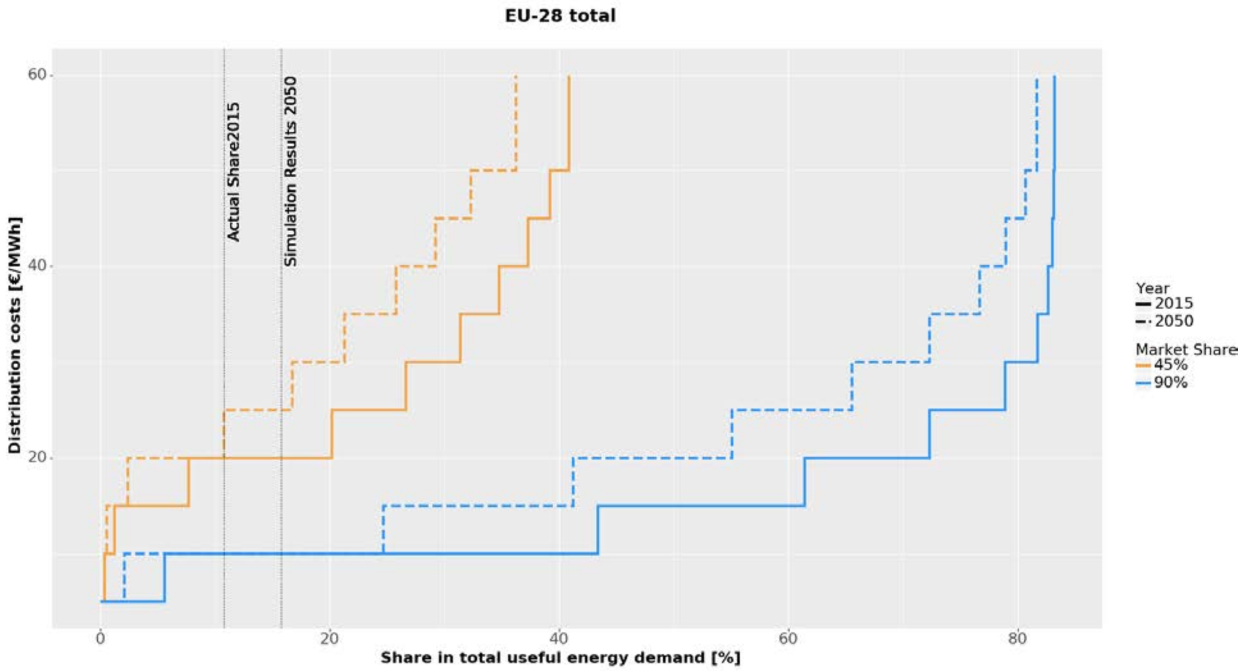

Figure 61: Estimated heat distribution costs for EU 28 in the current policy scenario for heat densities in the year 2015 and 2050 and district heating market shares of 45% and 90%

5.4 Results on District heating potentials for selected MS

As the analysis is conducted for multiple regions within countries, the results for all member states are displayed in Figure 62 to Figure 63. It can be seen, that regarding share in total useful energy demand, that can be supplied via district heating as well as the corresponding costs to exploit the district potential, significant differences across the member states are observed. The vertical line in each subplot indicates the current share of district heating in the countries. It can be seen, that the country with the highest share of district heating (Denmark with a share of district heating in useful energy demand above 50 %) corresponds with underlying distribution costs around 20 €/MWh, if we assume 90% initial market share in the district heating areas. Again, the essential role of regulatory measures and zoning is pointed out.

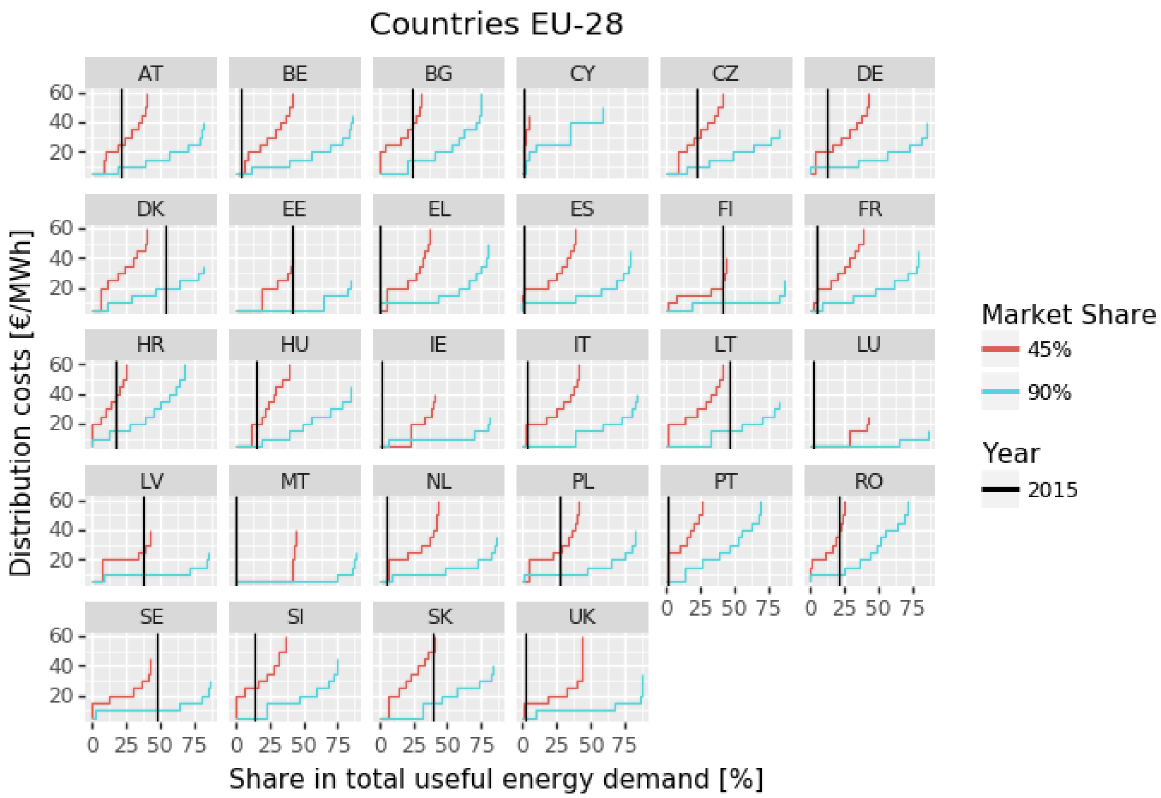

Figure 62: Estimated district heating distribution costs for all member states in the current policy scenarios for heat densities in the year 2015 and district heating market shares of 45% and 90%

Figure 63 displays the results for the year 2050, assuming a decrease in the useful energy demand according to the results of efficiency increases in the current policy scenario.

