Decarbonisation pathways

For the European building sector

By order of:

ehi
association of the
European Heating Industry

Submitted by:

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Executive Summary

The climate crisis and recent geopolitical tensions require unprecedented efforts to quickly cut emissions and fossil energy consumption – with buildings as a key sector. Major elements to achieve this are increasing efficiency in buildings and heating systems in combination with an accelerated fuel switch and the phase-in of more renewable energy. With the Fit-for-55 and REPowerEU packages, the EU is working on setting a policy framework committed to a net zero economy by 2050 as laid out in the European Climate Law (Regulation (EU) 2021/1119), and to become independent of energy imports from Russia, in a fast-paced and cost-effective way.

This study elaborates on pathways to decarbonise heating in the building sector, which meet these policy objectives. The approach combines a model reflecting the European building sector, with an analysis of the impact on electricity and gas infrastructures. In addition, options for decarbonising heating with staged deep renovation for individual buildings and the affordability for households are assessed to take into account social acceptance. Main indicators include investments in efficiency measures and heating systems, heating cost for households, aggregated consumption, and the impact that heating systems have on peak load, along with resulting investments into the electricity and gas infrastructure.

The evaluation compares two pathways. Common to both is that electric heat pumps play a key role in short and long term. Additionally, both pathways focus on energy efficiency measures in the building, including the installation of efficient heat emitters (underfloor heating, low temperature radiators) where needed, a sharp reduction of consumption of gaseous fuels compared to today as well as the phase-in of renewable alternatives and strengthening of district energy. They differ in that pathway A assumes a very high level of electrification with heat pumps and little space for other technologies or energy carriers. In pathway B, electrification via heat pumps plays a fundamental role, but also a higher heating system replacement rate that focuses on old, inefficient boilers. Additionally, hybrid heating solutions support the fuel switch – especially in buildings that are not yet ready for heat pumps – and a significant contribution of green gases is considered. Green gases are also used in renewable-ready boilers (modelled technology) as well as in thermally driven heat pumps, micro-cogeneration and fuel cells (qualitatively considered).

The study concludes that pathway B achieves the objectives of Fit-for-55 and REPowerEU in an easier, cheaper, and more socially acceptable as well as flexible way than pathway A, with an **aggregated cost benefit of over 520 bn EUR until 2050**. In addition, relying on the variety of technologies featured in pathway B reduces the peak load from heating by more than 50% - assessed during a windless and dark winter week. It also cuts natural gas use the fastest, achieving 45% reduction in gas consumption in 2030.

More in detail:

- Both Pathways **cut natural gas use by over 40% in 2030, as well as CO_2 emissions by 60%,** compared to 2020, mainly through the accelerated deployment of hydronic heat pumps and the accelerated replacement of old, inefficient boilers. Pathway B is more feasible because the deployment of heat pumps is facilitated by a higher share of hybrid heat pumps and hybridisation, and by a broader mix of efficient and renewable-based heating technologies, which helps to overcome relevant limitations of the electricity system and the condition of the building stock. Additionally, it cuts natural gas use the fastest (-45% by 2030).

- Pathway B is **more practical and cheaper; hence, it can increase social acceptance of decarbonisation measures**. Increased efficiency measures are relevant and important to prepare the building stock for the ongoing transformation. But a significant share of hybrids enable the electrification of those parts of the building stock that are not yet suitable for standalone electric heat pump installation. The upgrade of the envelope can follow at a later stage, but significant decarbonisation potential can be leveraged earlier through this approach. The broader technology mix allows for tailored building decarbonisation pathways, addressing the complexity of the heterogeneous building stock and household income distribution. In the case of hybrids, with lower initial upfront investment than for a deep renovation case, the consumption of gas (or oil) can be reduced by 70-90%. Subsequent investments can increase renovation depth as part of staged deep renovations leading towards zero emission buildings.

- Pathway B **achieves full decarbonisation by 2050, while lowering overall system cost**. A diversification of technologies – especially with hybrid systems – reduces constraints for electricity generation adequacy. With 133 GW, in pathway B, the additional peak load from electrification of heating is about 54% lower than in pathway A. This entails reduced investments into firm additional peak load generation and electricity transmission and distribution capacities.

- By 2050 Pathway B requires **less than a third of today's consumption of gaseous fuels in the heating sector, with no use of natural gas**. The total demand of renewable gases (biomethane and hydrogen) will amount to 395 TWh/year by 2050. These fuels will stem from renewable sources such as wind and photovoltaic electricity as well as waste-based feedstock, with diversified supply as foreseen by the Fit-for-55 and REPowerEU packages.

To bring the EU on the optimal pathway towards the objectives of REPowerEU and Fit-for-55, a revised regulatory framework should:

1. Accelerate the decarbonisation of buildings, through the most cost-effective mix of measures to make it also work for 'hard to abate' buildings and to stay within the remaining carbon budget.

2. Enable the use of a broad system mix of highly efficient, renewable ready and future-proof heating technologies, and safeguard the efficient transformation towards a decarbonised energy system

3. Foster fast replacement (around 6% per year) of inefficient heat generators and optimisation of hydronic heating systems with heat pumps, hybrid heat pump systems, solutions ready for renewable gases and other key heating decarbonisation technologies

4. Support the necessary upfront investments for higher efficiency in buildings, efficient and renewable-ready heating systems, and the energy system to achieve an affordable transition for the end users

5. Ensure that the necessary qualified work force is available, thanks to private and public sector training as well as reskilling initiatives

6. With regards to the building envelope, it is important to aim for the most cost-effective energy efficiency measures, with a view to achieving the desired standards of the energy performance of buildings directive

7. Stimulate the ramp up of renewable electricity and mainstream the assessment of the impacts of electrification of heating and its potential for demand side flexibility into network planning

8. Stimulate the ramp up of green gases and ensure the availability of well dosed volumes for the heating sector to reach 2030 and 2050 goals. Drive the adaptation of power and gas distribution infrastructure, in a logic of system efficiency and sector integration. Where relevant, support further involvement of local grid operators in regional planning

9. Through product and climate policies (eco-design and energy labelling) support innovation and deployment of highly efficient heating technologies, ready for zero carbon energy carriers, including “readiness” to run on hydrogen

10. Ensure that high efficiency of heating systems is guaranteed in operation

1. Introduction

The decarbonisation of the building sector – and therefore heating[1] – is necessary. And yet, it has so far proven to be one of the most challenging aspects of the European energy transition. The complexity of decarbonising this sector is increased by the large upfront costs, long investment cycles and the situational differences of each building. There is no one size fits all solution.

This complexity has slowed down the uptake of decarbonisation measures for the sector over the past years. To achieve the EU ambitions formulated in the Fit-for-55 programme and climate target plan (CTP)[2] of -60% GHG direct emission in the power and building sector in 2030 compared to 2015, we need to act now. In addition, the war in Ukraine has brought the discussion about the dependency on fossil fuels back into focus and the EC is setting up their strategy with REPowerEU on how to rapidly become more independent from Russian energy imports.

To achieve this, it is indisputable that electrification by means of heat pumps will play a key role. However, it is still unclear which decarbonisation pathway is the most suitable in terms of cost effectiveness and practical feasibility. The European Heating Industry (EHI) would like to support this discussion by providing its industry knowledge. EHI commissioned Guidehouse to conduct this study to identify the most cost-effective and efficient decarbonisation pathway for the European heating sector. This assessment took into consideration not only the key role of heat pumps and building insulation, but also decarbonisation options such as district heating, renewable and decarbonised gases, solar thermal systems, the efficient use of bioenergy (e.g.: biomass and bioliquids), as well as innovative heating technologies (e.g., thermally driven heat pumps and fuel cells).

To this end, Guidehouse models and compares two pathways for the decarbonisation of the building sector. Pathway A focusses on very high electrification with little space for other technologies or energy carriers. Pathway B considers a high electrification which relies on an optimisation through more available solutions. This includes a significant share of hybrid heating systems, but also other heating technologies and energy carriers. Furthermore, core elements in both pathways are increasing energy efficiency measures in the building's envelope. On top of that, more efficient heat emitters, i.e.: underfloor heating and radiators play an important role, by helping buildings' readiness for low temperature heating. Additionally, the installation of solar thermal systems can reduce the need for further electric or fuel-based energy use.

The following section provides details on the methodology and tools used, while the results are presented in section 3. Additional considerations, namely social and regional aspects, are elaborated on in section 4. Subsequently, final conclusions of the analysis are given, and the report closes with policy recommendations on necessary actions to enable the heating sector's decarbonisation on the proposed pathway.

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[1] Space heating and domestic hot water represent around 80% of the energy consumption in buildings.

[2] CTP formulates the goal of -55% emissions until 2030 (compared to 1990) and 'Fit-for-55' package aims to bring EU legislation in line with the 2030 goal. Building and power sector are assumed to deliver -60% direct emissions in 2030 (compared to 2015).

2. Methodology

This study compares two pathways for the decarbonisation of the European building sector until 2050. The goal is to identify the most beneficial pathway. The focus is on the impact on societal costs and resource adequacy of the power grid, that the choice of heating systems has. In addition, societal considerations are taken into account.

The two decarbonisation pathways are defined in section 2.1 and 2.1.2. To compare which of the pathways is most beneficial for Europe – from a societal, energy system and end consumer perspective. There are key indicators listed in section 2.2, like overall cost or resulting electricity peak to the power grid. These indicators are analysed with a model, representing the European heating sector (see section 2.3). Finally, there are additional assessments to complement the quantitative assessment: Societal and regional considerations, as further described in section 2.4.

2.1 Decarbonisation pathways

The assessed pathways need to achieve the same climate and fossil fuel reduction targets, as well as other goals formulated by the European Commission. To get there, however, each pathway applies different measures, e.g., different focus on heating systems used. First, the common targets are outlined and subsequently, the individual pathways are formulated.

2.1.1 Underlying climate and fossil fuel reduction targets

This study aligns with the following GHG emission targets for the future of the building sector:

- 2030 - The CTP defines the target of power & building sector together with -60% GHG direct emission reduction compared to 2015. Direct emissions are fossil fuels burned on site, which excludes electricity and district heat (indirect emissions).
- 2050 - The EPBD[3] set the target that all buildings should be zero emission buildings by 2050 and should use carbon neutral energy carriers for all buildings.

To achieve these targets, we created two pathways for the decarbonisation of the building sector. Chapter 2.1.2 explains how these two pathways differ from each other. However, there are also similarities within the pathways. Both pathways assume the same renovation rate for the modelling.

The two pathways also share some assumptions on the future of newly installed heating systems. Electrification will be one of the important elements to decarbonise the building sector. Other important heating sources are wood boilers and stoves as well as district heat. Newly installed oil boilers will be limited as it is expected that regulators will start to ban new installations of oil boilers, if they cannot run on renewable fuels. New buildings will be mainly equipped with heat pumps. From 2030 onwards, heat pumps will be the heating system with the highest single share in the building stock. There is a transition from consumers to prosumers. Heating systems will increasingly be an integrated solution, combined with rooftop PV[4] and energy management systems.

Furthermore, the goals formulated in REPowerEU, relevant or impacted by the heating sector, are fulfilled, too. This implies having an additional 30 million heat pumps in the building stock by 2030 and reducing the use of natural gas for heating in buildings

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[3] Energy performance of buildings directive

[4] rooftop PV is considered to be fed to grid and not considered in cost calculation

significantly. The updated goals for biomethane and hydrogen available by 2030 are considered as well.

2.1.2 Pathway development

This study focusses on two pathways, called A and B. Both pathways have similar assumptions regarding new constructed buildings. They assume the same construction rate and energy performance of new buildings. In addition, the heating system efficiencies and the renovation rate are independent of the pathway. Pathway A and B differ in their heating mix, green gas shares, heating replacement rate and renovation standard. Chapter 2.1.2.1 and 2.1.2.2 elaborate on the differences between the two pathways.

2.1.2.1 Pathway A

The first pathway – pathway A – focusses on the use of electric heat pumps for the heating sector and therefore represents the solution currently dominating in many debates on the decarbonisation of buildings. Other technologies, like district heat and biomass boilers are still relevant, but electric heat pumps are the by far dominating technology. If the heating system of a building needs to be replaced, pathway A assumes that there is always a preference for the replacement with an electric heat pump instead of other technologies. Only in exceptional cases another heating installation would be chosen over the electric heat pump, for example when district heating is in place or biomass boilers are used since the buildings condition leaves no electrification choice.

The role of natural and green gas is limited in pathway A. Some countries practically ban gas boilers, causing a significant decrease in installed gas boilers. In pathway A, we assume that policy makers prioritise other use cases for green gas, e.g., transport and some heavy industrial sectors, which are deemed to be more difficult to directly electrify. This translates into a share of green gas in 2030 of only 3%. In 2050, it is assumed that gas will be phased out. Until then, the gas share in the heating system is only used for a minor share of hybrid systems and remaining combustion boilers. This will result in the dismantling of the gas infrastructure on distribution grid level, with only locally remaining parts for industry.

A heating system replacement rate of 4.4% in 2030 is assumed, hence an increase of around 30% compared to today’s system replacement rate of 3.5%. This is needed, despite the fact that the major share of newly installed systems is heat pumps, to reach the reduction in direct emissions defined in the CTP.

To enable the electric heat pump technology, deep renovation of buildings will be necessary. The standard for deep renovated buildings aligns with the Zero Emission buildings (ZEB) standard defined in the EPBD. Electric heat pumps will also be installed in less efficient buildings if district heat or solid biomass aren’t available. The resulting mix and ambition level for renovation is shown in subsection 2.3.1.3.

Because of the focus on electric heat pumps, there is a need for an extension of the electric power network, beyond the extension anyway needed for build out of renewable energies on the supply side and the electrification of other sectors, like mobility. The extension is necessary to ensure security of supply also during cold winter days, by enabling the power delivery during demand peak times. The extension of the electricity grid is complemented by additional generation capacity to ensure that there is also sufficient electricity available in peak times. Especially during windless winter weeks, where there is limited renewable electricity production, and a high heating demand, the grid and generation capacity will be challenged. The size of the grid extension and additional generation capacity assumed is calculated on the electric heat pump demand during the windless winter weeks (methodology on peak load calculation follows in section 2.3.2).

2.1.2.2 Pathway B

Pathway B doesn't focus on one single technology but instead takes a balanced technology mix into account for the heating of buildings. Besides electric heat pumps, pathway B also considers other technologies like hybrids and highly efficient boilers. Especially hybrid heat pumps will have a significant role. Additionally, thermally-driven heat pumps and micro-cogeneration (including fuel cells) have a higher share than in pathway A. To decarbonise the building sector with this mix of technologies, pathway B needs a significant amount of green gas, namely biomethane and hydrogen. In 2030, the green gas share should already be 19% of the total gas demand for the building sector. There are less objections against the installation of new condensing gas boilers from the regulator if electrification is no efficient solution and they are renewable-ready.

A heating system replacement rate of 6% in 2030 is assumed in pathway B. This is combined with a focus on replacing old, inefficient heating systems. Thereby, a significant emission reduction is achieved within a couple of years – without a massive fuel switch necessary. Hybridisation (installation of a heat pump, in combination with an already existing efficient condensing boiler) allows for accelerated impacts on the stock of heating systems, even if the lifetime of heating systems is not yet at the end.

The use of green gases and hybrid systems enables a lower average renovation depth which means taking pressure from 'hard to abate' buildings. Pathway B has therefore a lower renovation level than pathway A, but still considers an ambitious ZEB level until 2050. The resulting mix and ambition level for renovation is shown in subsection 2.3.1.3.

The impact on the grid will be less drastic than in pathway A. Because of the use of multiple technologies, the electricity peak will be lower and thus the investment in grids and generation capacity limited. However, the gas grid and heating systems need to be retrofitted to enable green hydrogen blending. Besides retrofitting of some gas pipelines to dedicated hydrogen grids, this pathway doesn't account for new dedicated infrastructure to be built.

2.2 Key indicators

Pathway A and B show different decarbonisation pathways to reach the climate targets in 2030 and 2050. To compare which one of the two pathways would be more beneficial from a societal and individual household's perspective, the indicators 'end consumer costs' and 'system costs' are used.

End consumer costs reflect the costs that have to be paid by the consumer. These costs consist of building shell investments, replacement of heating systems and use of energy. With system costs, the additional infrastructure cost in the energy system, namely generation capacity, distribution and transmission network, is considered.

The building shell costs are dependent on the renovation depth of the pathway and needed insulation levels. The heating system costs are based on the combination of a pathway's heating mix and the replacement rate, hence the type and number of systems installed. Energy and infrastructure costs are both dependent on the chosen heat demand and energy mix. Energy costs are driven by the expected price developments for the different energy carriers. The modelling of the heating sector allowed to analyse future cost for heating in buildings.

