Zero carbon buildings 2050

Background report

CE Delft

Committed to the Environment

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The report was prepared by (CE Delft): Katja Kruit, Joeri Vendrik, Pien van Berkel, Fenneke van der Poll and Frans Rooijers
Climact (modelling): Quentin Jossen, Hugues de Meulemeester

Project coordination (The European Climate Foundation): Renée Bruel, Stijn Carton, Adeline Rochet, Ting Zhang

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Further information on this study can be obtained from the contact person, Katja Kruit (CE Delft)

CE Delft
Committed to the Environment

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The willingness of these organisations and experts to be consulted in the course of this study should not be taken as an endorsement of all its analysis and conclusions.

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Executive summary

This report highlights the importance and urgency of addressing residential buildings in achieving net-zero greenhouse gas (GHG) emissions targets in 2050 and identifies key policy levers at the EU, national and local level and the potential of those levers to reduce GHG emissions.

The GHG emissions from the built environment consist of operational emissions from energy use for heating, cooling, hot water, cooking, lighting and appliances, as well as embedded emissions associated with materials and construction processes over the whole lifecycle of a building or energy infrastructure.

Under current policies, annual emissions from residential buildings will decrease by only 30% by 2050. This figure was calculated based on the European reference scenario (EC, 2016a) and (Röck, et al., 2020).

For this study a scenario was developed by Climact using the EUCalc model to identify the measures needed to move to zero GHG emissions in 2050. These measures have been grouped into five ‘emissions target areas’:

- **Building envelope**: Improving the envelope of existing and new buildings to reduce energy demand for heating and cooling. A renovation rate of 3% per year and average energy savings of 55% were assumed. Because of the materials used, building envelope measures also lead to an increased embedded emissions.
- **Heating fuel switch**: Decarbonising residual heating demand by switching to zero-carbon energy carriers for heating (renewable electricity, district heating, zero-carbon gas, sustainable biomass). This switch encompasses decarbonisation of the energy carrier (fuel) as well as a different heating system in the building, and often also new or adapted energy infrastructure.
- **Home appliance efficiency**: Replacing electrical appliances by more efficient ones.
- **Renewable electricity**: Decarbonising residual electricity use by switching to 100% renewable power.
- **Decarbonised building materials**: Using recycled and zero-carbon materials in construction and renovation and switching to 100% decarbonised industry.

The main barriers to decarbonising buildings are the high investment costs and inconvenience for residents. Both are lowest at particular times: at the end of the economic lifetime of appliances, for example, or on sale or change of tenancy of a home. Policy measures should make full use of these occasions as trigger points for renovation. Because these occasions occur only frequently, such policies are urgently required, so as to not miss these least-cost opportunities.

The building envelope, heating fuel switch and building materials have the greatest decarbonisation potential, but at present are not comprehensively covered by regulatory policies at the EU level. A comprehensive policy package therefore needs to be elaborated to address each of these areas at the EU and/or national level, consisting of appropriate regulatory instruments (such as standards and obligations) and pricing instruments, flanked by financial support, funding policies and information campaigns.

To extend and enhance existing policies, a comprehensive policy package needs to be developed and implemented by the EU and by individual member states, comprising:

- Minimum energy performance standards for existing buildings that utilise key moments in the building's lifetime such as sale and change of tenancy.
- Regulatory policies on heating fuels switch and appliances, such as:
  - a cap on CO_2 emissions from energy carriers for energy companies;
  - local or regional heating plans to implement direct electrification of heating and district heating;
  - a phasing out of fossil fuel heating systems;
  - a ban on the use of fossil fuels for heating and cooking in new constructions.
- CO_2-based taxation of energy carriers for heating.
- Emissions requirements over the lifecycle of construction and renovation projects.
- Supporting policies to facilitate the transition, including financial support to mitigate energy poverty.

1 Introduction

This report is the outcome of a study by CE Delft and commissioned by the European Climate Foundation which aims to assess the policies and innovation required to achieve a fully decarbonised EU residential building sector by 2050.

1.1 Background

To achieve the global climate goals of limiting warming to well below 2°C, all sectors of the economy must decarbonise by 2050. Energy use in buildings accounts for 36% of greenhouse gas (GHG) emissions in the EU (EC, 2019a) and are thus one of the largest contributors to EU emissions. Buildings also directly impact the lives and behaviour of all citizens and, with 513.5 million stakeholders, constitute a complex, difficult sector to influence by means of government policy (Eurostat, 2020b).

Scaling up and accelerating the decarbonisation of buildings is an urgent issue, not only because building emissions remain high despite current policies, but also because many buildings in the EU are of low quality, resulting in low living quality and high fuel costs.

As Europe sets out to implement the European Green Deal, starts up its Renovation Wave and revises key Directives, as well as deal with the health and economic crisis caused by COVID-19, this report sets out recommendations for a long-term roadmap of policies that can deliver the essential carbon emission cuts in the buildings sector.

Policies addressing buildings play out at various different levels, from the EU to national, regional and local. As the diversity of the building stock and national circumstances limit what can be achieved at the EU level, this report also looks into policy alternatives at the national level.