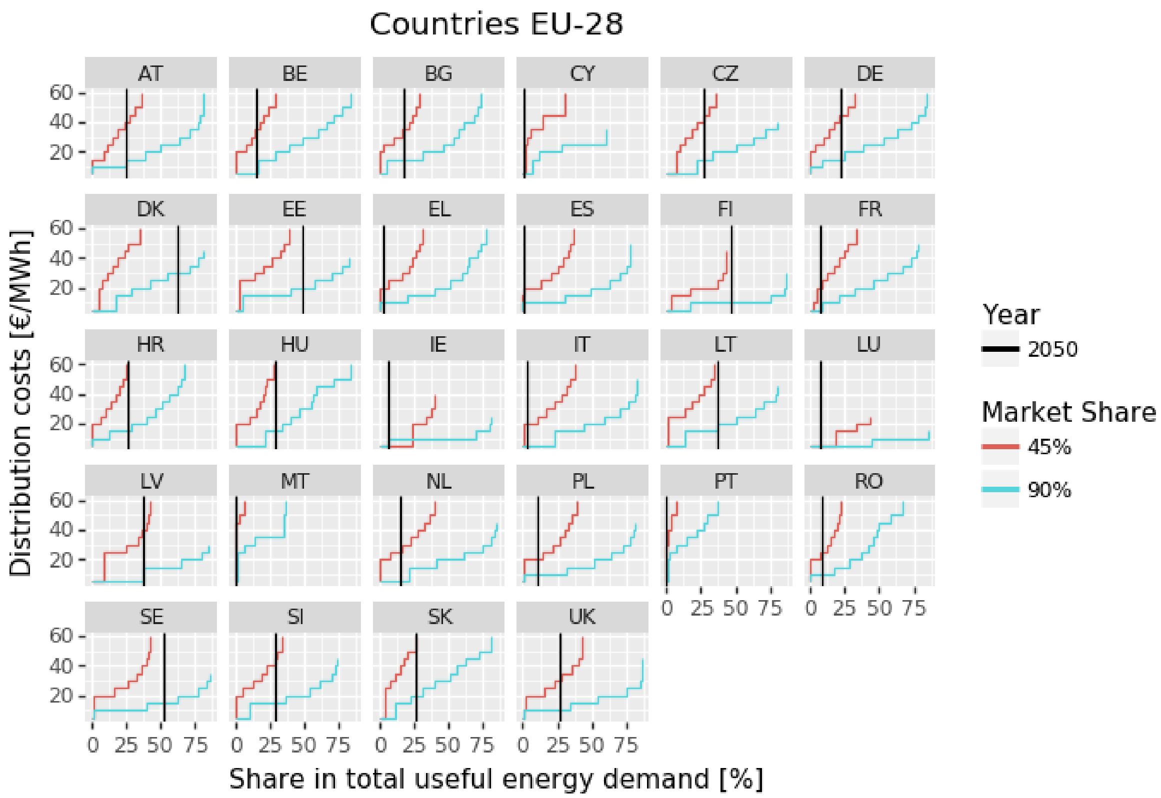

Figure 63: Estimated district heating distribution costs for all member states in the current policy scenarios for heat densities in the year 2050 and district heating market shares of 45% and 90%

5.5 Conclusions

The current analysis should point out the future role of district heating and can help to assess the related CHP potential in various scenarios, taking into account reduced heat demand and related heat densities.

Due to building refurbishment, heat demand will strongly reduce in strong decarbonisation scenarios. Even in the current policies scenario, heat demand (in terms of useful energy demand) reduces around 30 % between 2015 and 2050.

Of course, the economic effectiveness of district heating grid is correlated also to the heat densities. In rural areas, this leads to the fact that district heating may lose attractiveness. However, our analysis shows that also in scenarios with strong uptake of renovation activities, a large share of heat demand could be covered with reasonable district heating distribution costs. For example, the scenarios for the current policies scenario in Germany pointed out a heat demand reduction potential around 40 %, but considering market shares around 90% almost 40% of the remaining useful energy demand could be supplied with district heating distribution costs of 20 €/MWh.

6 Impact on the electricity system from heating and cooling and the role of flexibility in the building stock

In this chapter the impact of developments in heating and cooling the European building stock in the calculated scenarios on the electricity system will be discussed. First, the development of electricity demand for heating and cooling for both scenarios is illustrated. Then the most relevant findings that were found from the transformation of annual demands into hourly loads for heating and cooling will be presented. Furthermore the results from the integration of model outputs from the building stock model Invert/EE-Lab into the electricity system models Enertile and EMPIRE are presented focusing on the value of flexibility from heating and cooling for the electricity system.

6.1 Development of electricity demand for heating and cooling

As already discussed in chapter 3.1 the electricity demand for space heating and hot water is expected to decrease (see Figure 64) despite the significant increase in the diffusion of heat pumps. This development in both calculated scenarios is a result of increased thermal efficiency of buildings and the assumed phase out of electric direct heaters. Figure 65 reveals that the installed thermal capacity of electrical heating systems (direct electric and heat pumps) actually increases significantly from around 270 GW_{th} in 2015 to around 350 GW_{th} in the year 2050 in both scenarios. However by 2050 the main share of this installed capacity consists of heat pump which use significantly less electricity to generate the same amount of heat compared to electric direct heaters.

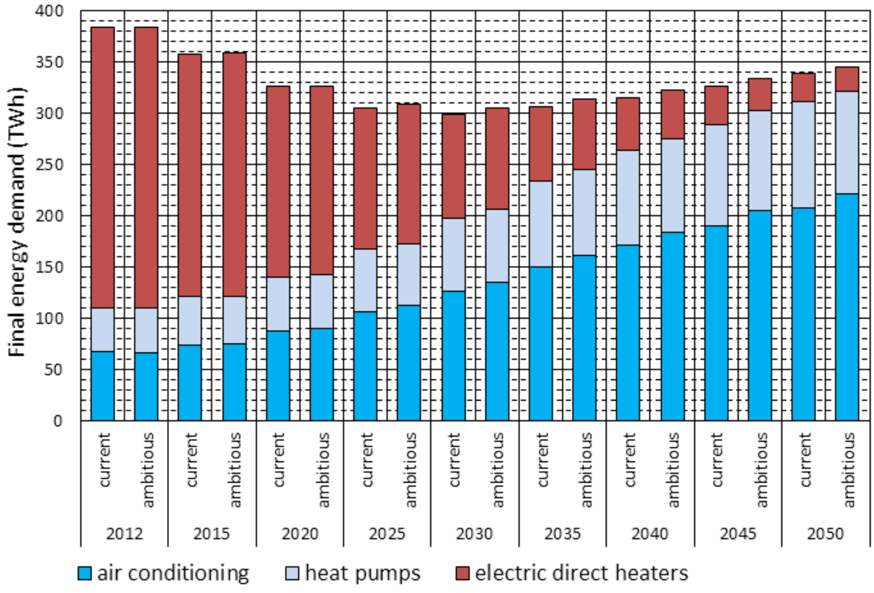

Figure 64: Total final energy demand for electricity for *current and ambitious* scenario for EU28 in TWh