We assume that the future comfort level in the houses should be comparable to today's, meaning that the inside temperature in buildings is kept at a similar level. Providing this comfort level is challenging for a decarbonised building sector during a windless winter week, where the heating demand is high and the production of renewable energy limited. During this period, there will be the need for additional generation capacity to cover the new electricity demand from heating. This capacity will likely have to come from low carbon gases, as these can buffer renewable energy systems. Short term storages, like electric battery storage, are not capable of balancing one week. They are only able to shift load for a couple of hours, maximum one day, but not more. The costs for additional generation, needed in the windless winter weeks, is captured in the infrastructure costs, as described in 2.3.3.

In both pathways, additional cost for gas infrastructure retrofitting for hydrogen readiness is considered. If the share of hydrogen is rather low and biomethane is used, not all gas infrastructure needs to be retrofitted (also considering significant less gas demand in total); also considering that hydrogen can be blended up to 20 vol.% to the existing natural gas grid and the EU is proposing to have already 3 vol.% by 2030[5]. Additionally, the cost for so called ‘hydrogen valleys’ are not accounted for in the buildings sector, as they will be driven by other sectors like industry and transport.

2.3 Modelling of the European buildings sector: BEAM² model

In order to have a quantitative assessment as the basis for our argumentation, the European buildings sector is modelled. The used model has already been applied in various studies for the European Commission, like the impact assessment of the EPBD and is called BEAM².

The following section describes which inputs are taken on by the model and defines the initial values used.

2.3.1 Inputs to the building sector model

The BEAM² model is used to quantify the pathways and input on the key indicators, as listed in 2.3. A set of model inputs/outputs have been used as a baseline for the European building sector. The set of parameters is as follows:

- **Building Stock Data** as square meter distribution per reference building, age group and heating technology for the start year 2020
- **EU Reference Zones** dividing Europe’s Members States in five Reference Zones (Northern, North-Eastern, Western, South-Eastern and Southern Zone)
- **Climate Data** showing average monthly temperatures of the five Reference Zones
- **Reference Buildings** for three residential (SFH, SMFH, LMFH) and five Non-Residential Buildings (Office, Trade and Retail, Education, Touristic and Health, Other)
- **Building shell efficiency levels** for the Reference Buildings and their original level (not renovated and already renovated) per Reference Zone and Age Group
- **Efficiencies of heating systems** as system efficiencies per heating and hot water system
- **Energy prices** per Reference Zone
- **GHG- and PE-factor** developments from today until 2050

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[5] REPowerEU, 2022: https://energy.ec.europa.eu/system/files/2022-05/SWD_2022_230_1_EN_autre_document_travail_service_part1_v3.pdf

- **Building Stock Development**, meaning how shares of buildings' different energy performance levels within the total floor area will develop within the total building stock as a result of the chosen pathway
- **Investment costs** for the measures in building stock and infrastructure (differ between the climate zones)

Apart from the above "no-change" model inputs/boundary conditions the following parameters change between pathways:

- **Building shell efficiency levels** for the Reference Buildings and their retrofit and new-built levels per Reference Zone and Age Group will develop within the total building stock
- **Specific pathway Inputs**, e.g., renovation rates or target levels for renovation
- **GHG factor** for gas because of different green gas shares

2.3.1.1 Definition of EU zones

The assessment with the BEAM² model is clustered in five zones, covering all member states of the EU-27, see Figure 1. Impacts of different pathways are calculated for each of these zones individually, since some key parameters (like climate, building stock etc.) differ significantly and therefore will be treated separately. The analysis with BEAM² is done in yearly timesteps until 2050.

Figure 1 Reference Zones for the EU-27

2.3.1.2 Climate data

For the five BEAM² Reference Zones Northern, North-Eastern, Western, South-Eastern and Southern shown in the previous section representative city climates[6] have been chosen. To reflect the future-oriented approach of the BEAM² model future climate data from 2030 (IPCC pathway B1) is used.

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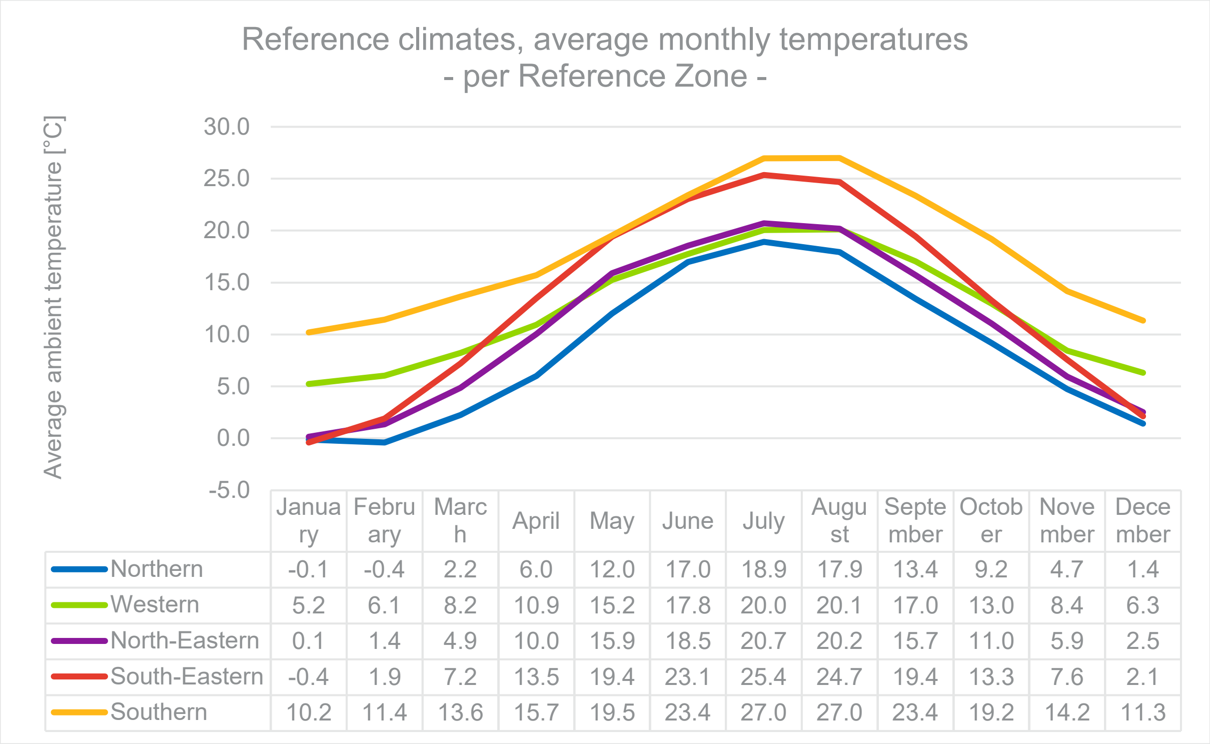
[6] Northern: Stockholm; North-Eastern: Warsaw, Western: Brussels; South-Eastern: Bucharest; Southern: Basrcelona

Figure 2 shows the average monthly temperatures of the reference climates in the respective Reference Zones.

Figure 2 Average monthly temperatures of the reference climates in the Reference Zones



	January	February	March	April	May	June	July	August	September	October	November	December
Northern	-0.1	-0.4	2.2	6.0	12.0	17.0	18.9	17.9	13.4	9.2	4.7	1.4
Western	5.2	6.1	8.2	10.9	15.2	17.8	20.0	20.1	17.0	13.0	8.4	6.3
North-Eastern	0.1	1.4	4.9	10.0	15.9	18.5	20.7	20.2	15.7	11.0	5.9	2.5
South-Eastern	-0.4	1.9	7.2	13.5	19.4	23.1	25.4	24.7	19.4	13.3	7.6	2.1
Southern	10.2	11.4	13.6	15.7	19.5	23.4	27.0	27.0	23.4	19.2	14.2	11.3

The climate data forms the foundation for determining the energy needs of the respective combinations of reference buildings (RB), age groups (AG) and retrofit levels (RL) on an hourly basis.

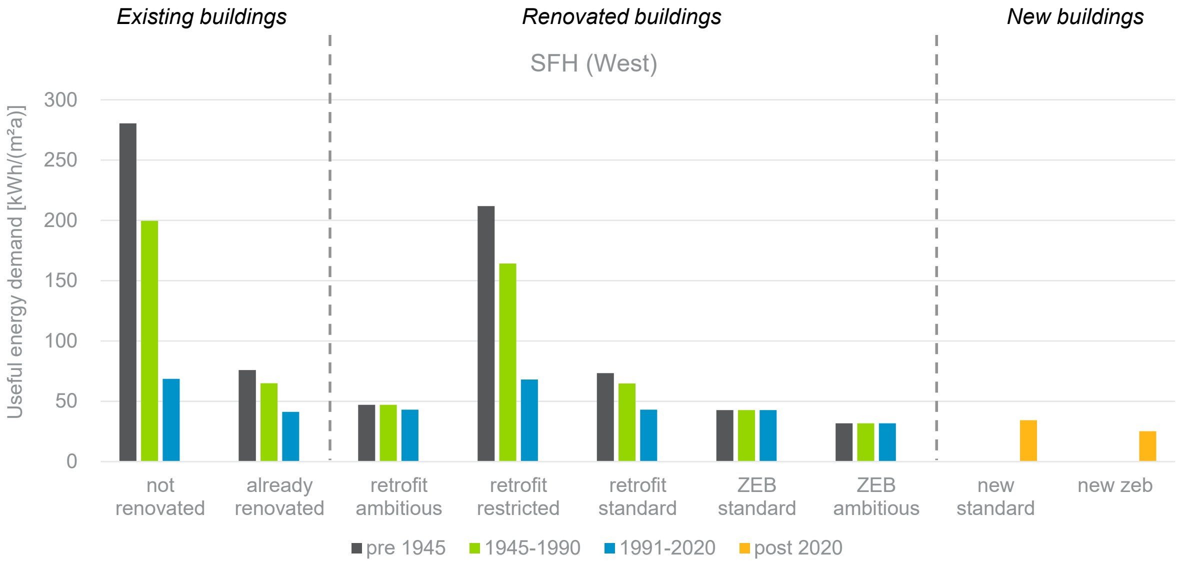
2.3.1.3 Reference buildings

The reference buildings are equal for both pathways, but the share per building type is different. Two different ambition levels are chosen for retrofitting and ZEB levels. The distribution of these building types differs per Pathway. A detailed description of the reference buildings used can be find in the appendix A.1. Here only representative case is shown to explain the methodology used (Figure 3).

Figure 3 shows the different building categories that are considered. It depends on the year of construction (pre-1945, 1945 – 1990, 1991 – 2020 and post 2020) and the renovation standard. Beyond that, there are the different types of buildings, i.e., three residential (SFH, SMFH, LMFH) and five Non-Residential Buildings (Office, Trade and Retail, Education, Touristic and Health, Other). For each of them the categories in Figure 5 are calculated, respectively.

The existing building stock is described with the six buildings on the very left. For the development of the building stock overtime the 30 building categories under 'renovated buildings' are chosen by the model plus the two 'new building' types for new construction.

Figure 3 Exemplary renovation level, expressed vie energy need, of SFH in zone West

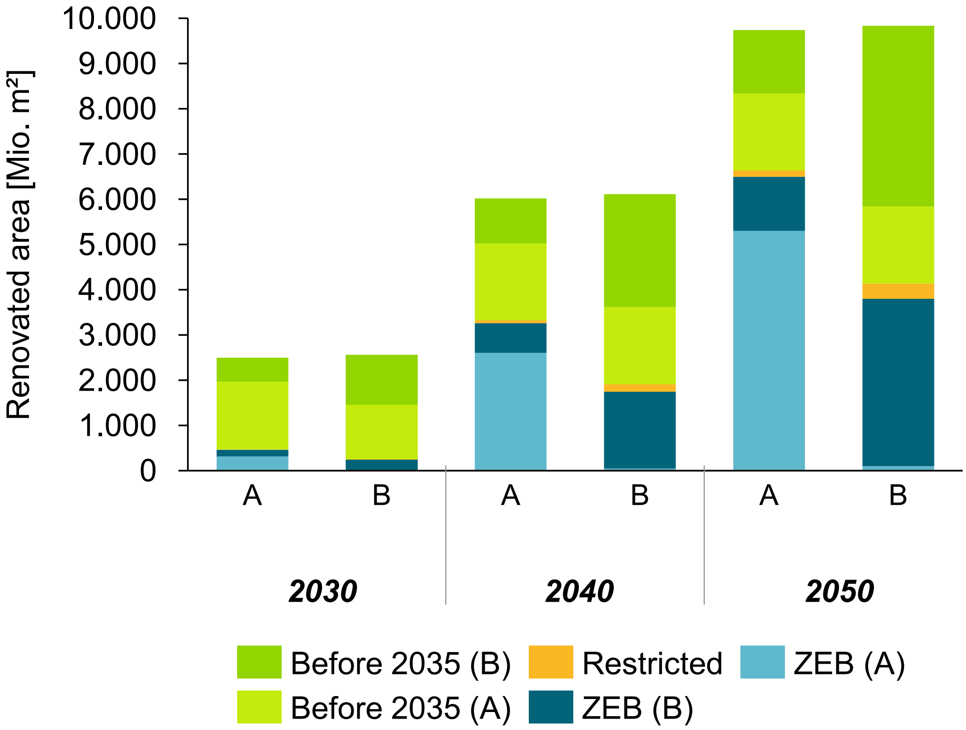


The renovation rates define how many square metres have transformed from the existing buildings into renovated buildings each year and the new building rate defines how many square metres of additional new buildings are added per year. While the renovation rate and the new buildings rate are equal across the pathways, the share of each building category is chosen differently.

Figure 4 shows what the different standards have as impact on the energy need. Subsequently in Figure 5 the graph shows the share of each of these building standards that is used in the two pathways. Buildings of similar type, but different depth of renovation are labelled with A and B – in accordance with the scenario where they are mostly, not exclusively, used.

Figure 4 Difference in average energy need between the standards of pathway A and pathway B

Figure 5 The shares of each renovation standard per pathway



2.3.1.4 Heating systems

The considered heating systems are listed in the following. It is to mention that the newly installed gas condensing systems are assumed to be “hydrogen ready”. Solar is mainly considered to provide hot water and has only minor reduction on space heat generation.

With the label heat pumps the study includes all systems, i.e., air-water, air-air and ground source systems. Since the European building stock is dominantly based on hydronic heating systems, the installation of hydronic heat pumps (air-water, ground source) is mainly considered in this model. They have the advantage of being easier to implement in existing hydronic distribution systems in buildings, being also more efficient in most building configurations and allow for hybridisation of existing condensing boiler. Thereby, the CO_2 saving potential is increased, more resilience for energy system and the implementation can be realised faster.

Micro cogeneration, like fuel cells and thermally driven heat pumps are not considered explicitly in the modelling. They can play a significant role for the decarbonisation of the building stock in the future. However, due to their minor role today and the technology still being in its infancy, they are not considered in the main model, but qualitatively.

The following heat generators were considered in the model:

- Gaseous fuel[7], condensing (H_2 ready)
- Gaseous fuel, non-condensing
- Liquid fuel, condensing (green liquid fuel ready)
- Liquid fuel, non-condensing
- Heat pump
- Hybrid heat pump
- District heating
- Solar (mainly for domestic hot water)
- Wood (boiler and stove)
- Electric-direct

Additional heat generators were considered qualitatively:

- Micro cogeneration (incl. fuel cells)
- Thermally driven heat pumps

The use of low temperature heat emitters (underfloor, low temperature radiators) has been considered with relevant adaptation of heating systems.

2.3.1.5 Economic inputs

Inputs on investment costs and energy prices are described in the appendix A.2.1.

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[7] All boilers working with gaseous fuels are assumed to be able to use also biomethane

2.3.2 Determination of electricity peak load

One of the key indicators to determine which of the pathways is most beneficial is the resulting electricity peak load from heating. Therefore, the assessment focuses on the worst-case pathway which is a cold and windless winter week. This might be all the more important, taking into account the parallel efforts needed to tackle the mobility challenge and the expected increase in electricity demand from electric vehicles. However, this is not modelled or considered in the cost communicated in this study.

Definition and implications of a windless winter week

The assumption is that during a windless winter week there will be limited renewable electricity generation, since no wind is blowing, and it is mostly dark and cloudy. On the other hand, the very cold temperatures lead to the situation that heating systems in buildings are running at their maximum capacity. This situation lasts for at least one week. While these circumstances have limited impact today, since most of the generation is still flexible (conventional) and there is a limited amount of electric heating systems in the building stock, this will change drastically in the future: With an electricity system having a major share of renewable energies and a building stock with mostly electric heating systems, i.e., heat pumps. Since it lasts one week, short term flexibility, like electric batteries or most demand side flexibility, cannot be used to overcome the lack of firm power generation. This must be provided by flexible conventional generation plants, i.e., gas power plants. Additionally, the huge amount of electricity needed for electric heating systems will put constraints on the electricity transmission and distribution grids, hence, grid extensions are necessary to prepare the energy system.

