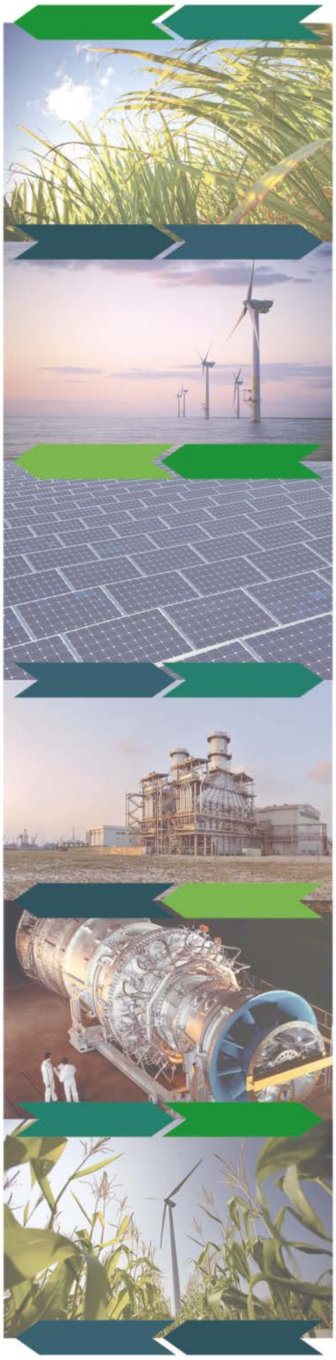
NAVIGATING THE ROADMAP FOR CLEAN, SECURE AND EFFICIENT ENERGY INNOVATION



D.5.2: Issue paper on heating and cooling demand and supply in buildings and the role for RES market integration

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1 Introduction

This issue paper 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.

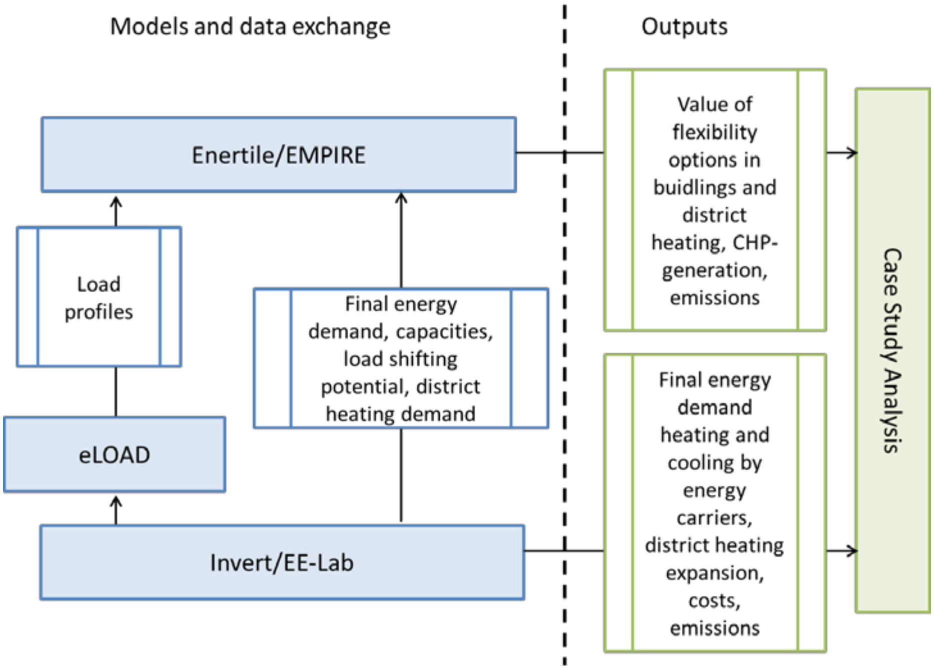
This specific case study aims to analyse the link between energy efficiency improvement in buildings, heating system choice, demand side flexibility options and RES deployment. The goal of the case study is to analyse the role of these elements in different **future energy transition pathways** and in particular to identify measures needed to decarbonize heating and cooling supply of the European building stock. Within this issue paper 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 (section 3.1), related costs for heating and cooling from an end user perspective (section 3.2), potentials for district heating (section 3.3) as well as an analysis of the impacts on the electricity system (section 3.4) and main policy conclusions (chapter 4).

For details and additional results please see the full case study report (deliverable 5.3 of the SET-Nav project).