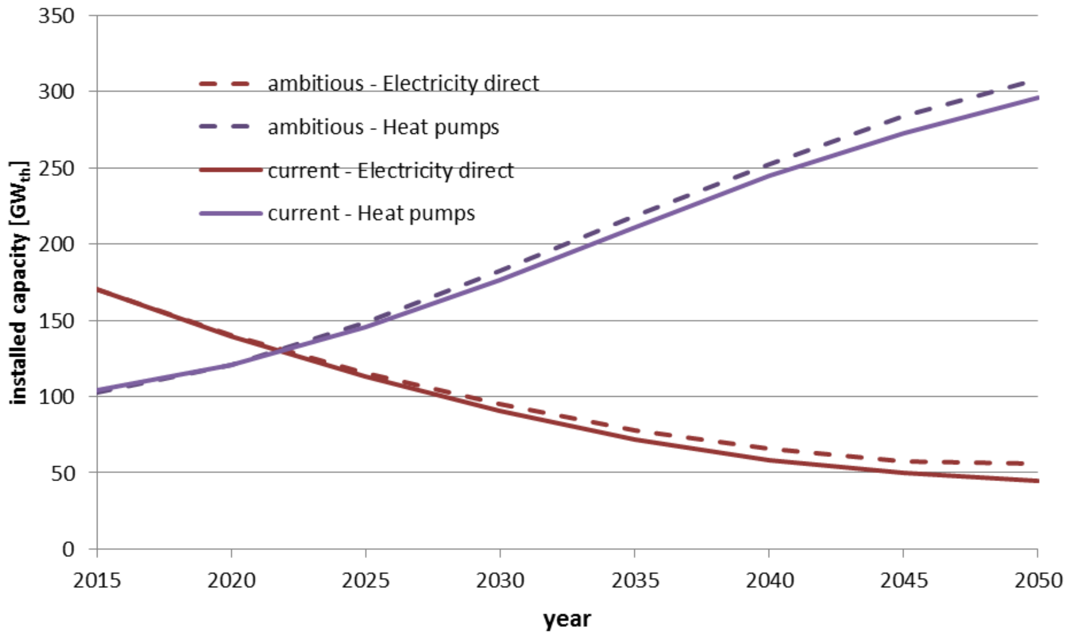

Figure 65: Installed capacities of direct electric heaters and heat pumps in EU28 for the current and ambitious scenario.

Electricity demand for cooling on the other hand is expected to increase across all EU28 member states. It should be noted that both the current, as well as future electricity demand for space cooling is subject to high uncertainties. For the status quo there are much less data sources available than for heating. The existing sources deviate strongly in their assessment of space cooling demand in Europe. (e.g. see (Frederiksen and Werner, 2013,) (Werner, 2015) or (Jakubcionis and Carlsson, 2017)). However, most sources agree that demand for space cooling can be expected to increase significantly in the following years. It should be noted that from a modelling point of view the main influencing parameter is the diffusion of air conditioning systems rather than the actual increase of space cooling needs. The development of cooling needs presented in this study are based on estimated diffusion curves using market data on the current diffusion of air conditioning systems in Europe and simplified assumptions on building physics in the building stock model Invert/EE-Lab. Under those assumptions electricity demand for space cooling was estimated to increase from 67 TWh to more than 200 TWh. The results suggest that by 2050 more electricity will be used for space cooling (64%) than for heating (36%) in contrast to the current situation where electricity for space cooling only accounts for 17% of electricity demand from heating and cooling. Table 15 summarizes the modelling results for electricity demand development for heating and cooling in both scenarios.

Table 15: Final energy demand for electricity by technology 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.
	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(+/- %)	(+/- %)
Air cond.	**67**	17%	**207**	61%	**222**	64%	+210%	+232%
Heat pumps	**43**	11%	**104**	31%	**100**	29%	+140%	+130%
Electr. direct	**273**	71%	**27**	8%	**23**	7%	-90%	-91%
Electr. Heating total	***317***	*83%*	***132***	*39%*	***123***	*36%*	*-58%*	*-61%*
TOTAL	**383**	100%	**339**	100%	**345**	100%	-12%	-10%

6.2 Load profiles from heating and cooling

To create hourly load profiles the results for both scenarios on annual electricity demand for heat pumps, direct electric heaters and air conditioning systems calculated by the model Invert/EE-Lab where transformed to load profiles using the model eLOAD. The eLOAD model uses a database which includes hourly temperatures and various load profiles for hot water, space heating and air conditioning. Using hourly temperature data and information on weekdays, weekends and holidays on country level, electrical load profiles where calculated for each member state and simulation year. For all simulation years temperature data from the year 2010 was used. The eLOAD database also includes the total electrical system load for each country and allows to directly calculate the changes on total system loads that result from changes in heating and cooling loads in each simulation year. The resulting load profiles for each year where finally provided for the electricity system models. Figure 66 provides an overview of the approach to derive hourly profiles within the case study.

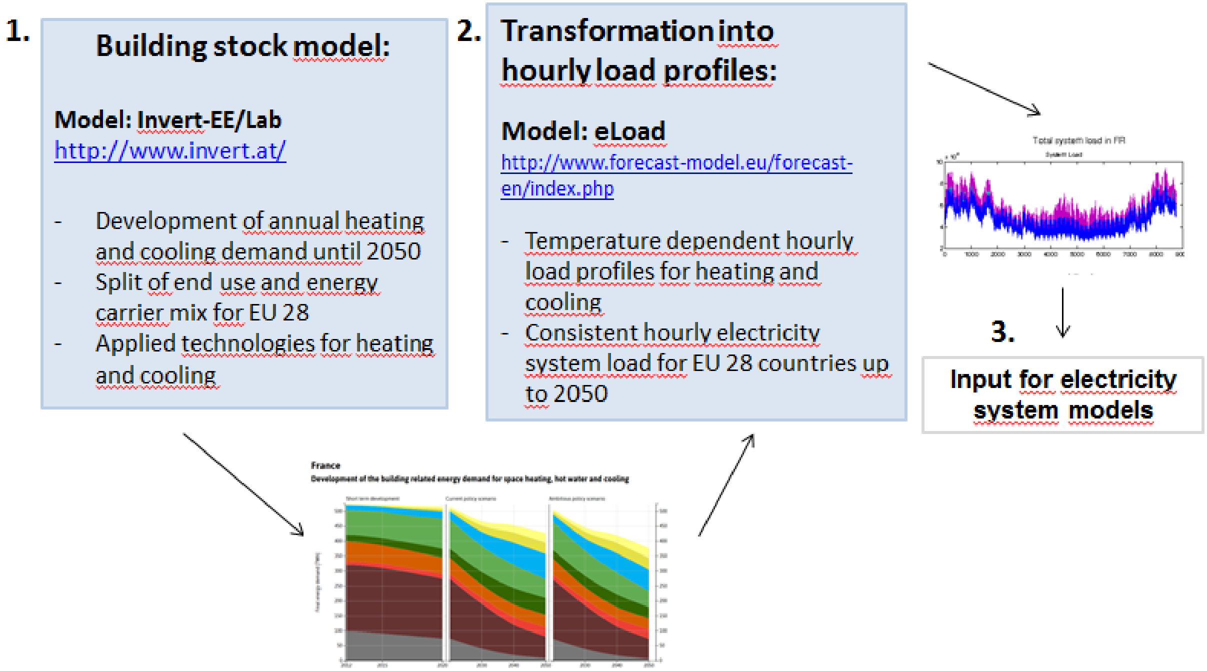

Figure 66: Overview of models and data exchange to create hourly load profiles for heating and cooling for the case study

Figure 67 illustrates total electric load for EU28 including the development of electrical heating and cooling loads for the years 2015, 2030 and 2050. Note that this analysis does not include changes in electricity demand from other sectors such as industry or transport. It can be seen that while under those assumptions electrical loads in winter are hardly affected, cooling loads in summer are expected to increase significantly. By the year 2050 electrical loads from cooling are expected to cause the highest electrical peaks which are currently occurring in winter in the majority of EU28 member states. Again it should be stressed that the modelled development of cooling demand is subject to high uncertainty and mainly depends on the diffusion of air conditioning systems across Europe.

The results also suggest that from an overall electricity system perspective the diffusion of heat pumps appears to be feasible with respect to electrical peak loads in winter. Note however that those results are based on the assumption that heat pumps are mainly installed in new buildings and thermally refurbished buildings with suitable low temperature heat distribution systems. Also note that the results of the model Invert/EE-Lab imply a mix of air source and ground source heat pumps. If the majority of heat pumps installed until the year 2050 would be air source heat pumps with lower coefficients of performance (COPs) electrical loads in winter would be significantly higher than the results shown in Figure 67 indicate. Finally it has to be noted that in both calculated scenarios the share of direct electric heaters decreases which significantly reduces peak loads from direct electric heaters compared to the current status. In the following sections the results from an electricity system perspective including the potentials to shift electrical heating and cooling loads will be discussed.