The peak will be mostly caused by all electric heat pumps, when looking at the future heating system mix. To determine it two major steps are performed: (1) Determination of heat load and (2) the resulting electricity peak.

First, to estimate the resulting heating load, the design power of all electric heating systems in the reference buildings is determined (this excludes hybrid setups, where conventional, condensing boilers can provide the heat in peak times). The design temperature of the heating system depends on the geographical location and is assumed to be the average temperature of the assessed winter week. Then, the design power of each reference building is accumulated, according to the distribution of building types and retrofitting level in the stock, as calculated by the model. The result is a heating peak load.

This is transformed into the resulting electricity peak load, by applying the efficiencies of the heating system, plus some other considerations. With the latter, the limited options to provide still flexibility to the power grid are considered. The efficiency of heat pumps is reduced during the assessed winter week (compared to the average COP over the year) since they operate around and below their design temperatures. It is important to note that significantly higher efficiencies are applied as an average over the year. A summary of our considerations is given in the following.

The calculated heating load is reduced (in both pathways) by 57%, to reflect the resulting electricity peak load to the power grid. Single considerations and assumed measures that lead to this reduction are:

- Even in peak times 50% of heat is still provided via heat pump, although with a very low efficiency (around 2.0), while the other 50% are generated with a direct electric heat element. In conclusion, we assume an overall coefficient of performance (COP) of 1.5

- 15% is covered with ground source heat pumps, that operate with a COP of 2.8 (under these conditions)
- Although the level of comfort is assumed to remain very similar to today, some minor reductions are expected to be acceptable. Load shifting option of 2h/day is possible, whereby the overall peak can be reduced by 15%
- Heat pumps are usually oversized. Although oversizing is expected to decrease in time, we have assumed a factor of 10-20%. The additional power capacity available, can be used to reduce the very peak by 15%, by using the mass of the building and water contained in heat emitters as short-term thermal storage

2.3.3 Infrastructure cost assumptions and calculation

The additional grid infrastructure costs of the two pathways are calculated based on the peak demand during the windless winter weeks. This period has the highest delta between electricity peak caused by heating systems and power generation, and therefore represents the peak that the distribution grid should be able to provide.

To calculate the infrastructure costs needed to cover the peak demand, we considered the grid expansion costs and additional generation costs. The grid expansion costs are split between TSO, high voltage, and DSO costs, low- and medium voltage. The average grid expansion cost in Euro/kW for medium- and high voltage are derived from Ecofys 2016[8]. For low voltage investment costs, the study provided an average Euro/household/year, as the low voltage grid extension is also dependent on the number of households with heat pumps. The average electricity grid expansion costs from the Ecofys 2016 study[9] include OPEX, assumed to be1.5% of annual CAPEX. The OPEX include the maintenance, net losses and office costs. The investment costs take into account an interest rate of 5% but exclude inflation predictions. There are two important technical assumptions. First, it is assumed that the difference in infrastructure costs between rural areas and cities averages out over regions, as rural areas need extra cable length while cities have higher digging costs. Second, the economic lifetime of an asset is assumed to be 40 years. For the generation costs, the peak is multiplied by the total costs of a power plant[10].

2.4 Additional assessments

The former chapters elaborate on the technical and economic aspects of the study. There are two additional assessments executed to provide a broader perspective on the difference between the two decarbonisation pathways presented. The first is the social considerations, assessing the impact on a household level. The second is the country assessment, analysing differences within the European Union.

2.4.1 Social considerations

For the comparison of the two pathways, we take into account additional social considerations. As the overall end consumer cost analysis does not consider the social reality of all building owners. In reality, the installation of a heat pump is most efficient in a building with high efficiency standard, which most buildings do not have today. If the heater breaks and the owner is obliged to install a heat pump, it is recommended to perform a substantial renovation, including high capital investments. If the building owner does not have the capital available there are two options: Installing a larger heat pump, that is more

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[8] https://www.netbeheernederland.nl/_upload/Files/Rapport_Ecofys_Waarde_van_Congestiemanagment_86.pdf

[9] Costs are assumed to not change significantly from 2016 to 2021, since technology for transformers and powerlines has been well developed over decades; only inflation adaption considered.

[10] https://elib.dlr.de/135971/1/MuSeKo-Endbericht-2020-08-31.pdf

expensive and will be oversized after future renovations or get a credit for the renovation. The first option would be probably more expensive over time and the second one implies capital cost or could lead to lower willingness to act in the first place. All these aspects should be considered when decarbonisation pathways are developed and compared.

For the social considerations we compare renovation pathways and test their flexibility to the individual situation of the building and financial situation of the owners. The analysis helps to understand if these alternative pathways are significantly more expensive and which technologies are fit to do so. Since they usually take the retrofitting measures ‘step-by-step’ they are called staged renovations. To calculate the additional costs of the staged renovation approach, the methodology is to compare the cost of staged renovation with a 1-step renovation (deep renovation + heat pump). The comparison period is 30 years for both options. The costs that are considered for the analysis are CAPEX, OPEX and residual value of an installation. These are accumulated to compare the two approaches.

2.4.2 Country assessments

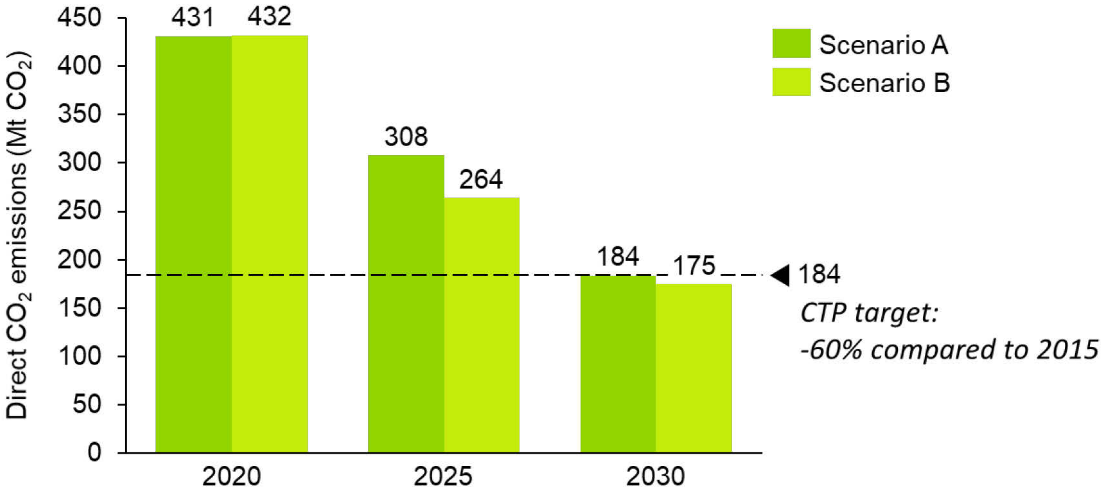
The European Union has with its 27 countries a wide variety of building sector specifics. Differences can be caused by the heating mix, available energy carriers and complementing infrastructure of a specific country. Or by the buildings- and related energy system policies, and future climate plans of national governments. To illustrate these differences, we analyse the impact of the two pathways for five specific countries, spread over the EU climate zones. These five countries are: Germany, France, Italy, Spain and Poland. We create a factsheet for each individual country to showcase the country specific conclusions.

3. Results

3.1 GHG emissions (2030/2050)

The EPBD set the target: All buildings should be zero emission buildings by 2050. Additionally, buildings should only use carbon neutral energy carriers by 2050. Both pathways reach the 2050 target of zero emission buildings, using only carbon neutral energy carriers. For 2030 there is no specific target for the building sector defined by the FF55 package. However, the CTP defines the target of power & building sector together with -60% GHG direct emission reduction compared to 2015. Direct emissions are fuels burned on site, which excludes electricity and district heat. Both pathways reach the goal of direct emissions savings in 2030. Pathway B will achieve the targets using an efficient fuel switch, also considering individual situations, while pathway A has a massive fuel switch, without any options.

Figure 6 Direct CO_2 emissions in the EU buildings sector

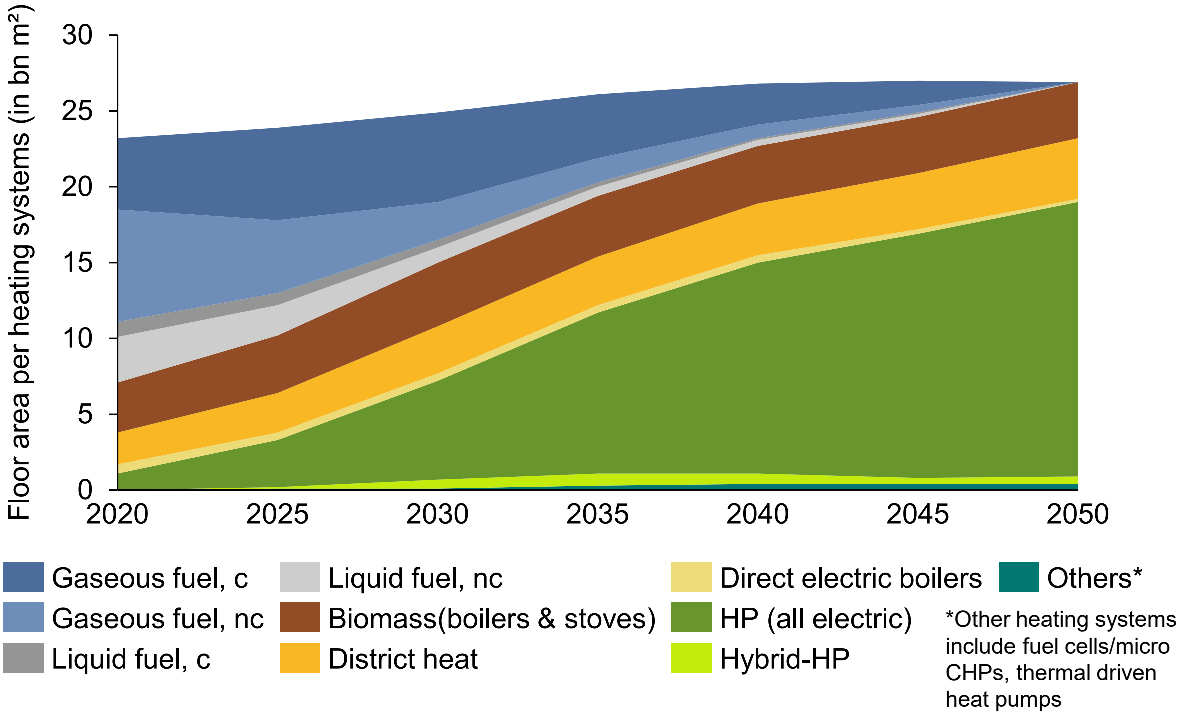


3.2 Technology mix development

3.2.1 Pathway A

Pathway A has an emphasis on the use of electric heat pumps as the main decarbonisation technology. This translated in the modelling results. From 2030 onwards, all electric heat pumps have the highest share of heating system in the building stock. Hybrid heat pumps have only a minor share and are mainly used as bridging technology. In 2050, the hybrid heat pumps are phased out in Europe. Moreover, in 2050 there will be no gas used in the building sector. Other technologies do play a role in the future technology mix of pathway A. For example, biomass and district heat keep increase their current shares slightly towards 2050.

Figure 7 Development of heating systems (based on m²) for pathway A



*Other heating systems include fuel cells/micro CHPs, thermal driven heat pumps

Table 18 in Annex shows an indication of the number of heating systems in the building stock for pathway A. This is derived based on the modelling results shown above in m².

3.2.2 Pathway B

The development of heating systems in pathway B is different from pathway A in multiple ways. The main reasons are the use of green gas and the higher heating system replacement rate (6%/year). The higher heating system replacement rate leads to a faster decrease of inefficient boilers and quick emission reduction. To replace the inefficient boilers, hybrid solutions are used. There is a share of 22% hybrid heat pumps operating in 2050 and an additional 16% of gaseous fuel boilers. All electric heat pumps still play an important role and account for 31% of the installed heating systems in 2050. Other heating systems, like fuel cells/micro-CHPs or thermally-driven heat pumps, are present from 2030 onwards in the market. They might play even larger roles, but this will be determined as soon as the technology is fully developed and tested extensively in the market. The heating systems are supported by efficient heat emitting systems (e.g., surface/underfloor heating) and lead to significant savings of the final energy demand. Another energy demand saving technology is the use of solar thermal, further increasing the heating demand by 10% around 2050.

Figure 8 Development of heating systems (based on m²) for pathway B

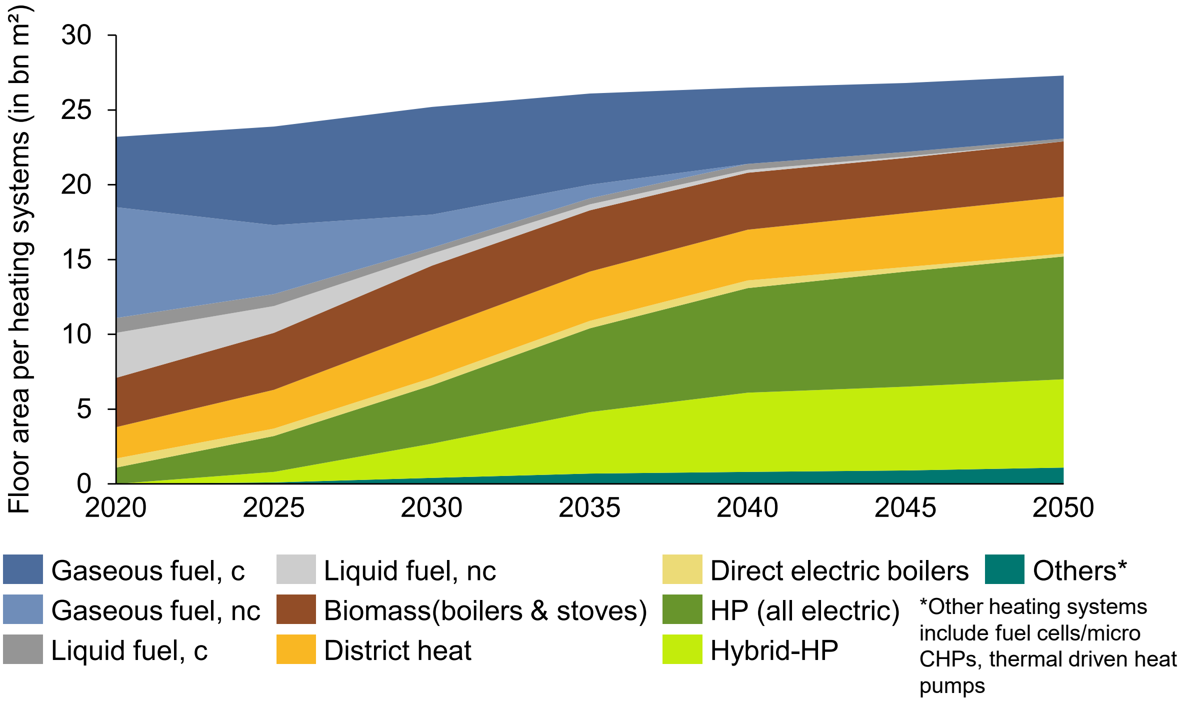
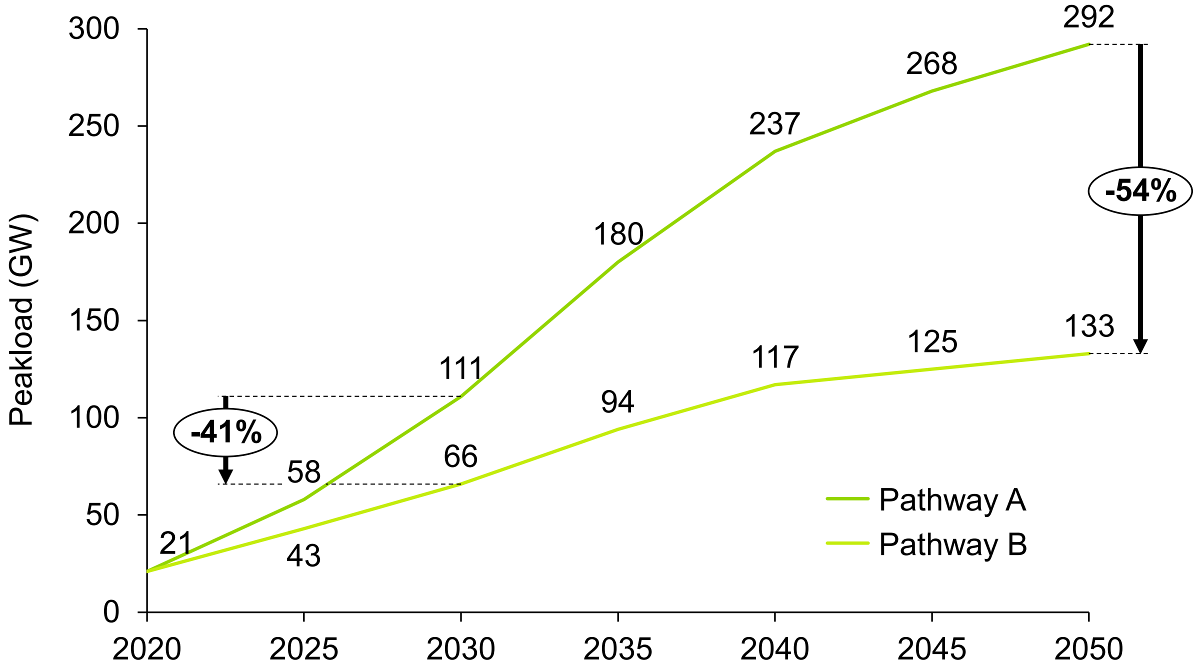


Table 19 in Annex shows an indication of the number of heating systems in the building stock for pathway B. This is derived based on the modelling results shown above in m².