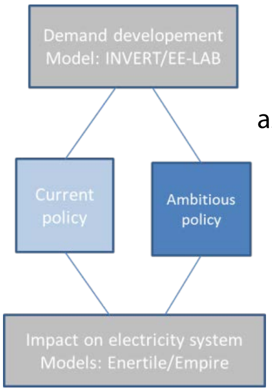
2 Methodology and scenario definition

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 potentials 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. A simplified version of the data exchange concept and involved models for case study 5.2 is illustrated in figure 1 below.

Figure 1: Data exchange concept and model links 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. 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. 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/) were used. In the **ambitious policy scenario** measures already implemented in the current-policy scenario were intensified. The policy approach regarding the applied set of instruments per country remain the same. With regard to the model implementation of policy instruments described above, the 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. Biomass use in all involved models are finally compared with model results from the Green-X to analyse the feasibility with respect to overall available biomass potentials.

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

In this chapter 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.

3.1 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 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. 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.

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 are decreased 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**, 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 therefore 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 3 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 because 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. In both scenarios 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.

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 in section 3.3.

Figure 2: Development of final energy demand for heating and cooling per energy carrier – EU28

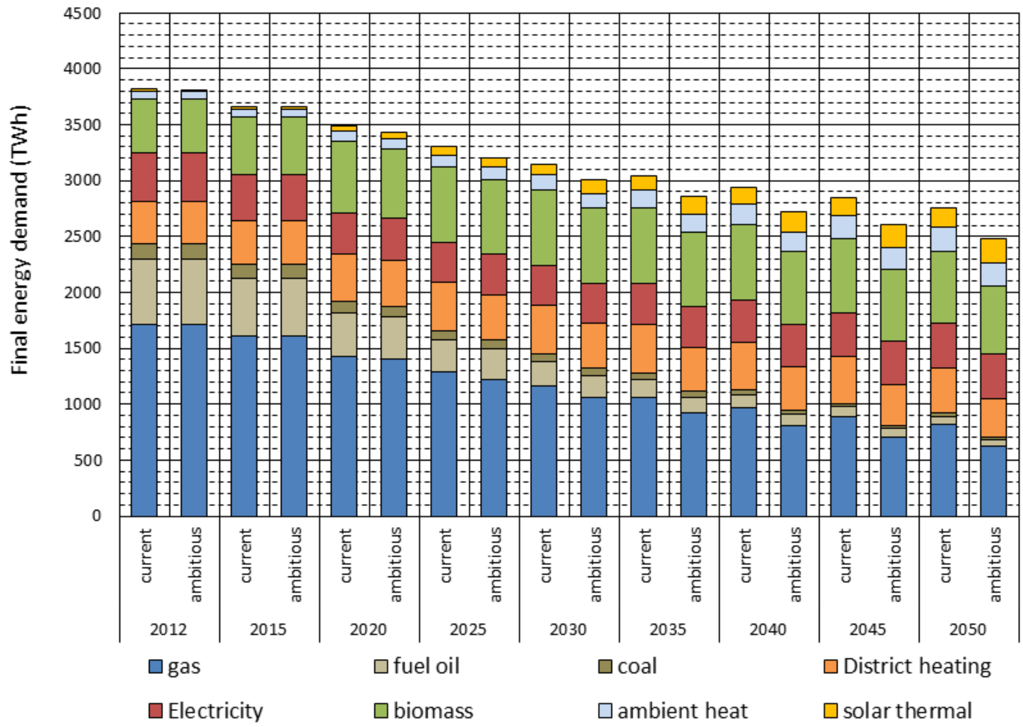
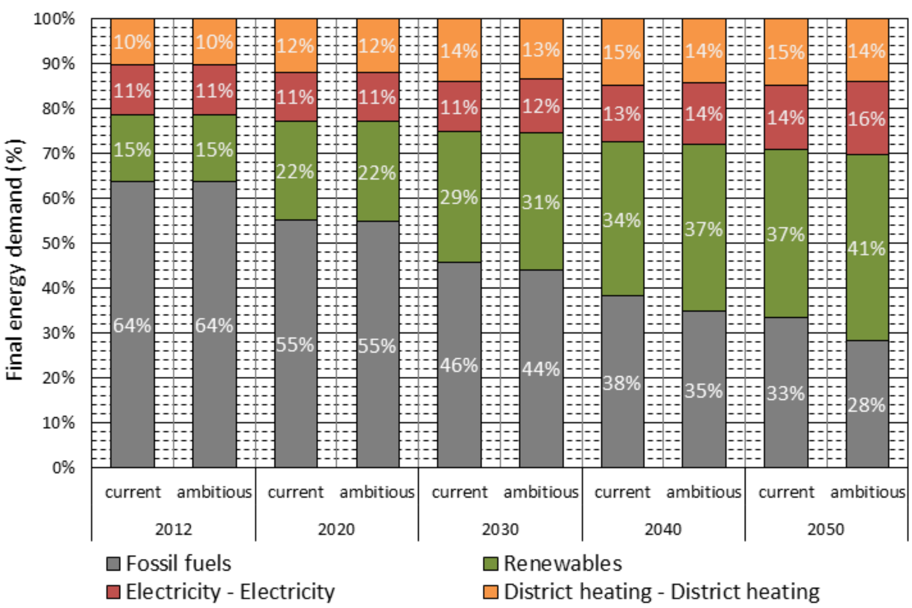