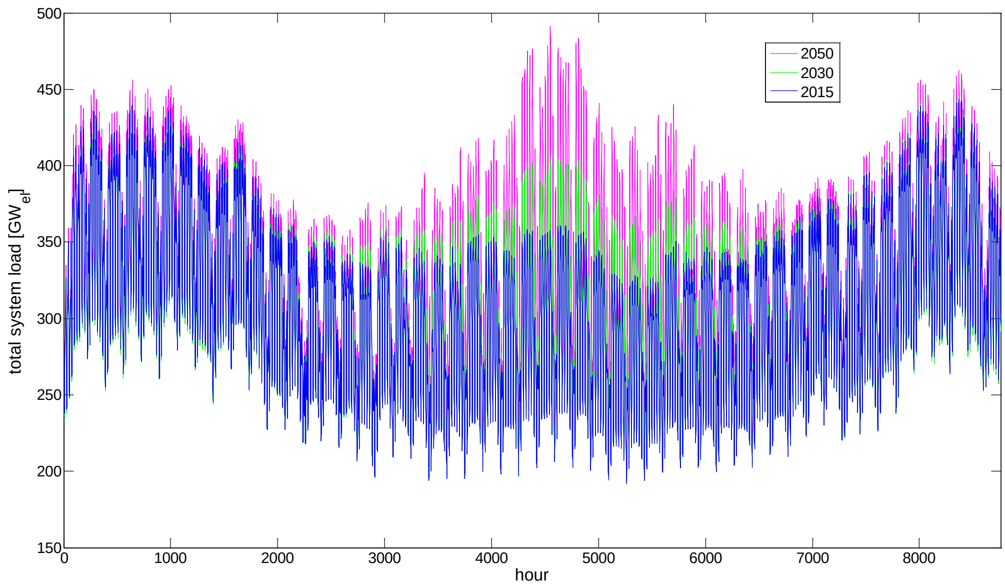

Figure 67: Total electrical system load of EU28 including changes in heating and cooling loads for the years 2015, 2030 and 2050

6.3 Results from the electricity system model EMPIRE

The results from the electricity system model EMPIRE within this case study provide insights on the development of the electricity generation mix until 2050 and the potential uptake of flexibility options from heating and cooling in the two scenarios based on the derived changes in electricity demand due to the development of heating and cooling demand in the building stock. As described in section 2.3.3 the uptake of flexibility options is based on cost assumptions for investments to control heating and cooling loads and resulting temporal cost differences (hourly resolution) due to the variability of electricity supply and demand.

6.3.1 Development of electricity generation mix

Figure 68 illustrates the generation mix resulting in the decarbonisation scenario implemented for this case study in the EMPIRE model. The generation mix is very similar for the inputs of the current policy and ambitious policy from the building stock model which is why only the results for the current policy scenario is shown. Also total system costs do not deviate significantly between the scenarios. Note that in contrast to the scenarios calculated by the Enertile® model no difference in CO_2 prices or emission reduction targets where assumed. Also note that due to the stochastic nature of the model, the results are less sensitive to rather small changes in electricity demands. Therefore the differences in electricity demand from heating and cooling between the scenarios result in very similar results for the optimal generation mix. In both scenarios the aggregated generation mix (Figure 68) is characterized by a strong uptake of electricity generation from PV and onshore Wind. Electricity production from coal is phased out and also electricity production from nuclear power plants decreases significantly. While electricity generation from natural gas increases in a transition phase, by 2050 natural gas is also strongly reduced mainly serving as backup for hours with low feed-in from variable renewable energy sources. Figure 69 illustrates the resulting electricity generation mix per technology in 2050 for selected countries.

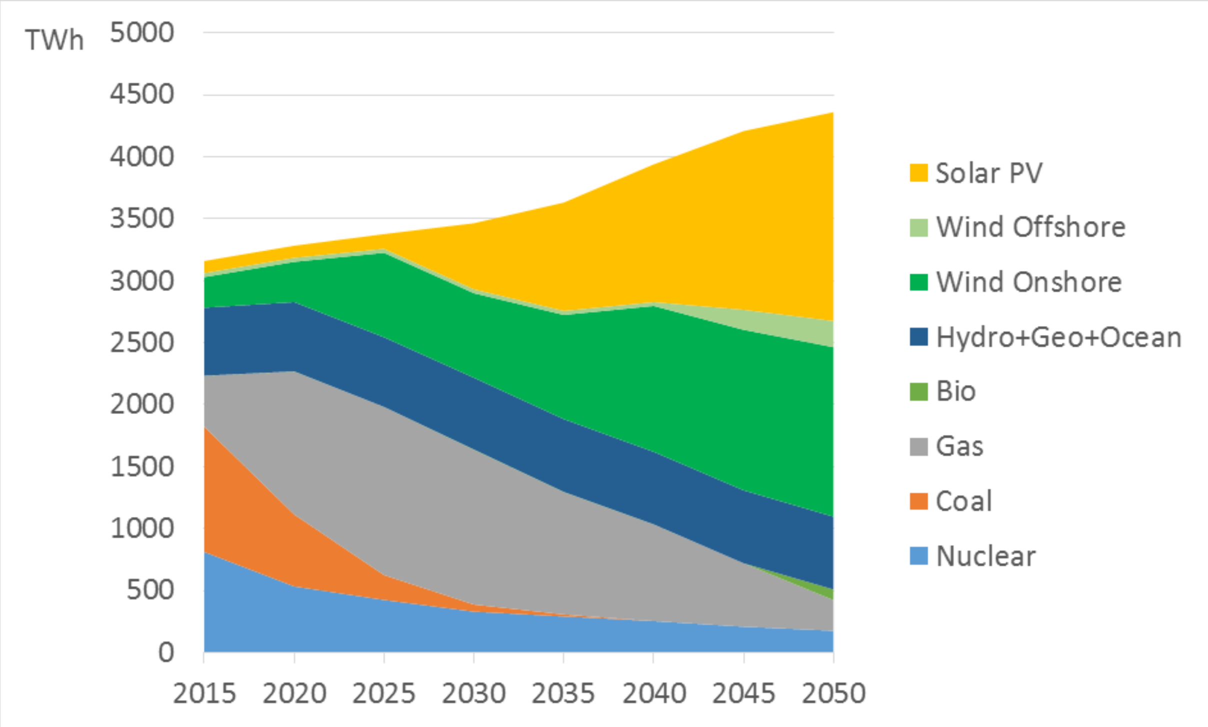

Figure 68 Aggregated generation mix evolution in Europe. The development is characterized by a substitution of coal by gas until 2025 and a substantial uptake of solar PV from 2035 to 2050.