3.3 Infrastructure impact

Both pathways result in an increased peak load for the electricity grid and generation as both pathways have high shares of electric heat pumps. Pathway A has the highest share of electric heat pumps and therefore also the highest resulting peak load. In 2030, the resulting additional peak in pathway A is 111 GW and increases to 292 GW in 2050. Compared to pathway B, pathway A has a 41% higher peak load by 2030, and 54% by 2050.

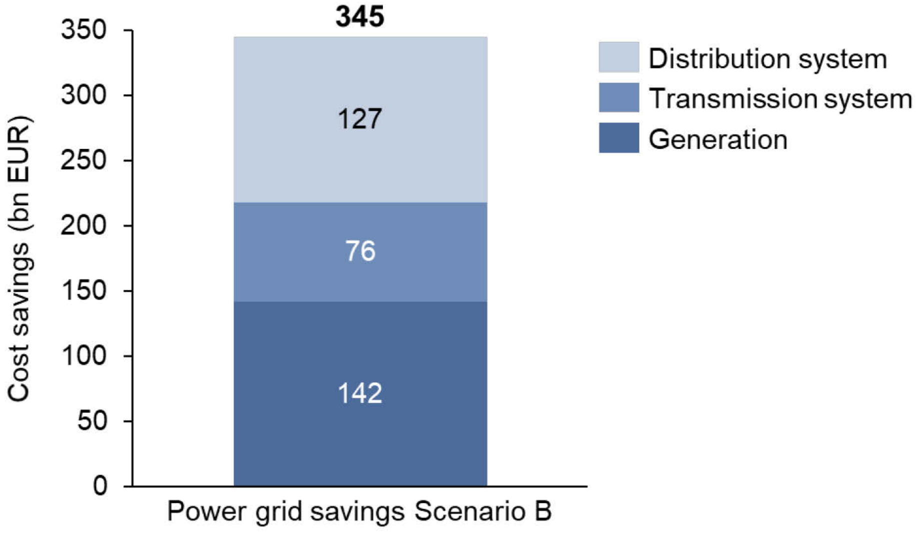
Figure 9 Comparison of resulting peak load demand from heat pumps



For both pathways, system efficiency and peak mitigation measures reduce the theoretical peak load based on energy need. See section 2.3.2 where this is explained in detail. The application of the peak load measures results in an 57% reduced peak load compared to pathway where the following peak mitigation measures are not applied.

The peak load demand is the main driver for the calculation of the power grid and generation costs. The total savings from today till 2050 will be over 300 bn Euro if pathway B is followed, as illustrated in Figure 10. The difference is mainly caused by the savings for the extension of the distribution grid and lower additional generation capacity needed. Additional savings result from less extension needs in the transmission network.

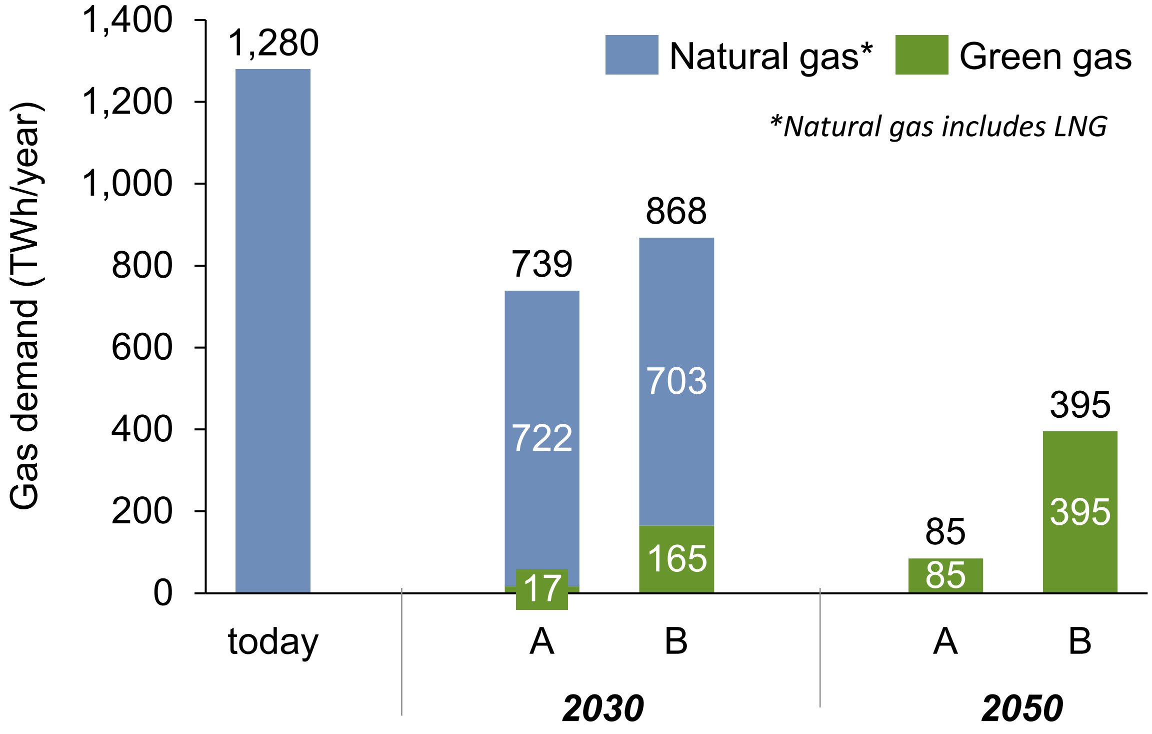
Figure 10 Cost savings of power infrastructure of pathway B



3.4 Consumption of gaseous fuels over time

Pathway A and B show both that the gas demand decreases significantly by 2030 and 2050. The decrease is driven by the fuel switch, hybridisation and efficiency measures in buildings. In 2030, pathway A needs 739 TWh/year of which 17 TWh/year is green gas. Pathway B has a gas demand of 868 TWh/year of which 165 TWH/year is green gas (about 80% biomethane and 20% hydrogen assumed). The demand for 2030 fits within the REPowerEU, which set the goal of 350 TWh of biomethane and considers hydrogen blending to the grid of about 45 TWh (1.3 Mio. t)[11]. In 2050 the gas demand is further decreased for both pathways and only consist of green gas. Pathway B has a higher gas demand than pathway A, as pathway A mainly focusses on electric heat pumps. For pathway B, there is a gas demand of 395 TWh left (composed of 60% hydrogen and 40% biomethane), about -70% compared to today's gas demand. Since the gas demand is reduced significantly, it is very likely that enough green gas is available to supply this amount to the building sector.

Figure 11 Total future gas demand for pathway A and B (EU)



3.5 Cost derivation from the pathways

The total cost savings from today till 2050 will be over 500 bn EUR, if pathway B is followed. The main driver are the savings for less grid extension and lower additional generation capacity needed, where pathway B has accumulated savings of 345 bn EUR. Additional savings result from the lower insulation ambitions and therefore less investments into the building shell (147 bn EUR). Higher energy costs (31 bn EUR) are compensated by

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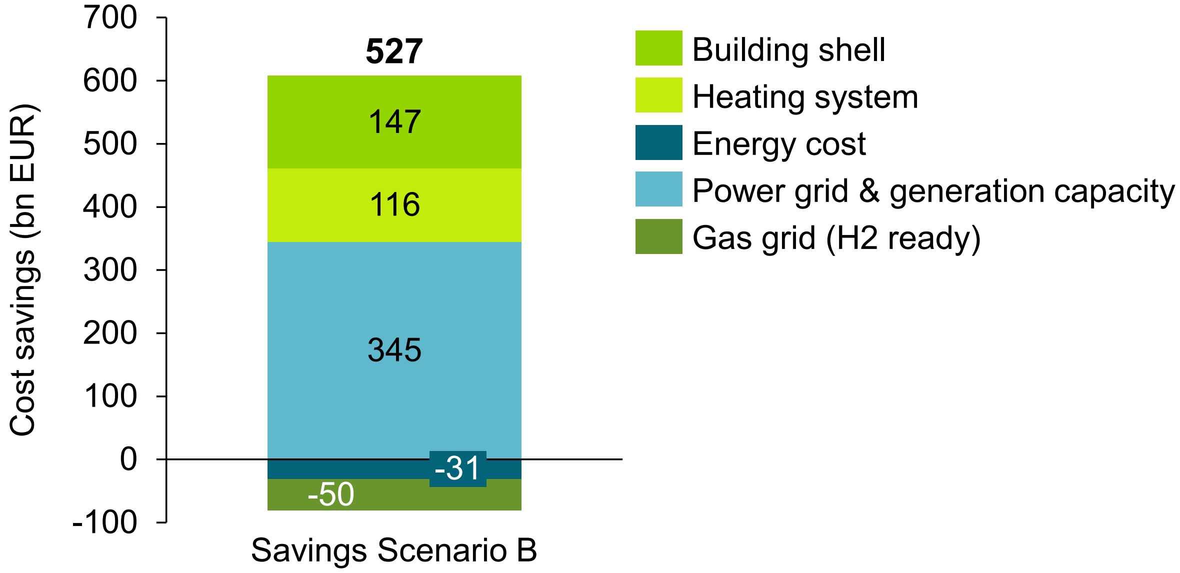
[11] REPowerEU, 2022

the lower cost for heating systems (116 bn EUR). Additional investments into the gas distribution grid to enable dedicated hydrogen pipelines are 50 bn EUR.[12]

Figure 12 Cost savings of pathway B compared to A



3.6 Work force needed

The assessment of the pathways showed that the targets or the European Commission cannot be achieved without an acceleration of heating system replacement rate, renovation rate of buildings combined with a massive fuel switch. Both, the acceleration as well as the technologies needed - mainly heat pumps – needs a (1) higher number and (2) up- and reskilling of workers. This does not even yet consider the significant implications on the wider supply chain (up-/downstream), which increases the need of workers further.

The EC communication on the Impact Assessment (part 1/4) of the EPBD[13] calculated in a similar assessment that a total of 1.4 million additional low- and medium-skilled jobs will be created by 2030 compared to 2020 – if the scenario is realised. Another 450,000 additional jobs will be created in the high-skilled segment. This provides a good idea of the efforts needed on the installation and supply chain side to make the transition happening.

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[12] In the EPBD Impact Assessment, the additional cost for a target leading decarbonisation of buildings scenario (e.g., S3-I) compared to not target-leading BAU is about 4 trillion EUR within the period 2020-2050 - SWD(2021)453 (1/4), p. 82 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en

[13] Impact assessment report - SWD(2021)453 (1/4), pp. 92. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en

4. Additional considerations

4.1 Social aspects

For the analysis a reference building is assessed to compare the staged renovation with the 1-step renovation. The reference building is a small apartment building that is constructed in 1980 and not renovated. The starting point of the analysis is that the heating system needs to be replaced. The roof and windows should be retrofitted within the next 5 years. However, the facade has at least another 10 years until it needs to be renewed.

There are four pathways for staged renovation assessed, as shown in the table below. Over the time, the same measures are taken in all cases. But whereas in the 1-step reference case (#1) all measures are implemented in the 1st year, the staged renovation approach takes a measure about each 5 years. After 20 years, the heating system needs to be replaced again.

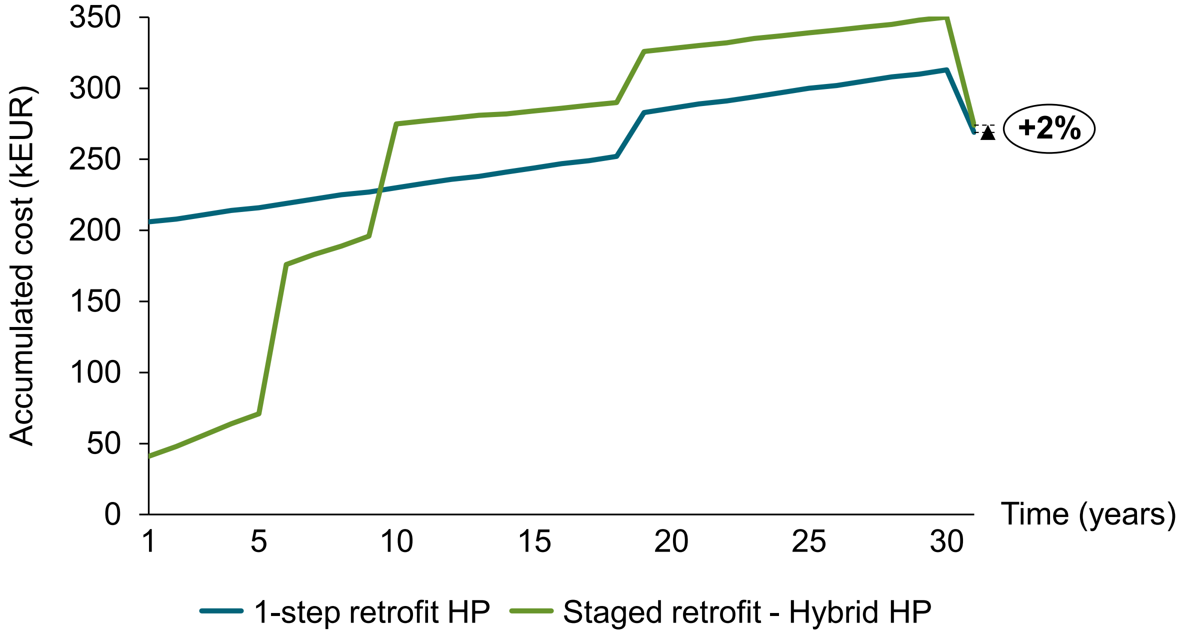
Table 1 Four renovation pathways

#	Options	1st year	5th year	10th year	20th year
1	**Heat pump + 1-step renovation**	New heat pump; Roof, windows, facade retrofit	-	-	New heat pump
2	**Heat pump + staged renovation**	New heat pump; Roof and windows retrofit	-	Facade retrofit	New heat pump
3	**Hybrid heat pump + staged renovation**	New hybrid heat pump	Roof and windows retrofit	Facade retrofit	New hybrid heat pump
4	**Gas boiler + staged renovation**	New gas boiler	Roof and windows retrofit	Facade retrofit	New gas boiler

In order to identify the impact of a one-step renovation versus a staged renovation approach the first case (heat pump + 1-step renovation) is compared to the staged renovation cases depending on different heating systems. For the comparison the accumulated total cost over 30 years are chosen.

The results show that if a one-step renovation cannot be afforded, since the initial investment are too high, the accumulated costs overtime will be higher. But there is a significant difference between technologies. While conducting a staged renovation with a heat pump or condensing boiler leads to additional costs of over 10%, a hybrid heat pump set up only results in 2% additional costs, which could be considered marginal. The comparison of the latter case is shown in Figure 13. the others can be seen in appendix A.4.1.

Figure 13 Case 1 (heat pump + 1-step renovation) vs. case 3 (hybrid heat pump + staged renovation)



4.2 Regional aspects

The results presented in chapter 3 show the difference between the two pathways for the EU-27. The EU-27 can be organised in different climate zones with different characteristics. Not only the climate, but also the current infrastructure, heating mix and policies in place create different situations over the EU-27 countries. To highlight the difference between the individual countries, the following chapter will showcase a breakdown of the results on country levels for: Germany, France, Italy, Spain and Poland. It is important to note, that no country-based modelling was conducted. The results presented here, should only give an orientation what the results could mean per country.

4.2.1 Germany

4.2.1.1 Background

The German discussions on the building sector decarbonisation focusses on renovation and electrification. There is already, though, a role of gas discussed in the distribution grid as well. For the electrification of the building sector, the government aims to install 6 Mio. heat pumps by 2030 and 14 Mio. by 2045. The German government invests in funding for energy efficiency and renewable energies (BEG[14]: Volume €8 bn by 2021, e.g., 45% of investment for replacing oil boilers by heat pumps or biomass boilers). The new coalition plans include several policy measures for buildings: More ambitious standards for new construction (GEG: EH 55[15]); New heating systems are required to have a share of min. 65% renewable energy from 2024 onwards (although questionable if this is realistic); Shift of funding support (BEG) more to renovation. In 2025, an additional 10 bn EUR for energy efficient buildings is available. 'Major' GEG amendment in 2023, including the implementation of the EPBD (minimum energy performance standards, etc.) expected.