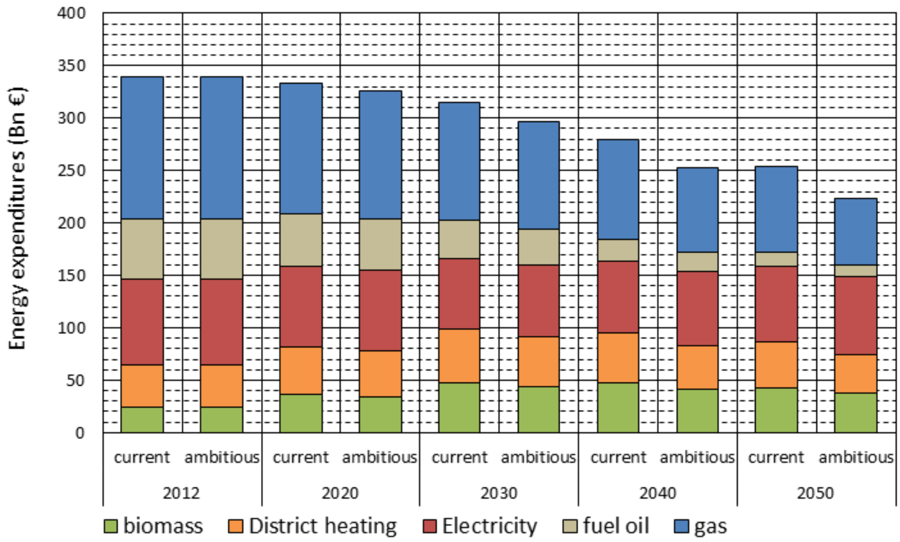
Figure 3: Shares of fossil fuels, renewables, electricity and district heating in final energy demand for space heating, hot water and space cooling supply in EU28 until 2050



3.2 Results on investment costs and 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 4 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 4: 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 3 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 5: Annual investments in thermal refurbishment and heating systems in EU28 until 2050