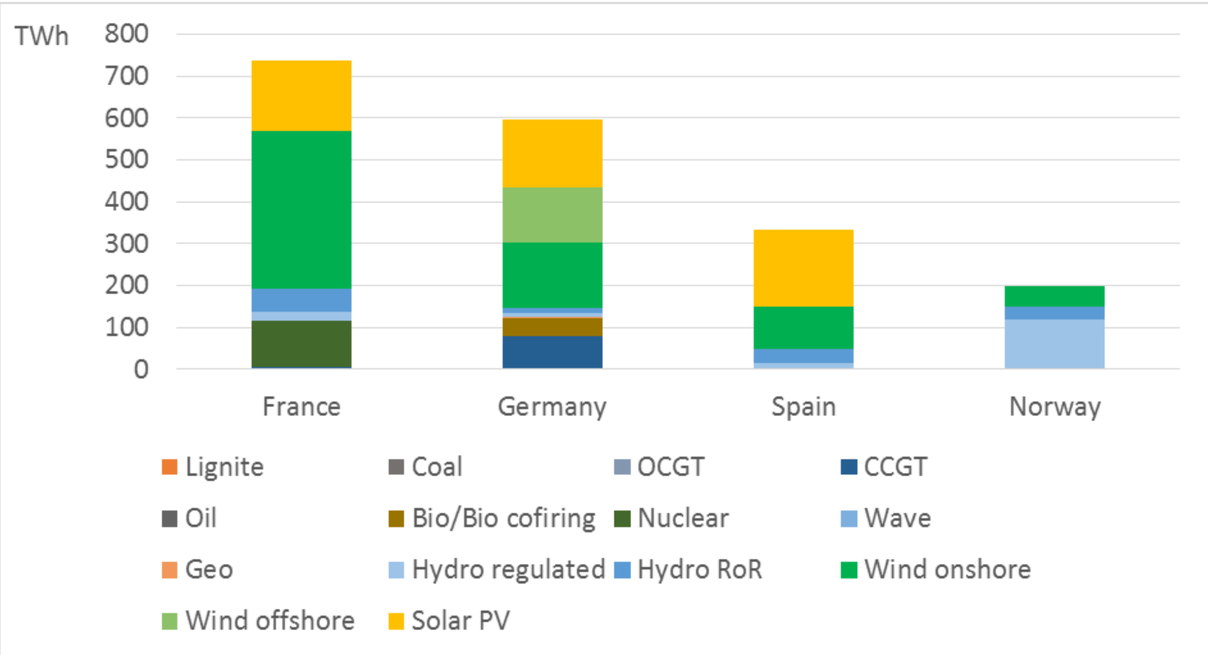

Figure 69 Generation mix by technology in selected countries in the reference scenario

6.3.2 Uptake of flexibility options from heating and cooling

Under the assumptions on investment costs for flexible loads presented in section 2.3.3 the EMPIRE model estimates a strong uptake of flexible heating and cooling loads to be optimal from a cost perspective. Note that non-economic barriers and are not included in this analysis. It is assumed that the technologies needed to control heating and cooling systems based on price or other signals are available for end users. It is also assumed that end users or other intermediaries are operating decentral heating and cooling systems in a cost optimal way, however under the load shifting restrictions implemented in the model.

Under those assumption the installed flexible loads for the current policy scenario in the heating and cooling sector ordered by capacity in 2050 are: commercial air conditioning, residential heat pumps, commercial direct heating, residential water heating, residential direct heating, residential air conditioning and commercial water heating with 19, 13, 10, 8, 2, 2, 1 and 1GW respectively (Figure 70). The total investment costs for flexible loads from 2015 to 2050 in flexible loads amounts to 6 bn€/2015.

The estimated evolution of demand response (DR) capacities illustrated in Figure 70 is directly linked to the electricity generation mix. The model estimates a strong increase in 2030 and 2040 due to the high penetration of solar capacity in Europe (see Figure 68).

Considering the peak loads of European electricity demand between 400 GW and 450 GW shown in Figure 67 the total installed flexible loads of more than 50 GW indicate a substantial flexibility potential to balance the supply of renewables. Note however that of course the hourly availability of flexible loads and also the energy shifting potential of each flexibility source varies significantly which was considered in the model runs but is not illustrated those aggregated figure.

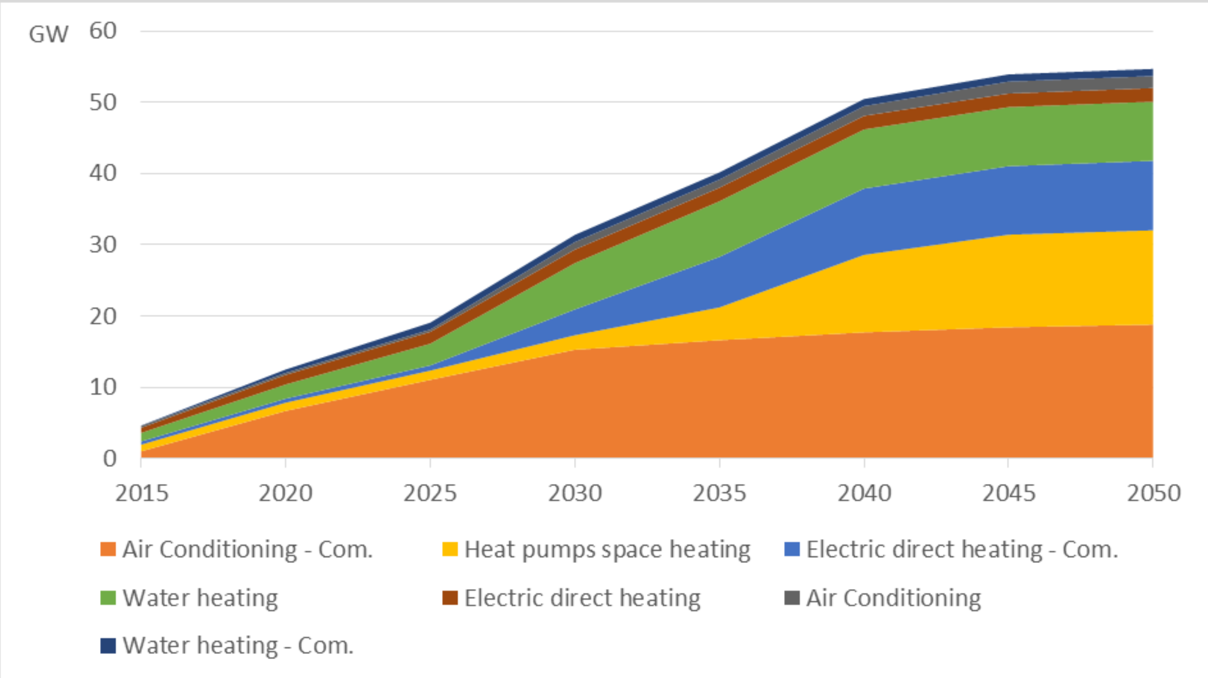

Figure 70 Installed flexible loads in the building sector by group.

The countries with highest DR capacity in the heating and cooling sector are shown in Figure 71. France, Italy and Germany are the countries with highest DR installed capacity with 13, 10 and 9GW in 2050. They are also countries with high shares of renewables, in particular PV. To compare different geographic locations across Europe, Figure 72 and Figure 69 show the flexible loads mix and generation mix of France, Germany, Sweden and Spain in 2050. Countries with high solar radiation such as France and Spain take advantage of shifting demand to times of high electricity generation from PV by means of these flexible loads. Flexible loads are not only used for shifting demand to times of high electricity generation from wind (Germany) or hydropower (Norway).