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[14] Bundesförderung für effiziente Gebäude (federal support for efficient buildings programme)

[15] Gebäude Energiegesetz: Effizienzhaus 55 (buildings energy law: efficiency standard 55)

In Germany, space heat and hot water account for 31% of the country's total final energy demand. The current residential heating mix is dominated by gas, oil and renewable heat. Electricity is also used for heating and the current emissions from electricity are 366 gCO_2/kWh when the electricity is retrieved from the grid. Germany has ambitious climate plans and aims to have a renewable energy share of 80% in 2030, while nuclear will be phased out by 2023.

Germany is the largest producer of biogas and biomethane worldwide. In 2019, Germany had 11,269 biogas plants operational producing 82 TWh, and 232 biomethane plants producing 10 TWh. For hydrogen, Germany is highly dependent on import, as the price for local generation is expected to be comparably high. The German hydrogen market is forecasted as largest demand in Europe, mainly driven by industry (steel, chemicals), as well as the power and heat sector. Germany expects to supply 20 - 50 TWh by 2030 with an increased 160 – 350 TWh by 2050.

4.2.1.2 Pathway results

The accumulated costs savings of pathway B compared to A are 121 bn Euro until 2050, of which 54 bn Euro comes from buildings (shell, heating system and energy cost) and 67 bn Euro from infrastructure savings (power and gas grid, generation capacity).

The infrastructure savings are the largest and mainly caused by the lower peak demand of pathway B to pathway A. In 2030 the difference is 10 GW and this difference increases to 29 GW in 2050. Numbers are derived from the results of the climate zone, by taking the share of national heat demand within the zone into consideration.

Figure 14 German electricity peak reduction in pathway B compared to A

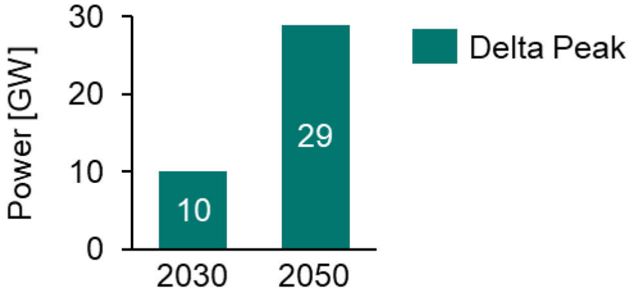
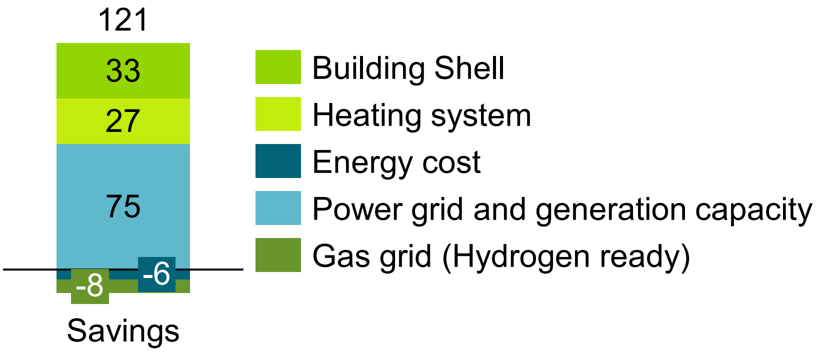


Figure 15 Accumulated German cost savings* of pathway B until 2050



** Derived from zone results by applying the share of national heat demand*

4.2.2 France

4.2.2.1 Background

In France there are two important building policies focused on energy efficiency. First, the Energy Transition Act of 2015 stated the goal of 28% reduction of final energy consumption of buildings in 2050 compared to 2012 level. One of the measures to achieve this reduction, is to retrofit 500,000 existing dwellings each year, of which half should be occupied by vulnerable consumers. A second important building policy is the Building Codes “RE2020”, that requires all new buildings to have a maximum primary energy consumption of 100 kWh/m^2 for all end-uses.

Between 2000-2017, the energy consumption of space heating has dropped by 10 percentage points thank to efforts made in the end-use. The heating mix in France is dominated by gas, renewables and electricity. Other sources that are used for heating are oil and a minor role for coal.

France has the highest number of biomethane plants in Europe and produced in 2020 about 2 TWh of biomethane. France continues to rapidly increase its biomethane production of biomethane with 306 upgrading plants in operation[16]. The French biomethane strategy is part of the Multiannual Energy Plan, a roadmap to 2028. The main biomethane target is to increase production for grid injection to 6 TWh in 2023 and up to 14 to 22 TWh in 2028 (6% - 8% of total gas consumption)[17].

Besides biomethane, France also has a national strategy to develop decarbonised and renewable hydrogen. In this strategy, France set out the goal to have 6.5 GW of electrolysers installed by 2030. The government set aside €1.5 billion to be invested in the development of a French electrolysis sector.

4.2.2.2 Pathway results

The accumulated costs savings of pathway B compared to A are 107 bn Euro until 2050, of which 48 bn Euro results from buildings (shell, heating system and energy cost) and 59 bn Euro from infrastructure savings (power and gas grid, generation capacity).

The infrastructure savings are the largest and mainly caused by the lower peak demand of pathway B to pathway A. In 2030 the difference is 9 GW, and this difference increases to 26 GW by 2050. Numbers are derived from the results of the climate zone, by taking the share of national heat demand within the zone into consideration.

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[16] Market state and trend report 2021, Gas for Climate, https://gasforclimate2050.eu/wp-content/uploads/2021/12/Gas-for-Climate-Market-State-and-Trends-report-2021.pdf

[17] French Ministry of Ecological Transition, Executive Summary – French Strategy for Energy and Climate, Multiannual Energy Plan, 2019-2023, 2024-2028, https://www.ecologie.gouv.fr/sites/default/files/PPE-Executive%20summary.pdf

Figure 16 France electricity peak reduction in pathway B compared to A

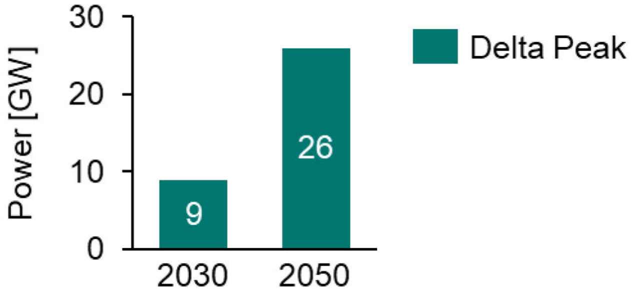
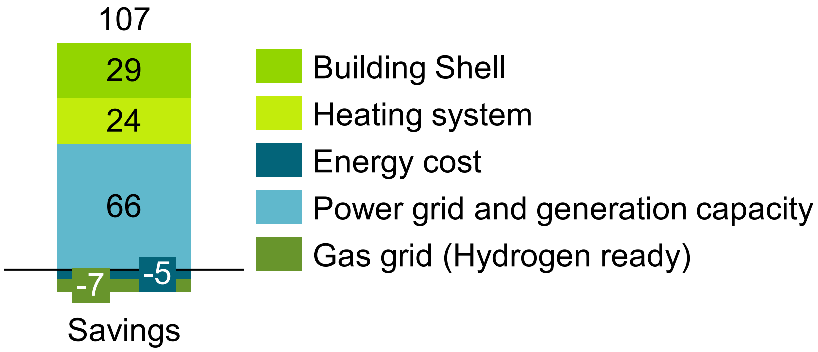


Figure 17 Accumulated French cost savings* of pathway B until 2050



** Derived from zone results by applying the share of national heat demand*

4.2.3 Italy

4.2.3.1 Background

There are several laws in Italy that financially incentivise energy efficiency and building renovation: Budget Law, Law Decree 34/2020 and Legislative Decree 48/2020. For the energy performance of buildings, there is a minimum requirement for new and existing buildings. Existing buildings have to undergo major renovation according to the type of building and the climatic area. New PA buildings, owned or occupied, shall be NZEB from 1 January 2019, all other new buildings from 1 January 2019[18]. Italy encourages public administrations and private parties to implement energy efficiency improvement actions in buildings and technical installations as well as for the generation of renewable thermal energy with the Thermal Account scheme (Conto Termico)[19].

The Italian residential sector has a share of 27.8% of total energy consumption in 2019. The energy consumption of households is dominated by gas, wood and electricity[20].

The first Biomethane Decree was established in 2018 and set targets for the production of biomethane. The targets were limited to the transportation sector. A new Biomethane Decree is being developed to include other sectors beyond transportation. The new incentive mechanism is expected to promote the production of a further 2.3-2.5 bcm/y of biomethane to decarbonise the industrial sector and the residential sector. The mechanism aims to stimulate the production of biomethane from the agricultural sector and will promote the

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[18] https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/italy.html

[19] https://www.odyssee-mure.eu/publications/national-reports/energy-efficiency-italy.pdf

[20] EBA Statistical Report 2020

conversion of existing biogas plants and the construction of new ones. Besides biomethane Italy also invests in hydrogen. In November 2020, the Ministry of Economic Development published the first Guidelines for the National Hydrogen Strategy. The guidelines expect up to €10 billion of public and private investments in hydrogen production, distribution, consumption research and development[21].

4.2.3.2 Pathway results

The accumulated costs savings of pathway B compared to A are 101 bn Euro until 2050, of which 37 bn Euro comes from buildings (shell, heating system and energy cost) and 64 bn Euro from infrastructure savings (power and gas grid, generation capacity).

The infrastructure savings are the largest and mainly caused by the lower peak demand of pathway B to pathway A. In 2030 the difference is 9 GW, and this difference increases to 29 GW in 2050. Numbers are derived from the results of the climate zone, by taking the share of national heat demand within the zone into consideration.

Figure 18 Italy electricity peak reduction in pathway B compared to A

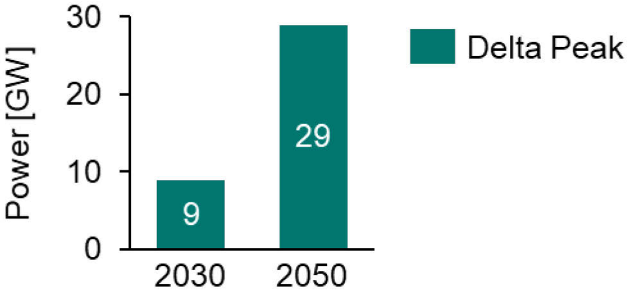
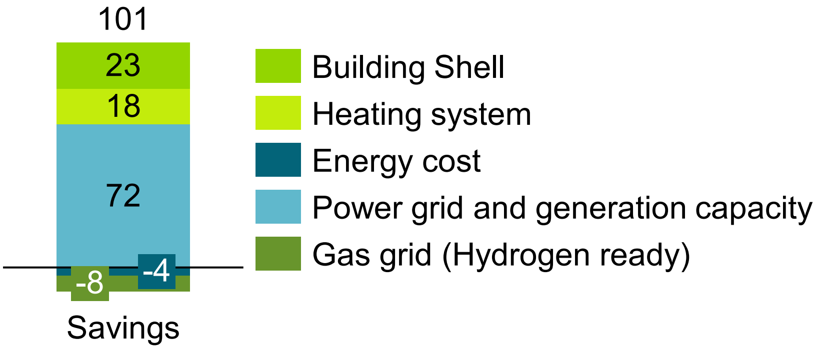


Figure 19 Accumulated Italian cost savings* of pathway B till 2050



** Derived from zone results by applying the share of national heat demand*

4.2.4 Spain

4.2.4.1 Background

Spain has two main mechanisms to improve the energy efficiency of the building sector. First, the State Housing Plan, which includes urban and rural renovation and regeneration. The State Housing Plan has programmes to fund works to improve energy efficiency and sustainability, paying special attention to the building envelope of collective residential buildings and single-family houses. A reduction of 20%-30% must be achieved in yearly

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[21] Market state and trend report 2021, Gas for Climate, https://gasforclimate2050.eu/wp-content/uploads/2021/12/Gas-for-Climate-Market-State-and-Trends-report-2021.pdf

energy demand in heating and air conditioning in buildings. Second, the Aid Program for energy rehabilitation actions in existing buildings (PREE). PREE has a budget of €300M and aims to boost the sustainability of the existing buildings[22].

The buildings residential and service sector accounts for 31.4% off the final energy consumption of 82.1 Mtoe in 2018. Around 43% of this consumption goes directly to heating. The Spanish energy consumption of households is dominated by electricity, natural gas, and equal shares of oil and renewables[23].

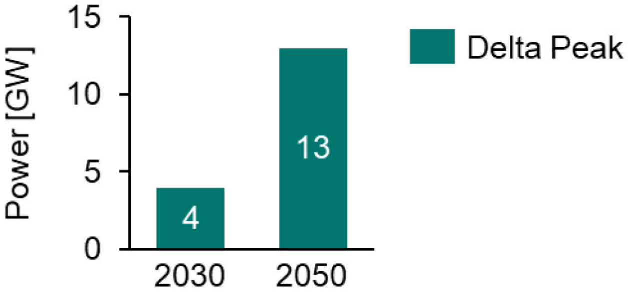
The Spanish biogas roadmap aims to boost the production and consumption of biogas and biomethane in the short and medium term. Spain foresees the biggest role for biomethane in heavy-duty transportation and as substitution for natural gas in the grid[24]. Spain has 120 biogas plants, producing 8 TWh in 2019. Sewage-based biogas is most numerous in Spain. For hydrogen, the Spanish Vision 2030 expects an installed capacity of 4 GW electrolysers. The estimation is that by 2024 the installed power of electrolysers would be between 300-600 MW. Spain seeks to support renewable hydrogen through administrative simplification, public utility direct lines/hydro pipelines, and a renewable hydrogen GoGO system[25].

4.2.4.2 Pathway results

The accumulated costs savings of pathway B compared to A are 27 bn Euro until 2050, of which 10 bn Euro comes from buildings (shell, heating system and energy cost) and 17 bn Euro from infrastructure savings (power and gas grid, generation capacity).

The infrastructure savings are the largest and mainly caused by the lower peak demand of pathway B to pathway A. In 2030 the difference is 4 GW, and this difference increases to 13 GW in 2050. Numbers are derived from the results of the climate zone, by taking the share of national heat demand within the zone into consideration.

Figure 20 Spain electricity peak reduction in pathway B compared to A



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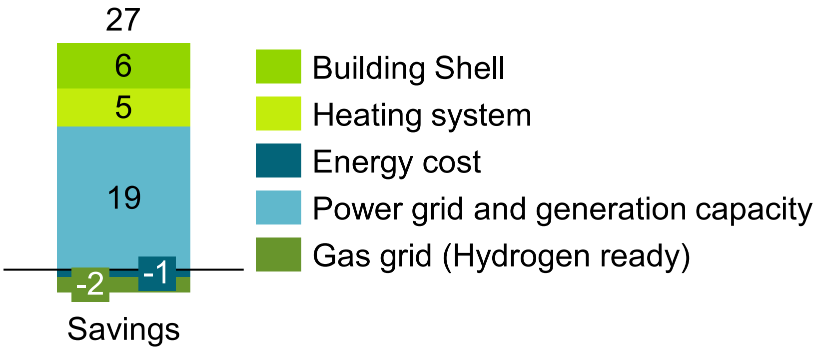
[22] Energy efficiency report Spain https://www.odyssee-mure.eu/publications/national-reports/energy-efficiency-spain.pdf

[23] EBA Statistical Report 2020

[24] The News 24, "The Government launches the roadmap to promote biogas in Spain," 15 July 2021, https://www.then24. com/2021/07/15/the-government-launches-the-roadmap-to-promote-biogas-in-spain/.

[25] Ministry for the Ecological Transition and the Demographic Challenge, Hydrogen Roadmap, 14 October 2020, https://ec.europa.eu/ info/sites/default/files/energy_climate_change_environment/events/presentations/02.03.02_mf34_presentation-spain-hydrogen_ roadmap-cabo.pdf.

Figure 21 Accumulated Spanish cost savings* of pathway B until 2050



** Derived from zone results by applying the share of national heat demand*

4.2.5 Poland

4.2.5.1 Background

Poland has adopted solutions to take measures aimed at improving the energy performance of buildings. These solutions should amount to 43 GWh targeted energy saving for the years 2021-2030. Poland has several funding mechanisms that aim to increase the sustainability of the building sector. Two that are particularly interesting are the Thermo-modernisation and Renovation Fund, and Thermo modernisation bonus. The Thermo-modernisation and Renovation Fund primary objective is to provide financial assistance to investors undertaking thermo-modernisation and repair projects and to pay compensation to owners of residential buildings. For 2021-2030 the expected energy savings are 70 ktoe/year. Second, the Thermo modernisation bonus is a tax relief that allows deduction from income (revenues) of the expenses related to the implementation of thermo-modernisation projects in single family residential buildings. It is expected that this bonus results in 200 ktoe/year of savings in the period 2021-2030[26].