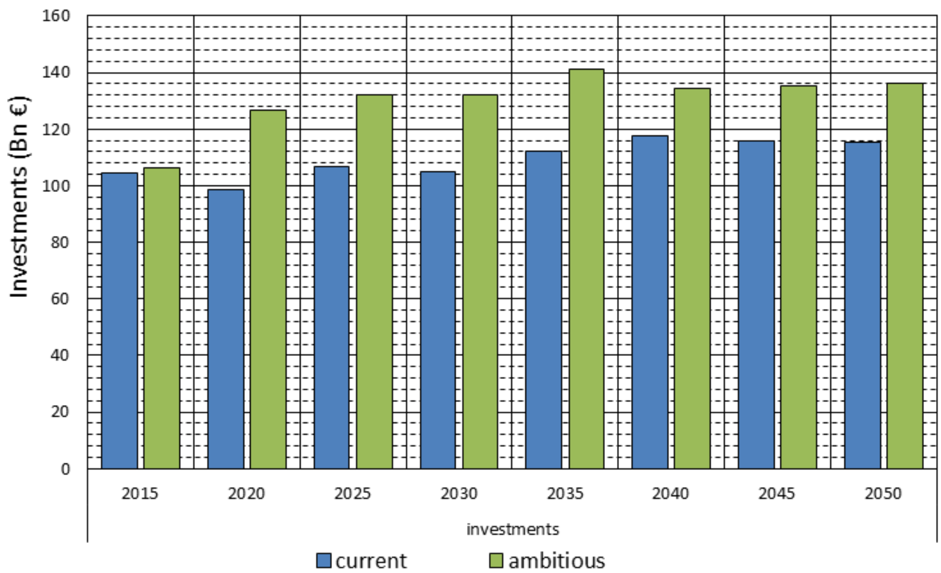
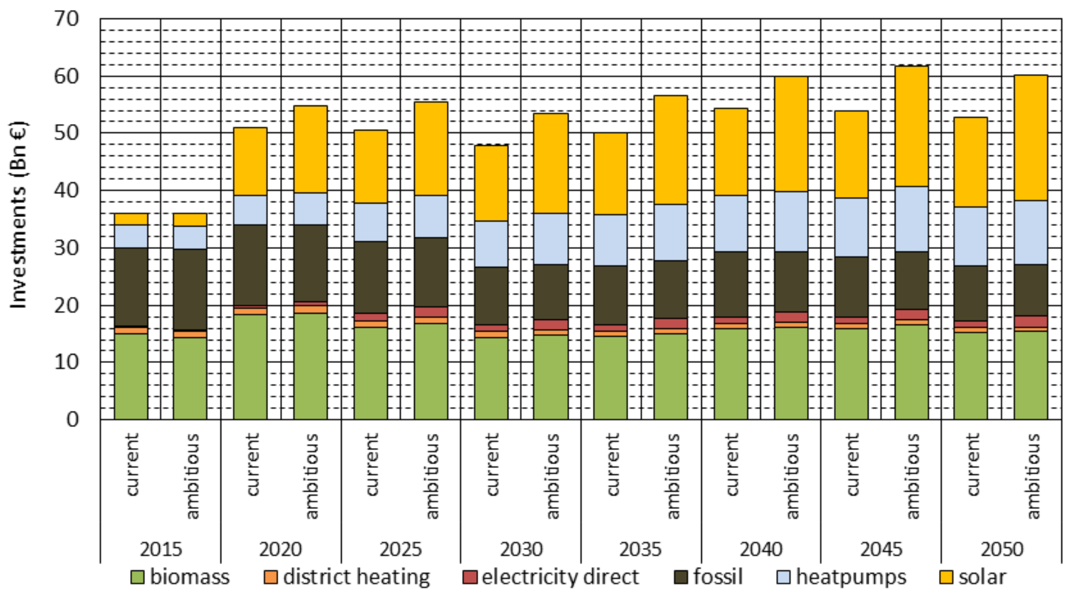


Figure 5 shows investments from an end user perspective in heating systems per energy carrier. The scenario results indicate that biomass boilers, heat pumps and solar thermal systems account for the main share of investments in new heating systems while investments in **fossil heating systems** (mainly 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. This is also crucial for the impact on the electricity system as direct electric heating systems would cause significantly higher demand for electricity and increase demand for backup generation capacity in particular for electricity system scenarios with high shares of PV and Wind in the generation mix.

Figure 6: Investments in heating systems per energy carrier from an end user perspective in EU28 until 2050.



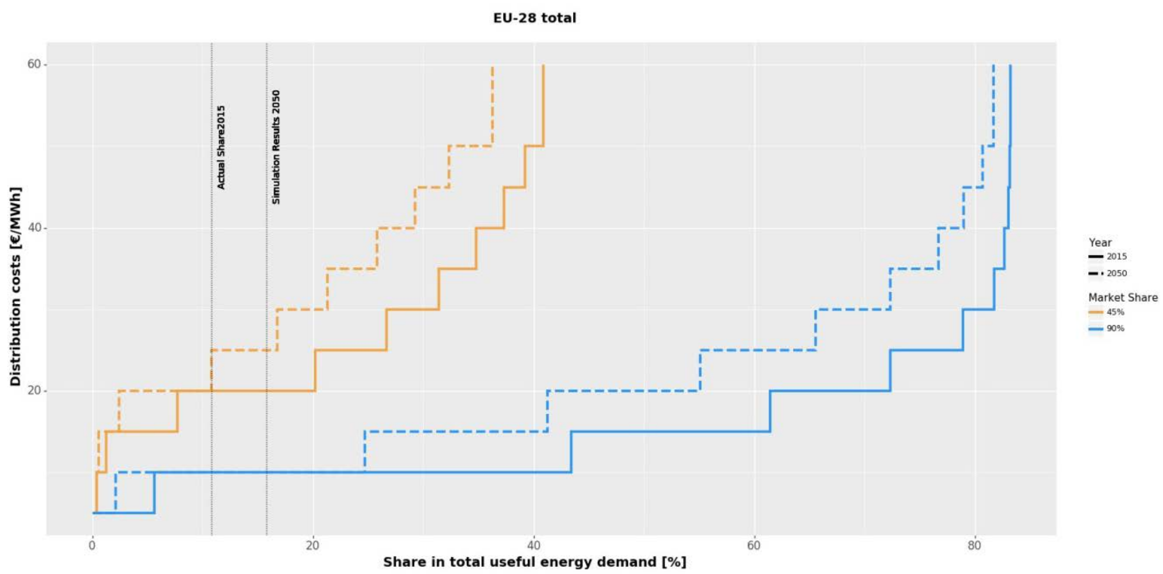
3.3 Results on district heating potentials