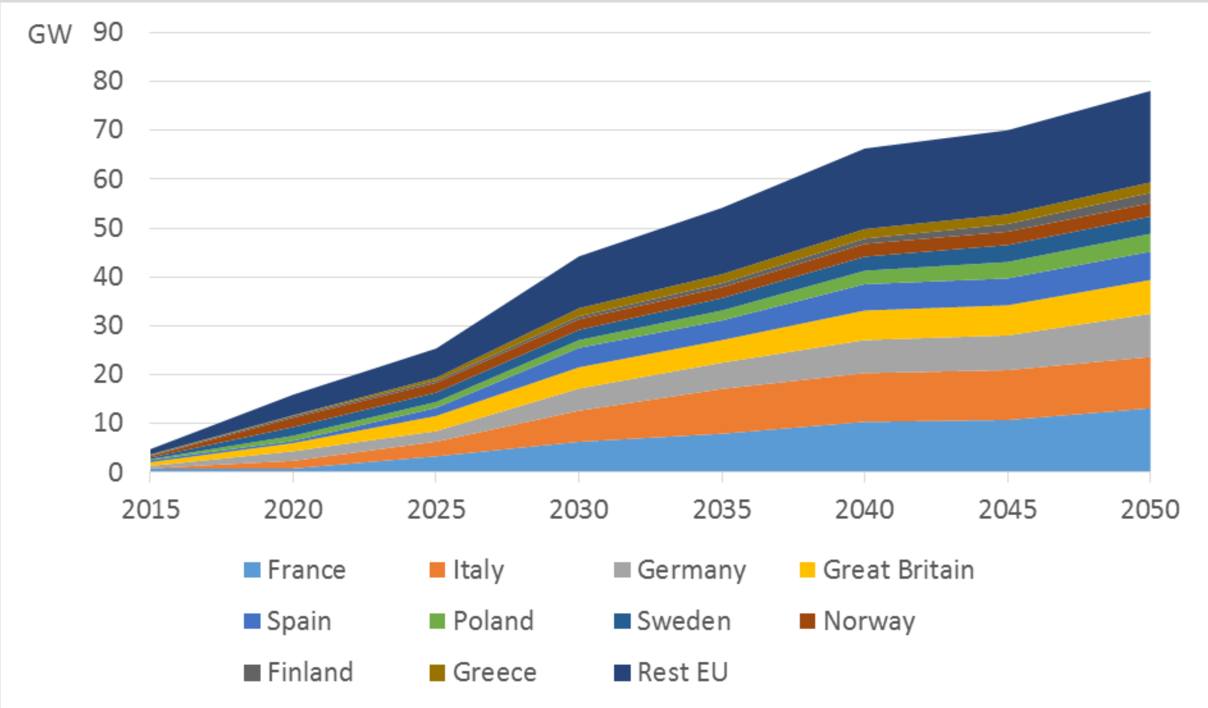

Figure 71 Installed flexible loads by country in the reference scenario.

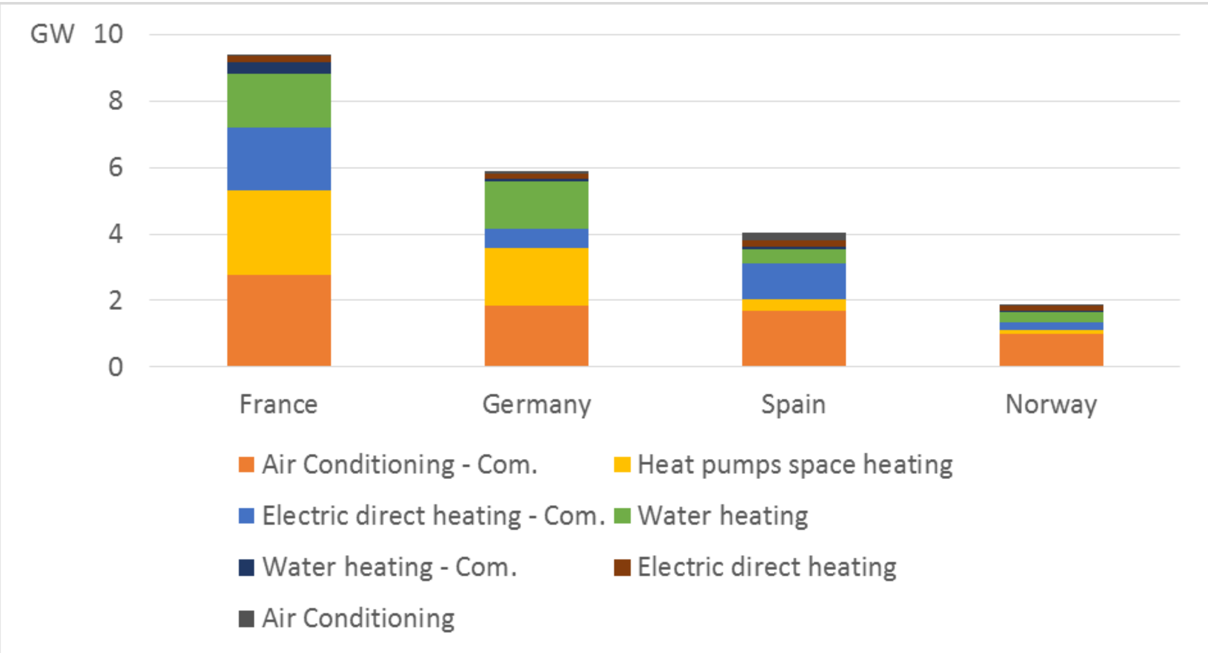

Figure 72 Installed flexible loads in selected countries in the reference scenario.

6.4 Results from the electricity sytem Enertile®

The analysis conducted with the electricity system model Enertile® within this case study focused on the value of flexibility from heat pumps for the electricity system and the combined analysis of electricity demand for heating and supply of heat for district heating.

6.4.1 The value of flexible operation of heat pumps

As already described in section 2.3.2, four scenarios were calculated using the Enertile® optimization model (cf. Table 4). For the current and the ambitious policy scenario, a flexible and an inflexible scenario were defined. The difference between these respective scenarios is the availability of a heat storage to allow for load shifting of heat pumps. In the real world it can be assumed that all houses and heat pump systems have some kind or thermal storage, even if it is only provided by the physics of the building itself. In the model the deactivation of the small heat storage emulates the situation where heat pumps operate without considering the situation of the electricity system. In the following, the scenario results are compared with regard to the total electricity system cost, electricity mix in the power sector and the specific heat generation costs of the heat pumps.

With a flexible operation of heat pumps the total system costs can be reduced by more than 1.6 billion €. These savings correspond to around 0.5% of the overall costs covered by the electricity system model. The main source for those cost reductions is the reduced demand for gas fired capacity that has to be installed to cover demand peaks in winter. The gas fired generation of electricity is decreased by around 15% in the current and 9% in the ambitious policy scenario. In both scenarios the flexible operation leads to a reduction of about 25 GW of gas fired electricity generation capacities.

Potential cost reductions for the electricity system are also reflected in the specific heat generation costs of technologies. Figure 73 illustrates the specific heat generation costs for flexible and inflexible heat pumps for the current and ambitious policy scenario settings in the year 2050. A comparison of the two inflexible operation scenarios reveals higher variable cost of heat generation in the ambitious policy scenario of 9%. In the ambitious policy scenario, we assume a higher CO_2-price of 150 €/t in 2050 in contrast to 88 €/t in the current policy scenario. This difference leads to the higher electricity cost of heat pumps and therefore higher specific heat generation costs. With an additional heat storage tank with a storage capacity of two full load hours of the maximum heat demand, significantly lower variable costs of heat can be achieved for both scenarios. Due to the additional heat storage, the operation of the heat pump can be postponed from hours of high electricity prices to hours with lower electricity prices. This can reduce the variable cost of heat pumps by around 5.8 €/MWh_{th} on average over all countries in the current policy scenario. This difference between flexible and inflexible operation is with an average of 6.4 €/MWh_{th} slightly higher for the ambitious policy scenario, again due to the higher CO_2-price.