Poland's household energy consumption was 18.2 Mtoe in 2019 of which 63.1% is allocated to space heating. The final energy consumption in the residential sector is dominated by natural gas, coal, and electricity.

Poland is in the top-3 EU countries with the largest daily hydrogen production[27]. It is expected that Poland will be one of the countries with the highest shares of hydrogen generated electricity. By 2050, Poland is estimated to have the greatest share of hydrogen produced electricity, with approximately 17% of the generated electricity coming from hydrogen[28]. Financial support to start biomethane production in Poland are being discussed. In 2019, Poland had 315 biogas plants, producing 3 TWh of biogas in 2019

4.2.5.2 Pathway results

The accumulated costs savings of pathway B compared to A are 35 bn Euro until 2050, of which 12 bn Euro comes from buildings (shell, heating system and energy cost) and 23 bn Euro from infrastructure savings (power and gas grid, generation capacity).

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[26] https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/poland.html

[27] Fuel Cell and Hydrogen Observatory, 2020a

[28] European Hydrogen Backbone. Analysing future demand, supply, and transport of hydrogen. June 2021 via https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf

The infrastructure savings are the largest and mainly caused by the lower peak demand of pathway B to pathway A. In 2030 the difference is 2 GW, and this difference increases to 11 GW in 2050. Numbers are derived from the results of the climate zone, by taking the share of national heat demand within the zone into consideration.

Figure 22 Poland electricity peak reduction in pathway B compared to A

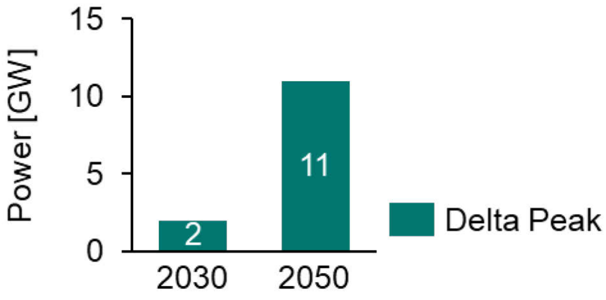
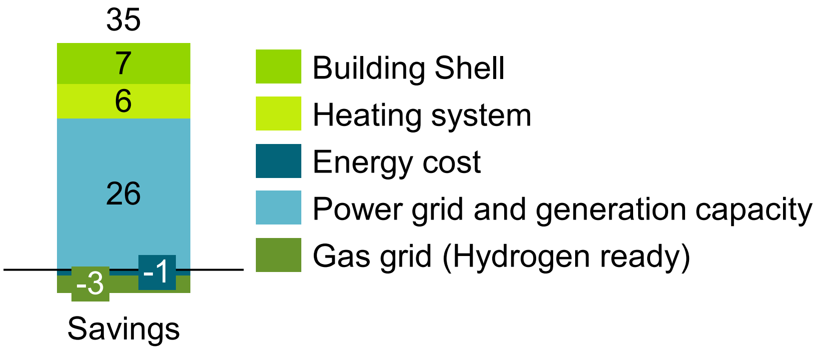


Figure 23 Accumulated Polish cost savings* of pathway B until 2050



** Derived from zone results by applying the share of national heat demand*

5. Conclusion

The comparison of the two pathways leads to the following conclusions:

A broader technology mix provides a cost-efficient pathway for society to achieve the decarbonisation of buildings by 2050

Our analysis shows that the energy and climate targets of the EC are achieved in both pathways, and they would require a fundamental and accelerated change of the heating sector along with significant investments.

In this context, pathway B – by tapping into the potential of several different heating technologies and energy carriers – requires lower investment costs and compared to pathway A, saves money to the end consumers and society: in total almost 530 bn Euro by 2050, making it more feasible and socially acceptable. These savings result from lower investments needed in the infrastructure, building shell and heating system. The heating technology mix chosen has impacts on the infrastructure costs. Here, we considered additional costs for the electricity system – on both: grid and generation capacity – during peaks caused by the heating needs during a dark, windless winter week (Dunkelflaute), when there is very limited generation of renewable electricity[29]. Investments into the gas infrastructure, due to the use of hydrogen, are also considered; but their impact is limited compared to the needs of the electricity system and a significant share of biomethane is used.

The resulting set of solutions proposed by the broader technology mix of pathway B enables the reduction of the additional electricity peak demand by over 50% in the year 2050, compared to pathway A. This leads, cumulated until 2050, to 340 bn EUR savings for power grid extensions and additional generation capacity. In comparison, the higher share of hydrogen used in pathway B demands the retrofitting of the gas distribution system to enable dedicated hydrogen pipelines. The estimated costs are 50 bn Euro[30] until 2050.

Fast replacement of inefficient heating systems, efficiency measures, hydronic heat pumps and hybrids are key to reach the 2030 climate targets

The heating sector – as a consumer of 33%[31] of total natural gas in the EU today – is spearheading the efforts to reduce natural gas demand. Cutting gas consumption has become even more urgent, following the war in Ukraine and the consequent REPowerEU communication. The two decarbonisation pathways show how the decarbonisation targets can be achieved by a mix of measures: efficiency increase, accelerating replacement of inefficient boilers, the accelerated rollout of hydronic heat pumps, hybrid systems and hybridisation as well as the cost-effective use of renewable gases. The amount of natural gas consumed in 2030 is only 55% of today's natural gas demand (pathway B).

Building shell efficiency measures are effective in the long term (2050) but are not able to play the dominant role in achieving the short-term targets of 2030. By doubling the renovation rate a demand reduction of around 10% is reached until 2030, but much more is needed. To achieve the necessary emission reductions, it is also required to significantly increase replacement rates of heating systems to 5% by 2025 and up to 6% by 2030 in combination with a focus of replacing old and inefficient systems. Fully electric heat pumps

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[29] The mentioned requirements are entirely due to the electrification of heating. As such, it does not consider the investments needed for the electrification of other end uses, i.e.: transport or renewable installations, i.e.: PV

[30] it should be considered that parts of the retrofitting might be necessary for industry, like SMEs that are not connected to the gas transmission system or happen anyways around so called 'hydrogen valleys'

[31] Only residential sector (ACER, https://www.acer.europa.eu/gas-factsheet)

will achieve a significant reduction in emissions and dependency from fossil fuels. However, their installation is currently not suitable for every building, since some buildings may need retrofits that entail large investment cost, and the power system is not yet dimensioned to cope with potential high electricity peaks in windless winter weeks.

Therefore, a broader mix of heating technologies and energy carriers are needed – provided they are fully compatible with the decarbonisation objectives. The rollout of new hybrid heat pumps and the hybridisation of existing efficient condensing boilers will have a special role to play, as they allow for a quick reduction in gas demand without creating additional strain on the electricity system. In fact, during peak times hybrid systems can shift entirely to an increasing share of green gaseous fuels, thereby causing no additional peak power demand. As such, the impact of electrification of heating on additional system adequacy is reduced significantly. When, at a later stage, additional energy efficiency measures in the building are implemented, the heat pumps can operate without the support of a boiler.

One of the major elements towards net zero 2050 is the decrease of the overall energy demand of buildings. Therefore, the doubling of the renovation rate, based on equivalent deep renovations, is essential in both pathways to achieve the sector targets of all buildings as specified in the energy performance of buildings directive by 2050.

Other heating technologies like micro cogeneration (e.g., fuel cells), thermally driven heat pumps, biomass boilers and green liquid fuel boilers can also contribute significantly to the decarbonisation of buildings, based on different use cases. Furthermore, the reduction in heat demand – and preparation of the building stock for heat pump applications – is supported by underfloor heating and other efficient low temperature heat emitters.

Such increase of renovation of building envelope and replacement of old and inefficient heaters will entail a growing need for additional workforce. Both installers and builders will be required. In particular, heat pump installers are needed in order to make the climate target plan goals happen. Moreover, pathway B requires a lower number of additional construction workers than today, due to the lower renovation depth needed.

Green gases play an important role in the decarbonisation of buildings

In this study, the use of green gases for heating is factored in both pathways but plays a more important role in pathway B. Green gases will not substitute fossil fuels on a one-to-one basis. This is explained by several factors, notably availability and costs, but also to a major shift in the energy demand of buildings, which is expected to decrease significantly. This reduction will come from reinforced energy efficiency measures and more renovation, while efficient technologies, especially heat pumps – as standalone and in a hybrid setup – will increasingly be phased in through accelerated electrification.

It is to be considered that different sectors may compete for the available green gases; the heating sector, however, could be a driver for supply and cost decrease during early stages of hydrogen supply. Important to note, that the heating sector is already today capable of taking on a significant share of hydrogen[32]. The REPowerEU[33] target for biomethane supply in 2030 is around 350 TWh (35 bcm), while the increased hydrogen supply targets over 600 TWh by 2030 and blending to the distribution grid is suggested. It is therefore assumed that, by 2030, the building sector could receive a significant share of all biomethane supply (ca. 40%), also because of the often-decentralised nature of biomethane production, and smaller

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[32] *Decarbonising the gas value chain, challenges solutions and recommendations* (2021) https://entsog.eu/sites/default/files/2022-02/Prime-Movers-Group-GQ%20and%20H2_SG2%20report_FINAL.pdf

[33] https://energy.ec.europa.eu/system/files/2022-05/SWD_2022_230_1_EN_autre_document_travail_service_part1_v3.pdf

shares of overall hydrogen supply (around 5 - 10% in pathway B). By 2050 Pathway B requires less than a third of today's consumption of gaseous fuels, with no use of natural gas. The total demand of renewable gases (biomethane and hydrogen) will amount to 395 TWh / year by then.

Benefits of a broad technology mix for end users

Another benefit of allowing the use of a more balanced technology mix is that it considers the feasibility of heating decarbonisation pathways across different building situations and income groups and allows for tailored and incremental emission reduction solutions. The decarbonisation of the building sector will certainly affect end consumer. A broader technology mix allows citizens to select the best solution for their specific situation if they need a new heating system or implement efficiency measures. Thereby, it allows to tackle individual cases more cost-effectively.

For several buildings, deep renovation and electrification is a very efficient solution. However, hurdles like high upfront investments, workers needed, etc. limit feasibility and actual realisation. For these building situations, demanding early deep renovations and allowing limited options of heating systems carries the risk of bypassing the social reality of the affected end consumers. Full renovation projects entail high initial investments in buildings. Instead, the pathway with a broad technology mix provides a solution that enables lower initial investment cost (e.g.: -50% for hybrid compared to all electric heat pump with relevant upgrades). This allows for a tailored choice of heating system with similar emission reduction potential and can prove to be more efficient from a system viewpoint. A "step-by-step" renovation (staged renovation) is therefore more affordable in certain cases, where lower income groups are involved. It can even accelerate emission reduction because the financial hurdle to act is lowered. This triggers faster and decisive action to reduce energy consumption in the building sector.

6. Policy recommendations

1. **Accelerate the decarbonisation of buildings, through the most cost-effective mix of measures to make it also work for 'hard to abate' buildings and to stay within the remaining carbon budget.**

   The analysis shows that it is key to decarbonise buildings and that it is a complex issue. For each individual building it depends on its starting situation and the individual conditions of the owners and users. Measures include replacement of old heating systems with efficient, renewable-ready, and future-proof technologies, hybridisation, applying demand side measures like thermal improvement of building envelopes and installation of low temperature heat emitters, fuel switch to zero carbon energy carriers, sector coupling and corresponding supply side measures like optimal sizing of both power and gas generation, transmission, distribution and storage capacities.

2. **Enable the use of a broad system mix of highly efficient, renewable-ready and future-proof heating technologies, and safeguard the efficient transformation towards a decarbonised energy system**

   The local development of the energy system (generation, grids) needs to be considered. Therefore, policy instruments should allow customised solutions depending on the starting position, as no “not one size fits all” solution exists. E.g.: heat pumps are a suitable solution for all low temperature ready buildings, while hybrids, future-proof, and renewable-ready boilers are solutions for staged renovations, for buildings with limited options to further improve the building shell.

   Moreover, the individual choices of the heating system have implications on the energy infrastructure and the required energy mix. Therefore, smart policy instruments should steer towards an overall wanted heating market which takes into account the constraints of the overall energy systems and give the flexibility to allow solutions depending on starting position.

   An individual retrofitting pathway is a good option to take the starting position of the building and the individual situation of the owners and users, as well as the local development of the energy system (generation, grids) into account and could show a plan for an efficient step-by-step renovation of a building.

3. **Foster fast replacement (around 6%/year) of inefficient heat generators and optimisation of hydronic heating systems with heat pumps, hybrid heat pump systems, solutions ready for renewable gases and other key heating decarbonisation technologies**

   To reach 2030 goals, exchange of old inefficient heating systems with efficient and renewable-ready technologies, especially heat pumps and hybrid heat pumps is key and should be fostered. This should be additionally supported with solutions ready for renewable gases and other key heating decarbonisation technologies. They include renewable-ready boilers, thermally driven heat pumps, biomass boilers, micro-cogeneration units and fuel cells, as well as solar thermal systems.

4. **Support the necessary upfront investments for higher efficiency in buildings, efficient and renewable-ready heating systems, and the energy system to achieve an affordable transition for the end users.**

   Both pathways show that the decarbonisation of the building sector is an extensive transformation and requires large upfront investments in all kinds of different measure. Therefore, policy instruments should ensure constant high investments in decarbonisation technologies.

5. **Ensure that the necessary qualified work force is available, thanks to private and public sector training and reskilling initiatives**

   Both pathways require a large increase of qualified workforce, therefore the development of training and qualification schemes for installers and installation companies shall be fostered.

6. **With regards to the building envelope, it is important to aim for the most cost-effective energy efficiency measures, with a view to achieving the desired standards of the energy performance of buildings directive**

   Policy instruments should incentivise investments targeting cost-effective and more ambitious efficiency levels for building elements.

7. **Stimulate the ramp up of renewable electricity and mainstream the assessment of the impacts of electrification of heating and its potential for demand side flexibility into network planning**

   Electrification requires the availability of renewable electricity. This also requires the adaptation of power distribution infrastructure and flexible generation capacity, as well as fully tapping into the potential of demand side flexibility and system integration.

8. **Stimulate the ramp up of green gases and ensure the availability of well dosed volumes for the heating sector to reach 2030 and 2050 goals. Drive the adaptation of power and gas distribution infrastructure in a logic of system efficiency and sector integration. Where relevant, support further involvement of local grid operators in regional planning**

   Pathway B, which is from the societal perspective more suitable, entails the ramp up of biomethane and other green gases to meet the 2030 goals and to decrease dependency on Russian gas. Both also requires the adaptation of power and gas distribution infrastructure, where necessary and reasonable.

9. **Through product and climate policies (eco-design and energy labelling) support innovation and deployment of highly efficient heating technologies, ready for zero carbon energy carriers, including “readiness” to run on hydrogen**

   The policy framework should contribute to the transition towards future-proof technologies, capable to operate on green energy carriers, with a view to matching different types of buildings and local needs. The goal is that investments are "fit" for the decarbonisation pathway, without creating lock-in effects.

10. **Ensure that high efficiency of heating systems is guaranteed in operation**

    This can be seen as a key element for a just, affordable energy cost and reasonable payback of investment cost premium of zero emission heating systems.

Appendix A. **Inputs BEAM model**

A.1 Reference buildings

A.1.1 Definition of refence buildings

In the residential sector reference buildings per Reference Zone and for existing and new buildings have been developed based on the TABULA[34] reference buildings of each Member State for:

- Single Family House (SFH)
- Small Multi Family House (SMFH)
- Large Multi Family House (SMFH)

The following tables show the main geometry parameters for the residential reference buildings (existing and new buildings).

Table 2: Single Family House (SFH), existing buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	106	126	187	159	157	m²
Number of dwellings	1	1	1	1	1	-
Average room height	2.7	2.7	2.7	2.7	2.7	m
Exterior walls	153	120	158	200	165	m²
Windows	22	25	36	28	22	m²
Cellar ceiling	106	73	114	122	83	m²
Roof/ Upper Ceiling	112	79	129	127	88	m²

Table 3: Small Multi Family House (SMFH), existing buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	455	503	391	427	633	m²
Number of dwellings	6	6	5	4	6	-
Average room height	2.7	2.7	2.7	2.7	2.7	m
Exterior walls	364	383	397	504	685	m²
Windows	104	92	90	89	87	m²
Cellar ceiling	176	191	171	189	251	m²
Roof/ Upper Ceiling	211	205	171	209	278	m²

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[34] TABULA; EPISCOPE (2021): *Building Typology*. Available online at https://episcope.eu/building-typology/, accessed 1/29/2021.