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 described in section 3.1. 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 necessary to assess district heating potentials and costs for Europe. 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). 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 7 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 7 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 7: 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%

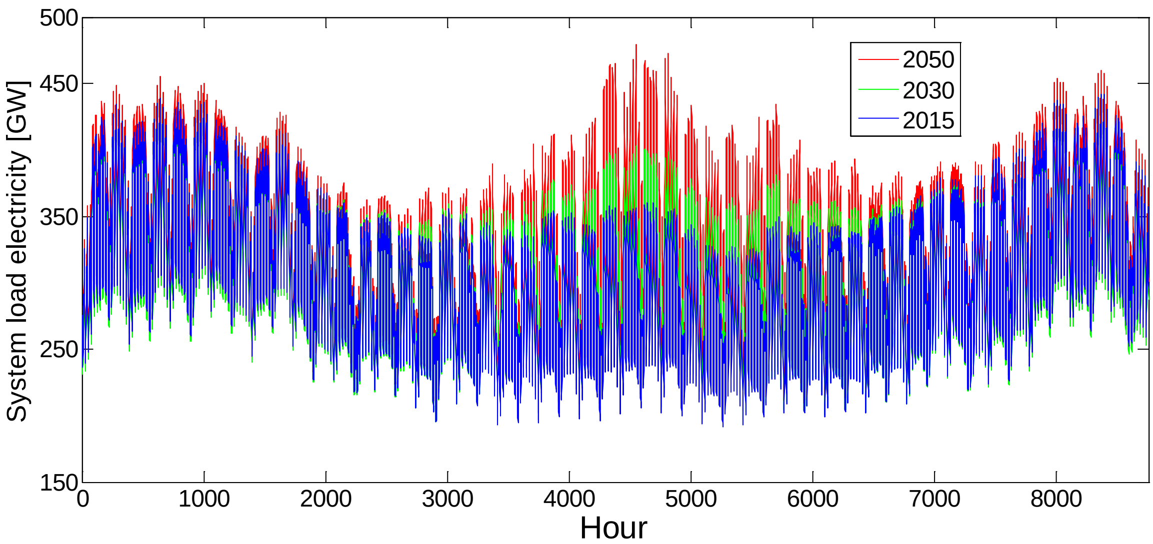


[1] Note that several other factors like available heat sources, costs of decentral heating options, energy prices etc. also influence the competitiveness of district heating. Distribution costs are therefore only one indicator and heat networks have to be assessed case by case to assess costs on a local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

3.4 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 6 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.