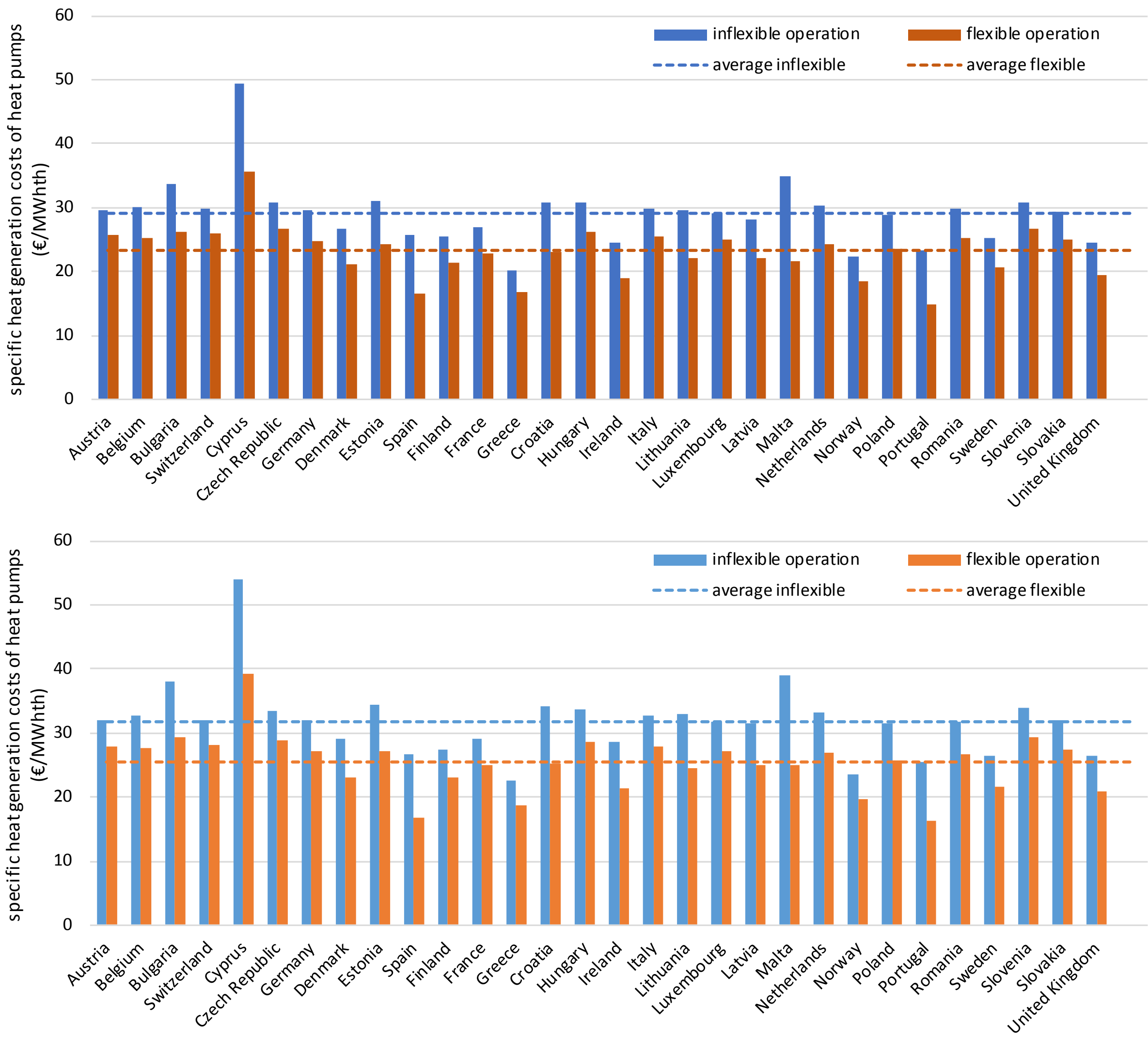

Figure 73: Specific heat generation costs[3] of heat pumps in 2050 in the current policy scenario (top) and the ambitious policy scenario (bottom) – comparison of flexible and inflexible operation of heat pumps in the Enertile® model

6.4.2 District heat supply

In the heat grid module of the Enertile® optimization model the following technology options for heat generation are available: combined heat and power plants, heating boiler based on fossil fuels, electric boilers and large heat pumps based on electricity and ambient heat. Switching between different heating technologies as well as using heat storages can provide flexibility. Figure 74 shows the heat generation of the different heating technologies for the current and ambitious policy scenario modelled with Enertile®. The heating demand of district heating networks is provided by the building stock model Invert/EE-Lab for each country. The total demand is substantially lower in the ambitious policy scenario. In the ambitious policy scenario the share of gas fired heat generation is reduced from 39% to 26%. The combined heat and power plants are not competitive in the ambitous policy scenario with higher CO_2-prices. Also in

[3] These values do not include investments in the heat pumps and storages.

the current policy scenario the optimal share of heat generation from gas fired CHP plants is relatively low. Although those results are based on simplified assumptions they indicate that by 2050 CHPs will face very difficult market conditions due to the high share of renewables with low marginal production costs.

Electricity-based heat generation using heat pumps and electric heaters on the other hand accounts for a large share. In the year 2050 the CO_2-price exerts a high decarbonisation pressure on the electricity and heating sector. Consequently, through the high share of renewables in the electricity sector the produced electricity can be used to decarbonise the heating sector. Also here it has to be noted that those results are based on simplified assumptions for heat networks including the assumption that the necessary temperature levels in district heat networks can be reached with large scale heat pumps in the future.

Furthermore biomass boilers and biomass based CHP plants were not included in the model. Both options are currently applied in particular for small scale heat networks in many countries and can also be considered as an important decarbonisation option for district heat supply. The role of biomass across all sectors and in particular for scenarios with higher shares of district heating will be further analysed in the pathway analysis within WP9 of the SET-Nav project.

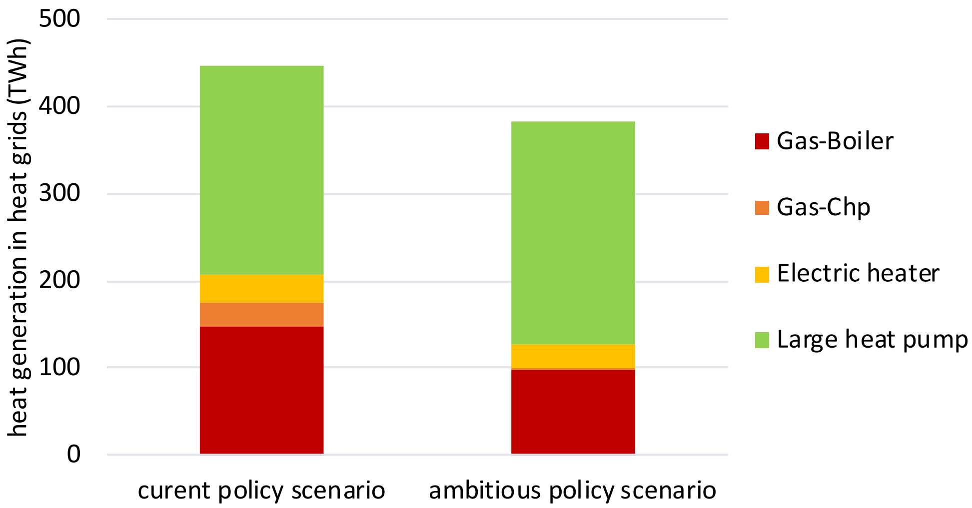

Figure 74: heat generation in district heating networks in Europe for current and ambitious policy scenario in the Enertile® model