Table 4: Large Multi Family House (LMFH), existing buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	1,418	2,333	3,585	1,729	1,858	m²
Number of dwellings	17	33	74	24	23	-
Average room height	2.7	2.7	2.7	2.7	2.7	m
Exterior walls	862	1,439	2,056	1,262	1,479	m²
Windows	247	428	850	377	265	m²
Cellar ceiling	491	473	544	402	392	m²
Roof/ Upper Ceiling	494	481	579	442	386	m²

Table 5: Single Family House (SFH), new buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	112	132	229	272	138	m²
Number of dwellings	1	1	2	1	1	-
Average room height	2.6	2.6	2.6	2.6	2.6	m
Exterior walls	188	139	227	237	145	m²
Windows	25	25	43	40	21	m²
Cellar ceiling	116	82	121	190	89	m²
Roof/ Upper Ceiling	118	86	147	201	90	m²

Table 6: Small Multi Family House (SMFH), new buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	409	419	409	399	637	m²
Number of dwellings	5	7	5	4	8	-
Average room height	2.6	2.6	2.6	2.6	2.6	m
Exterior walls	383	395	383	370	611	m²
Windows	72	73	72	71	127	m²
Cellar ceiling	152	191	152	112	159	m²
Roof/ Upper Ceiling	160	191	160	129	159	m²

Table 7: Large Multi Family House (LMFH), new buildings per Reference Zone

Parameter	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Total floor area	1,377	2,052	6,565	2,390	2,477	m²
Number of dwellings	16	27	153	34	29	-
Average room height	2.6	2.6	2.6	2.6	2.6	m
Exterior walls	868	1,216	3,432	1,274	1,821	m²
Windows	231	370	1,744	657	337	m²
Cellar ceiling	484	445	883	499	472	m²
Roof/ Upper Ceiling	487	445	933	611	460	m²

Non-residential Reference Buildings

In the non-residential sector reference buildings have been developed along Annex I.5 of the EPBD[35]:

- Office Building (OFB)
- Trade and Retail Building (TRB)
- Education Building (EDB)
- Touristic and Health Buildings (TOB_HEB)
- Other Non-Residential Buildings (ONB)

The following table shows the main geometry parameters for the non-residential reference buildings based on the last EPBD Impact Assessment.[36]

Table 8: Non-residential reference buildings

Parameter	Office (OFB)	Trade (TRB)	Education (EDB)	Touristic/Health (TOB_HEB)	Other (ONB)	Unit
Total floor area	1,801	1,448	2,552	3,694	2,434	m²
Average room height	2.6	3.6	2.6	2.8	3	m
Exterior walls	277	302	318	691	682	m²
Windows	150	130	106	229	201	m²
Cellar ceiling	360	724	1216	964	507	m²
Roof/ Upper Ceiling	360	724	1216	964	507	m²

A.1.2 Building shell efficiency levels

The building shell efficiency levels considered are differentiated per Reference Zone (and age group (AG)). The considered status quo levels, retrofit levels and new construction levels of the buildings in the stock are:

Status quo levels

- not renovated
- already renovated

Retrofit levels

- retrofit ambitious
- retrofit restricted
- retrofit standard
- retrofit zeb standard
- retrofit zeb ambitious

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[35] EU (2018): *Consolidated version of Directive (EU) 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). EPBD, revised* amended by Directive (EU) 2018/844 of the European Parliament and of the Council of 5/30/2018 and Regulation (EU) 2018/1999 of the European Parliament and of the Council of 12/11/2018.

Note: Hospitals and hotels and restaurants are listed under Touristic/Health buildings (TOB_HEB). Sport facilities are addressed with other non-res buildings (ONB).

[36] Boermans, Thomas; Bettgenhäuser, Kjell; Ashok, John; Grözinger, Jan (2016): *Ex-ante evaluation and assessment of policy options for the EPBD. Final report*. ECOFYS, t. engineering sweco. Edited by European Commission (EC). Brussels.

New construction levels

- new standard
- new zeb

The tables showing the corresponding building shell efficiency levels for the residential buildings are followed by the tables for the Non-Residential Buildings.

Table 9: Building shell efficiency per Reference Zone and Age Group – Residential Buildings, not renovated[37]

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Pre 1945 not renovated						
Wall	0.70	1.90	1.40	1.68	1.80	W/m²K
Window	2.82	4.13	3.91	2.57	5.32	W/m²K
Floor	0.55	1.72	1.66	1.21	1.94	W/m²K
Roof	0.46	2.08	0.99	1.29	2.21	W/m²K
1945-1990 not renovated						
Wall	0.51	1.35	1.07	1.47	1.63	W/m²K
Window	2.51	3.79	3.00	2.49	4.90	W/m²K
Floor	0.37	1.31	1.20	1.09	1.87	W/m²K
Roof	0.31	1.34	0.74	1.13	1.70	W/m²K
1991-2020 not renovated						
Wall	0.26	0.44	0.48	0.80	1.08	W/m²K
Window	1.75	2.02	2.05	1.76	3.45	W/m²K
Floor	0.26	0.42	0.70	0.72	1.06	W/m²K
Roof	0.16	0.32	0.31	0.48	0.95	W/m²K

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[37] In addition to the indicated U-values, heat bridges of 0.15 W/m²K are considered in the “not renovated” level.

Table 10: Building shell efficiency per Reference Zone and Age Group – Non-Residential Buildings, not renovated[38, 39]

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Pre 1945 not renovated						
Wall	0.88	1.63	1.19	1.53	2.11	W/m²K
Window	2.76	3.71	4.02	2.85	5.53	W/m²K
Floor	0.53	1.46	1.45	1.10	1.64	W/m²K
Roof	0.43	1.39	0.98	1.29	1.65	W/m²K
1945-1990 not renovated						
Wall	0.52	1.47	1.05	1.27	1.72	W/m²K
Window	2.51	3.85	3.02	2.80	5.10	W/m²K
Floor	0.39	1.28	1.07	1.02	1.32	W/m²K
Roof	0.34	1.17	0.72	1.11	1.48	W/m²K
1991-2020 not renovated						
Wall	0.30	0.47	0.38	0.74	0.83	W/m²K
Window	1.60	1.92	1.91	2.24	3.05	W/m²K
Floor	0.33	0.46	0.77	0.70	0.89	W/m²K
Roof	0.16	0.34	0.20	0.52	0.65	W/m²K

Table 11: Building shell efficiency per Reference Zone and Age Group – Residential Buildings, already renovated[40, 41]

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Pre 1945 already renovated						
Wall	0.24	0.55	0.52	0.72	1.63	W/m²K
Window	1.75	2.24	3.91	2.57	4.70	W/m²K
Floor	0.25	0.54	0.56	0.60	1.27	W/m²K
Roof	0.17	0.35	0.37	0.46	1.20	W/m²K
1945-1990 already renovated						
Wall	0.21	0.45	0.43	0.60	1.26	W/m²K
Window	1.40	1.76	2.68	2.19	3.45	W/m²K
Floor	0.21	0.47	0.53	0.49	0.94	W/m²K
Roof	0.17	0.28	0.33	0.36	0.85	W/m²K

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[38] iNSPIRe, 2014

[39] In addition to the indicated U-values, heat bridges of 0.15 W/m²K are considered in the “not renovated” level.

[40] iNSPIRe, 2014

[41] In addition to the indicated U-values, heat bridges of 0.10 W/m²K are considered in the “already renovated” level.

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
1991-2020 already renovated						
Wall	0.17	0.33	0.33	0.50	0.84	W/m²K
Window	1.00	1.20	1.90	1.76	2.00	W/m²K
Floor	0.17	0.38	0.50	0.39	0.56	W/m²K
Roof	0.16	0.20	0.28	0.28	0.45	W/m²K

Table 12: Building shell efficiency per Reference Zone and Age Group – Non-Residential Buildings, retrofit ambitious[42], [43]

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Pre 1945 Already renovated						
Wall	0.24	0.55	0.52	0.72	1.63	W/m²K
Window	1.75	2.24	4.02	2.85	4.70	W/m²K
Floor	0.25	0.54	0.56	0.60	1.27	W/m²K
Roof	0.17	0.35	0.37	0.46	1.20	W/m²K
1945-1990 Already renovated						
Wall	0.22	0.45	0.43	0.60	1.26	W/m²K
Window	1.54	1.76	2.69	2.36	3.45	W/m²K
Floor	0.21	0.47	0.53	0.49	0.94	W/m²K
Roof	0.16	0.28	0.33	0.36	0.85	W/m²K
1991-2020 Already renovated						
Wall	0.20	0.33	0.33	0.50	0.83	W/m²K
Window	1.30	1.20	1.90	1.90	2.00	W/m²K
Floor	0.17	0.38	0.50	0.39	0.56	W/m²K
Roof	0.14	0.20	0.20	0.28	0.45	W/m²K

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[42] iNSPIRe, 2014

[43] In addition to the indicated U-values, heat bridges of 0.10 W/m²K are considered in the “already renovated” level.

Table 13: Building shell efficiency per Reference Zone – Residential and Non-Residential Buildings, retrofit levels[44],

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Already renovated [45]						
Wall	0.24	0.26	0.24	0.27	0.76	W/m²K
Window	1.00	1.47	1.24	1.14	3.71	W/m²K
Floor	0.31	0.28	0.32	0.30	0.64	W/m²K
Roof	0.15	0.19	0.16	0.25	0.68	W/m²K
retrofit restricted[46]						
Wall	*Depend on the respective „not renovated" start level.*					W/m²K
Window	*Depend on the respective „not renovated" start level.*					W/m²K
Floor	0.28	0.36	0.28	0.36	1.20	W/m²K
Roof	0.10	0.12	0.10	0.12	0.40	W/m²K
retrofit standard[46]						
Wall	*Depend on the respective „retrofit ambitious" start level.*					W/m²K
Window	*Depend on the respective „retrofit ambitious" start level.*					W/m²K
Floor	0.28	0.36	0.28	0.36	1.20	W/m²K
Roof	0.10	0.12	0.10	0.12	0.40	W/m²K
retrofit zeb[46, 47]						
Wall	0.14	0.18	0.14	0.18	0.60	W/m²K
Window	0.65	0.85	0.65	0.85	1.25	W/m²K
Floor	0.28	0.36	0.28	0.36	1.20	W/m²K
Roof	0.10	0.12	0.10	0.12	0.40	W/m²K

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[44] iNSPIRe, 2014

[45] In addition to the indicated U-values, heat bridges of 0.10 W/m²K are considered in the "retrofit average" level.

[46] In addition to the indicated U-values, heat bridges of 0.05 W/m²K are considered in the "retrofit zeb" levels.

[47] Automatic shading devices (except in zone N) are included in the „retrofit zeb" standard.

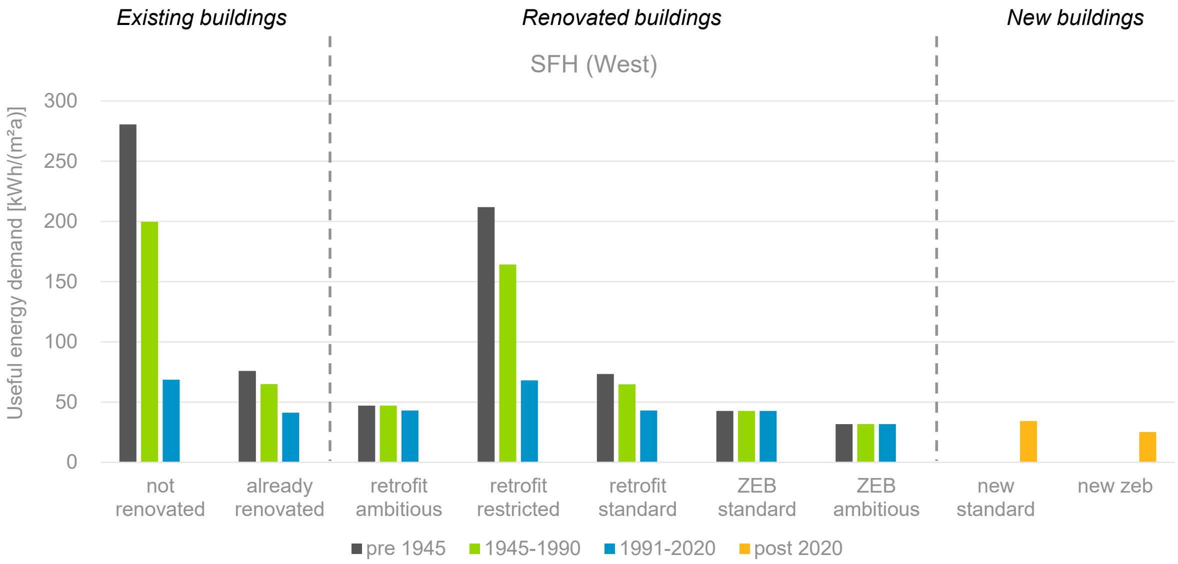
Table 14: Building shell efficiency per Reference Zone – Residential and Non-Residential Buildings, new construction levels[48]

Building shell component	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
new standard[49]						
Wall	0.19	0.20	0.19	0.21	0.60	W/m²K
Window	0.88	1.28	1.08	0.99	3.25	W/m²K
Floor	0.27	0.25	0.28	0.26	0.56	W/m²K
Roof	0.13	0.17	0.14	0.22	0.60	W/m²K
new zeb[50, 51]						
Wall	0.14	0.18	0.14	0.18	0.60	W/m²K
Window	0.65	0.85	0.65	0.85	1.25	W/m²K
Floor	0.28	0.36	0.28	0.36	1.20	W/m²K
Roof	0.10	0.12	0.10	0.12	0.40	W/m²K

A.1.3 Building shell efficiency (exemplary for zone West)

In addition to the definition of reference buildings, exemplary results for the resulting energy needs are shown here.

Figure 24 Single family house (SFH)



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[48] iNSPIRe, 2014

[49] In addition to the indicated U-values, heat bridges of 0.05 W/m²K are considered in the “new standard” level.

[50] In addition to the indicated U-values, heat bridges of 0.00 W/m²K are considered in the “new zeb” level.

[51] Automatic shading devices (except in zone N) and ventilation systems with heat recovery are included in the „new zeb“ standard.

Figure 25 Large multifamily house (LMFH)

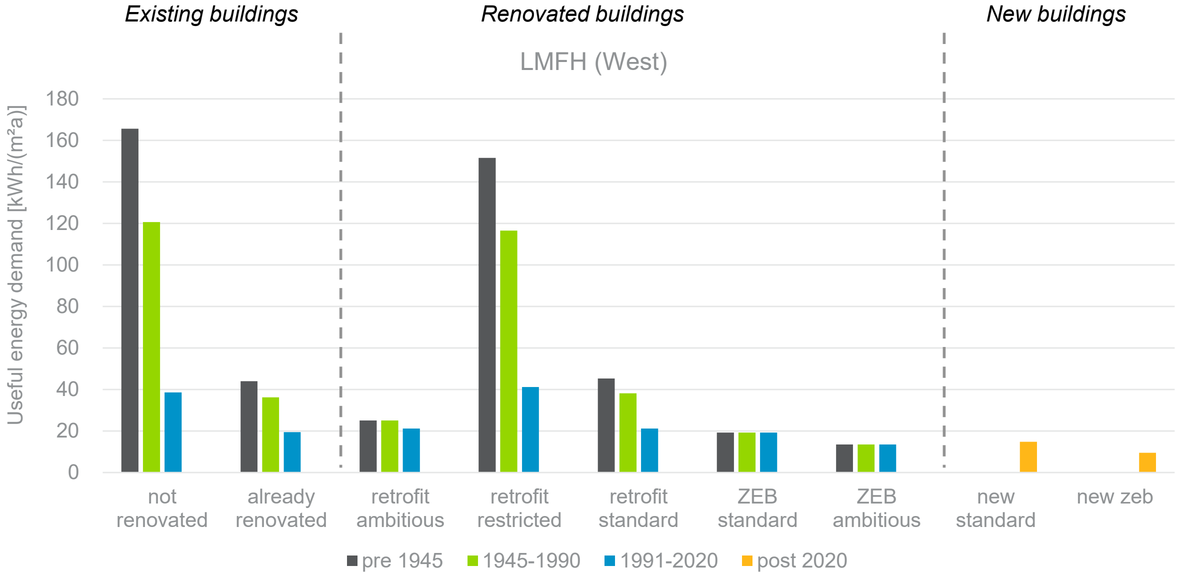
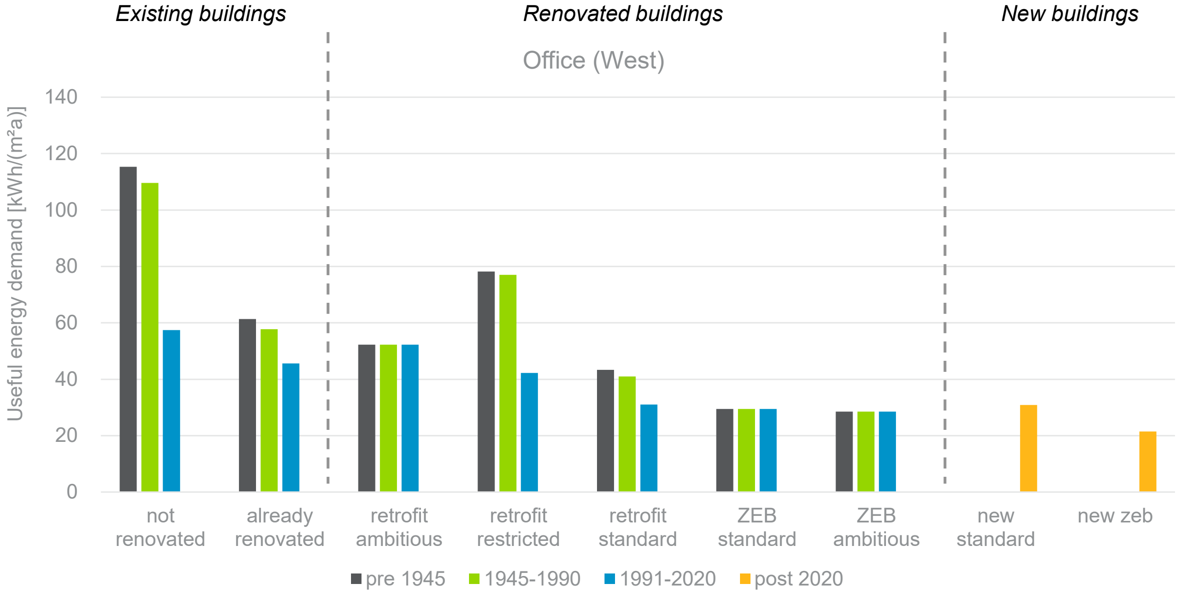


Figure 26 Office building



A.2 Economic assumptions

A.2.1 Investment cost

The investment costs used in this study are based on the investments used in the EPBD IA 2016. Extrapolation to 2020 costs has been implemented using the Eurostat Construction Cost Index (CCI) developments. The following table shows the resulting extrapolation factors per Reference Zone.