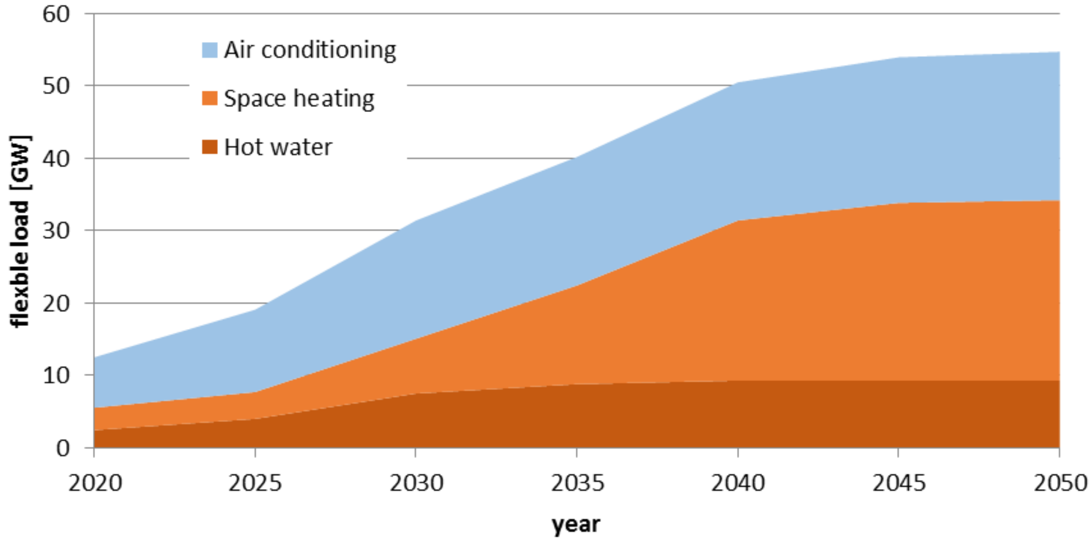
Figure 8: Change of hourly electrical load based on changes in heating and cooling demand from the current policy scenario



The estimated hourly loads 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 9 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.

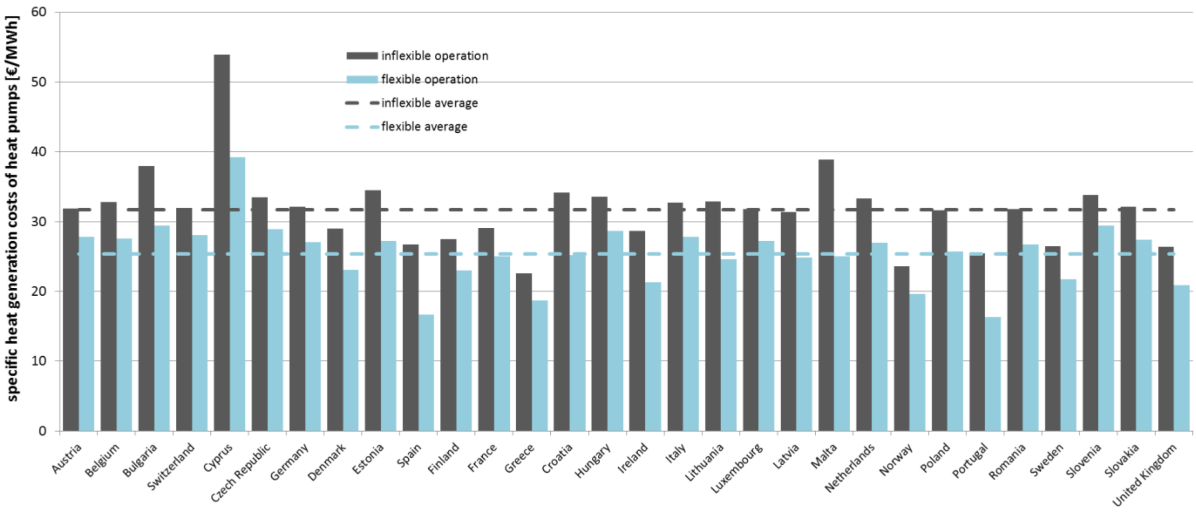
Figure 9: Uptake of flexible loads in buildings in the model EMPIRE based on heating and cooling loads from the current policy scenario



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 10 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 10: 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.



4 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 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. We also want to emphasize that even higher energy reductions in the European heating and cooling sector are most likely needed to reach the Paris climate target.
- The **share of renewables is expected to increase** significantly. 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. 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.
- **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

[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.

combination with large scale heat pumps are applied for 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.

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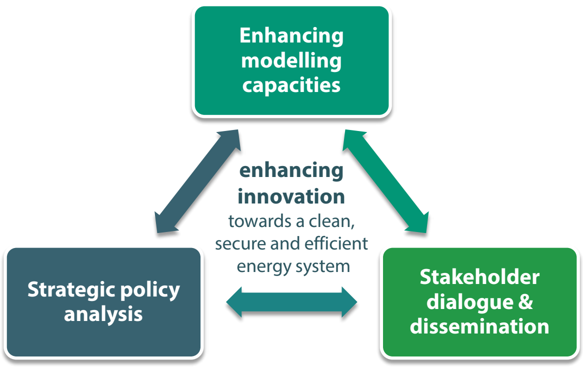
About the project

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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