6.5 Summary of impacts on the electricity system

Based on the calculated scenarios within the model Invert/EE-Lab and the optimization runs performed with the two different electricity system models conclusions can be summarized as follows:

- Electricity demand for heating in the assumed policy settings is expected to decrease due to increased energy efficiencies of buildings and a substitution of direct electric heaters. Under those preconditions a strong uptake of electrical heat pumps is not expected to significantly increase electrical peak load on EU28 level.
- Peak loads in some EU countries are nevertheless still dominated by electricity used for heating on very cold days in the short and mid term.
- In the long term space cooling could be the main driver for electrical peak demand on EU 28 level. However there is also a strong correlation between PV generation and space cooling

needs which might reduce the need for additional generation capacity. Residual load peaks in summer are more likely to occure on hot summer evenings

- The results from the electricity system model EMPIRE suggest that a strong uptake of flexible heating and cooling loads could be cost effective. In general there is a large potential for heating and cooling to contribute to balancing the variable supply of renewable electricity generation sources.
- The results from the electricity system model Enertile® suggest that flexible heat pumps can significantly reduce the need for back up capacity in the electricity system and which leads to a significant reduction of total system costs by the year 2050.
- A simplified analysis of district heat supply in strong decarbonisation scenarios indicates that by 2050 gas fired CHPs will face a difficult economic environment due to high shares of renewables with low marginal costs in the electricity system.

7 Summary, interpretation and lessons learned for decarbonisation pathways

Within this final chapter the main findings on the role of efficiency measures, uptake of renewable heating systems, the potential role of district heating and the interaction with the overall energy system are summarized. For each topic lessons learned for potential decarbonisation pathway of the overall energy systems which will be calculated within WP9 of the SET-Nav project are discussed.

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 – definitely beyond our "ambitious policy scenario" – 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 acitivies.

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.

Since also the ambitious scenario does not achieve renovation activities in line with the Paris targets, the further scenario development work in the project SET-Nav will take this into account and move one step further.

Uptake of renewable heating systems and energy carrier mix

The scenario calculations performed within this case study 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). This will be further analysed within the pathway analysis in the SET-Nav project.

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, which could only partly be captured by the modelling framework applied in this case study 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 grid is correlated also to the heat densities. In rural areas, this leads to the fact that district heating may lose attractiveness. However, our analysis shows that also 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 also to 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 increase improve economic effectiveness and support the uptake of district heating.

The experiences in the past 10 years in Europe showed that district heating companies react quite sensitive on the economic conditions and the economic effectiveness of different heat supply options. However, the lead time to implement renewable energy projects is also quite high, even if the economic and political framework is attractive. District heating is in many cases linked to heat supply from combined heat and power plants (CHPs). The simulation runs of the electricity system models indicate that by 2050 revenues for CHPs on the electricity markets could significantly decrease. Furthermore the results indicate that a combination of large scale heat pumps, boilers and to a lower extent CHPs could be the preferred option at least for large heat networks. This flexible heat generation approach is already demonstrated in several heat networks in Denmark.

Interaction with the electricity system and the role of flexibility

As already stated above, heat pumps are one of the key technologies for decarbonising the building sector.

Our analysis shows that in most countries the electricity demand for space heating and hot water can be kept within the current ranges (or even decreased). This is mainly the case, where currently a significant share of the heat demand is covered by electric direct resistance heaters, in particular in poorly insulated buildings. Replacing these electric direct heating systems by better suited heating systems and by renovating the building envelope of these builidngs can strongly bring electricity demand for heating down. The growth of heat pumps at least in our more ambitious policy scenario does not outweigh the decrease of electricity consumption of direct heaters. However, this will depend on the following conditions:

- Heat pumps are only installed in buildings with low heat supply temperaturer, thus ensuring high COPs of heat pumps.
- The trend towards a more and more increasing share of air source heat pumps is reversed. A reasonable mix of air-source and ground-source heat pumps is being installed.

It also has to be noticed that the uptake of heat pumps only leads to significant CO_2 emission reductions if electricty generation is decarbonised as well. Otherwise CO_2 emission can be in the range of natural gas boilers or even higher for heat pumps with low COPs.

In contrast to electricity demand for heating, electricity demand for space cooling is expected to increase strongly. Scenario results estimate an increase from around 67 TWh in 2012 to more than 200 TWh in 2050. While final energy demand for heating will still dominate the overall final energy demand for heating and cooling, electricity demand peaks from cooling in summer can be significantly higher than electricity demand peaks resulting from space heating in winter. In light of those results policies addressing reductions in cooling demands of buildings (e.g. shading, free cooling) should be enhanced. Those measures were not specifically addressed in the ambitious policy scenario.

The simulation runs performed with two electricity system models suggest that the flexible operation of heat pumps and air conditioning systems can provide substantial flexibility for the electricity system and contribute to reducing the need for additional backup capacity in the electricity system. Furthermore the flexible operation of air conditioning and electric heating also significantly reduces the need for curtailing renewables in scenarios with high renewable shares in electricity generation. To incentivize investments in demand response ready technologies market signals (e.g. variable electricity prices) or other monetary incentives should be passed on to end users.

8 References

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:

Frederiksen, S., Werner, S., 2013. District Heating & Cooling. Studentlitteratur Ab, Lund.

Jakubcionis, M., Carlsson, J., 2017. Estimation of European Union residential sector space cooling potential. Energy Policy 101, 225–235. https://doi.org/10.1016/j.enpol.2016.11.047

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

EMHIRES datasets, 2017. SETIS, Strategic Energy Technologies Information System, https://setis.ec.europa.eu/EMHIRES-datasets

Energy modelling, EU reference scenario 2016, European Comission 2016, https://ec.europa.eu/energy/en/data-analysis/energy-modelling

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

Open Power System Data. 2017. Data Package Time series. Version 2017. https://data.open-power-system-data.org/time_series/2017-03-06/.

Persson, U., Müller, B., Wiechers, E., Vad Mathiesen, B., Grundahl, L., 2017. Methodologies and assumptions used in the mapping; Deliverable 2.3: A final report outlining the methodology and assumptions used in the mapping (Deliverable). Aalborg University, Aalborg.

Persson, U., Werner, S., 2011. Heat distribution and the future competitiveness of district heating. Appl. Energy 88, 568–576. https://doi.org/10.1016/j.apenergy.2010.09.020

Pezzutto, S., 2018. D2.3 WP2 Report - Open Data Set for the EU28 (Deliverable). Hotmaps - TU Wien, Vienna.

Skar, C. et. al. 2016. A multi-horizon stochastic programming model for the European power system. CenSES working paper 2/2016. ISBN: 978-82-93198-13-0. https://www.ntnu.no/documents/7414984/202064323/1_Skar_ferdig.pdf/855f0c3c-81db-440d-9f76-cfd91af0d6f0

Sustainable and optimal use of biomass for energy in the EU beyond 2020 - Energy - European Commission [WWW Document],. Energy. URL /energy/en/studies/sustainable-and-optimal-use-biomass-energy-eu-beyond-2020 (accessed 3.12.18).

Werner, S., 2015. European space cooling demands. Energy. https://doi.org/10.1016/j.energy.2015.11.028