In general, investment costs in this study are defined as additional energy related costs. This means that only additional cost for measures that have an impact on the energy performance of the building are considered. General costs (e.g. scaffolding, plaster or painting) are considered to be occurring anyhow since an energy renovation by this definition is always coupled to a maintenance measure (coupling principle). As an effect, the rate of renovation activities cannot go beyond the rate of maintenance when assuming only additional energy related costs. In case higher renovation rates are assumed, at least a share of the general and maintenance costs needs to be taken into account for the energy renovation (which is not the case in this study).

Table 15 Investment cost extrapolation factors

	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Construction Cost Index extrapolation factors 2015-2019	1.11	1.13	1.10	1.23	1.03	-

A.2.2 Energy prices

Table 16 Energy price per zone

	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Residential energy prices						
Gas	0.107	0.069	0.050	0.038	0.074	Euro/kWh
Oil	0.156	0.084	0.075	0.037	0.104	Euro/kWh
District heat	0.153	0.107	0.072	0.063	0.114	Euro/kWh
Wood	0.119	0.073	0.044	0.043	0.071	Euro/kWh
Coal	0.082	0.063	0.039	0.029	0.038	Euro/kWh
Electricity	0.229	0.248	0.145	0.125	0.227	Euro/kWh
Non-Residential energy prices						
Gas	0.029	0.028	0.032	0.030	0.030	Euro/kWh
Oil	0.042	0.034	0.048	0.029	0.042	Euro/kWh
District heat	0.041	0.043	0.046	0.049	0.046	Euro/kWh
Wood	0.032	0.030	0.028	0.033	0.029	Euro/kWh
Coal	0.022	0.025	0.025	0.022	0.015	Euro/kWh
Electricity	0.138	0.159	0.110	0.122	0.159	Euro/kWh

Figure 27 Applied energy price index 2020-2050 (example for Western zone)

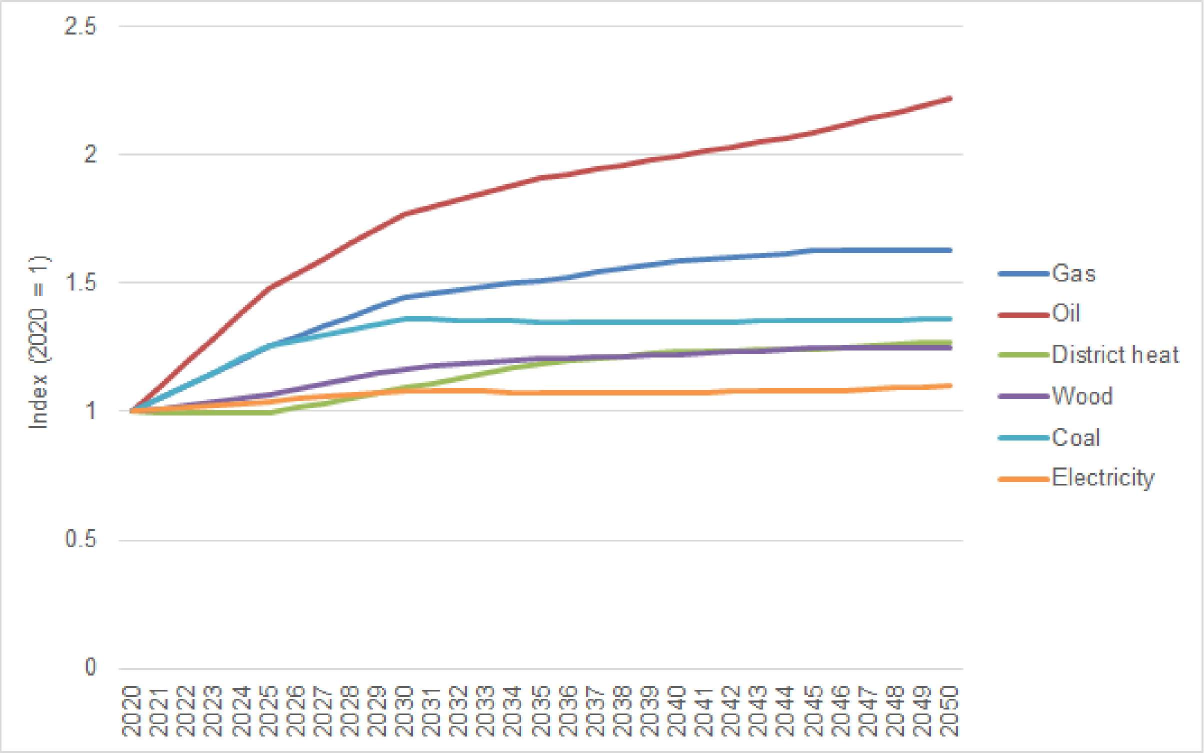
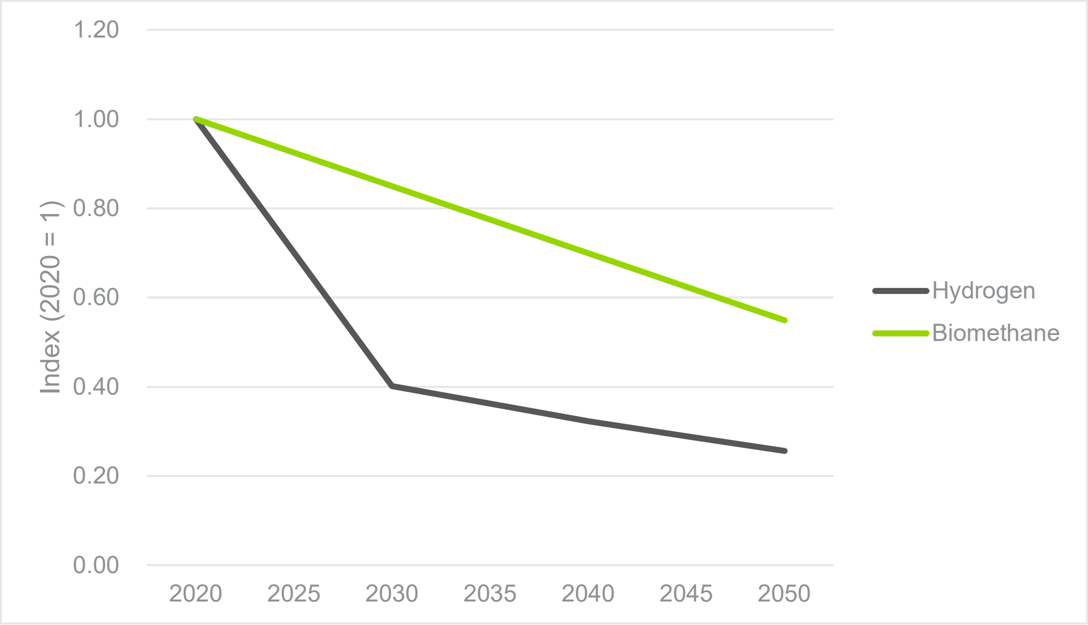


Figure 28 Applied energy price index 2020-2050 for 'new fuels'



A.3 Other inputs

A.3.1 Emission factors

Table 17 Emission factors in start year per zone

Energy carrier	Northern	Western	North-Eastern	South-Eastern	Southern	Unit
Gas	202	202	202	202	202	gCO_2/kWh
Oil	267	267	267	267	267	gCO_2/kWh
District heat	136	240	248	288	206	gCO_2/kWh
Wood	0	0	0	0	0	gCO_2/kWh
Coal	341	341	341	341	341	gCO_2/kWh
Electricity	65	211	563	388	337	gCO_2/kWh
HP electricity	81	208	367	304	281	gCO_2/kWh
Hydrogen	65	65	65	65	65	gCO_2/kWh
Biomethane	50	50	50	50	50	gCO_2/kWh

A.4 Additional output

A.4.1 Indication for the development of the number of heating systems per Pathway

Table 18: Indication on number of heating systems in the building stock (Pathway A)

in Mio.	2020	2025	2030	2035	2040	2045	2050
Gaseous fuel, c	33	44	42	30	19	11	0
Gaseous fuel, nc	40	26	14	9	6	3	0
Liquid fuel, c	2	1	1	0	0	0	0
Liquid fuel, nc	15	10	5	3	2	1	0
Biomass boiler/stoves	8	9	11	10	10	11	11
District heat	7	9	11	11	12	14	16
Dir. electric boilers	2	1	1	1	1	0	0
HP (all electric)	5	14	32	52	69	80	91
Hybrid-HP	0	1	3	4	4	2	3
Others*	0	0	1	1	2	2	2

*Other heating systems include fuel cells/micro-CHPs, thermally-driven heat pumps

Table 19: Indication on number of heating systems in the building stock (Pathway B)

in Mio.	2020	2025	2030	2035	2040	2045	2050
Gaseous fuel, c	33	46	48	40	34	29	26
Gaseous fuel, nc	40	24	11	5	0	0	0
Liquid fuel, c	2	1	1	1	1	1	1
Liquid fuel, nc	15	9	4	2	1	0	0
Biomass boiler/stoves	8	9	10	9	9	9	9
District heat	7	8	10	11	11	12	13
Dir. electric boilers	2	2	1	1	1	1	1
HP (all electric)	5	10	18	26	32	34	37
Hybrid-HP	0	5	17	27	32	31	30
Others*	0	1	2	3	4	4	5

*Other heating systems include fuel cells/micro-CHPs, thermally-driven heat pumps

A.4.2 Social considerations

Figure 29 Case 1 (heat pump + 1-step renovation) vs. case 2 (heat pump + staged renovation)

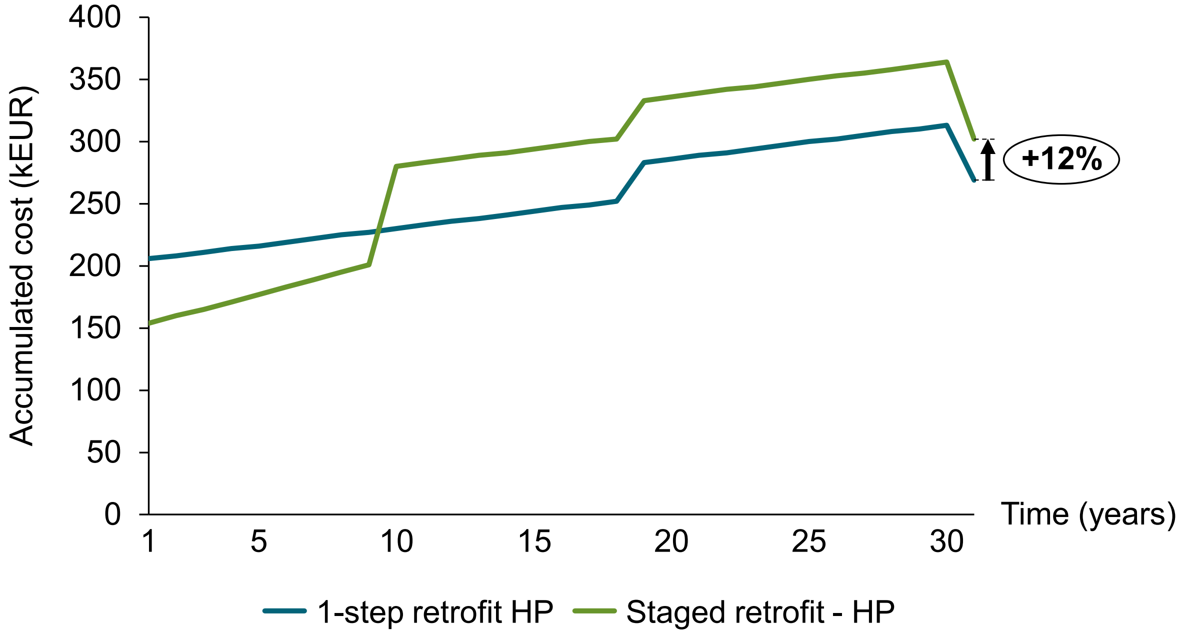
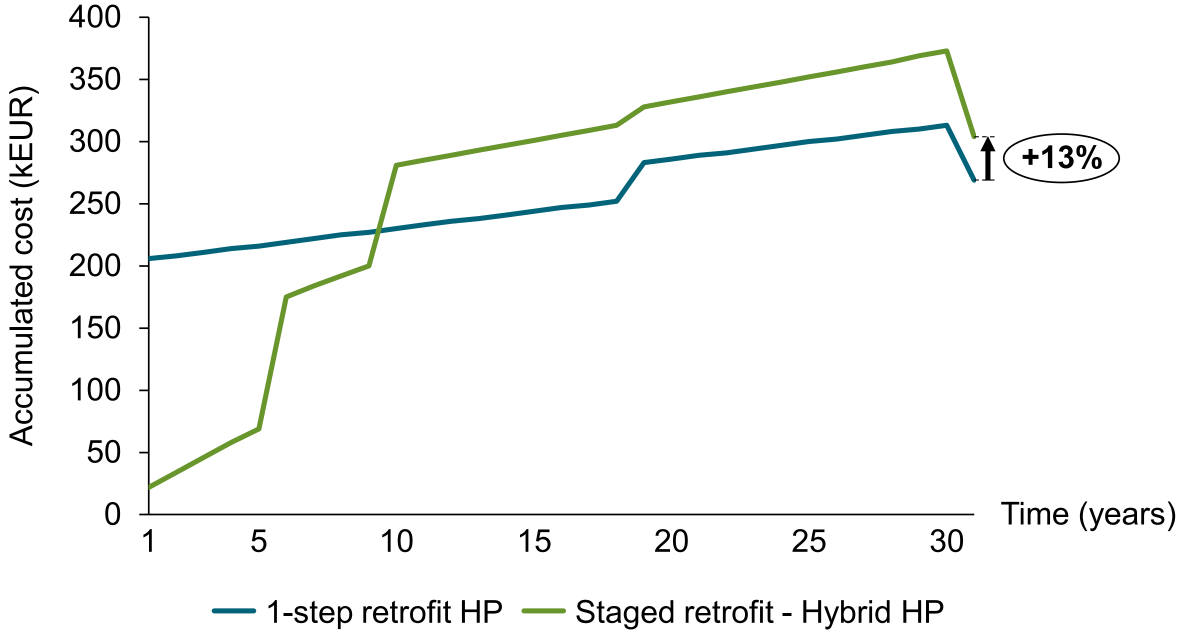


Figure 30 Case 1 (heat pump + 1-step renovation) vs. case 4 (condensing boiler + staged renovation)



Appendix B. **Regional aspects**

The situation in EU Member states is highly heterogeneous as regards to the building stock, heating and cooling needs, energy system characteristics and energy carriers. Regional aspects as well as the reality of the building stock must be taken into consideration.
There is **no one size fits all solution** for all member states, regional areas and buildings of the EU.
◊ ***Detailed insights into the situation of 5 member states with respect to their current goals, infrastructure and resources are presented in country fact sheets***

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