1.2 Objective and approach

The overriding objective of this report is to set out a high-level common understanding of what is needed to arrive at a decarbonised building stock by 2050. More specifically, this report aims to:
1. Highlight the importance and urgency of addressing residential buildings in achieving net-zero GHG emissions targets.
2. Identify key policy levers and the potential of those levers to reduce GHG emissions.

The potential for emissions reduction is based on existing data on current and projected emissions from the buildings sector and utilises a zero-emissions scenario developed by Climact using the EUCalc model. These outcomes are used to develop a framework for analysing policy priorities, determine gaps in existing policies and derive policy recommendations.

To illustrate these policy recommendations, examples of national policies were pulled from case studies of policy in Poland, Spain and the Netherlands. Finally, innovation needs were identified in consultation with an expert panel.

1.3 Scope

This is the background document to the Summary Report (CE Delft, 2020) published as part of the European Climate Foundation's Net-Zero 2050 series. For the EU to achieve net-zero GHG emissions the buildings sector must fully decarbonise, i.e. transition to zero GHG emissions. These emissions include not only the operational emissions due to energy use in the use phase of a building, but also the embedded GHG emissions associated with the materials and the construction processes used over the entire lifecycle of the building or energy infrastructure. The scope of this report is the residential sector. Residential buildings account for 75% of all buildings in Europe.

This report provides a high-level outline of the kinds of measures required to achieve full decarbonisation of the residential sector by 2050, focusing on how EU, national and local policies and innovation can be used to steer towards this goal.

1.4 Reading guide

In this report we develop and present a policy roadmap for achieving full decarbonisation of the EU residential buildings sector.

In Chapter 2 we first characterise the EU residential buildings sector and its current and business-as-usual emissions. In Chapter 3 we go on to outline five target areas for decarbonisation, consider potential reduction measures in each and assess their decarbonisation potential. In Chapter 4 we develop a framework for comparing policy instruments, which we use in Chapter 5 to discuss and analyse the existing EU policy setting and its current gaps. In Chapter 6 we present a policy roadmap to bridge these gaps and achieve full decarbonisation. To illustrate existing experiences and lessons from national policies, in Chapter 7 we highlight three country studies. Finally, in Chapter 8, we discuss innovation and policies to incentivise it.

2 EU residential built environment and its emissions

In this chapter we describe the current contours of the EU residential built environment and its emissions.

2.1 Characteristics of EU residential built environment

The EU residential building sector is far from homogenous, but differs widely across and within member states. This holds for the physical characteristics and energy use of the building stock as well as for ownership, making it impossible to discuss the built environment of the EU as a whole. In this and the next section we therefore review the main characteristics of the residential building stock in each member state.

Most residential buildings in the EU-28 are resident-owned. However, there are substantial differences: in some Eastern European countries over 90% are owner-occupied, while in certain Western European countries this figure is less than 60%. The remaining buildings are rented property, a proportion of which is social housing with reduced rent. While the share of rented housing is very low in most Southern and Eastern European countries, most of the rental sector there is social housing (Housing Europe, 2017).

On average, 42% of EU citizens live in single-family homes, with the remainder in multi-family buildings. Again there are substantial differences among member states, though: In certain countries, such as Ireland, the vast majority live in a single-family home (over 90%), while in others, such as Latvia, most people live in flats (over 65%) (Eurostat, 2020c).

In the EU as a whole, the largest share of the population lives in urban areas (40%), followed by suburban (31%) and rural areas (29%). In half the member states, though, the largest share lives in rural areas. Table 1 provides an overview of the aforementioned characteristics for each member state.

Table 1 - Characteristics of residential buildings in the EU-28

Member state	Resident-owned (% of total dwellings)	Reduced rent (% of total dwellings)	Building type (% single-family)	Location		
				Urban	Suburban	Rural
Austria	54%	24%	53%	30%	29%	41%
Belgium	65%	7%	77%	27%	57%	17%
Bulgaria	87%	3%	44%	43%	23%	35%
Croatia	89%	2%	78%	29%	29%	42%
Cyprus	69%	0%	72%	52%	22%	26%
Czech Republic	56%	9%	48%	30%	33%	37%
Denmark	50%	21%	67%	34%	21%	45%
Estonia	82%	2%	38%	41%	17%	43%
Finland	64%	13%	65%	45%	22%	33%
France	58%	17%	66%	38%	25%	38%

Member state	Resident-owned (% of total dwellings)	Reduced rent (% of total dwellings)	Building type (% single-family)	Location		
				Urban	Suburban	Rural
Germany	45%	4%	42%	34%	42%	24%
Greece	74%	5%	39%	50%	24%	27%
Hungary	92%	3%	71%	29%	35%	36%
Ireland	68%	9%	92%	35%	21%	44%
Italy	72%	4%	47%	33%	42%	25%
Latvia	81%	0%	34%	42%	20%	38%
Lithuania	89%	0%	39%	41%	5%	54%
Luxembourg	73%	5%	62%	18%	37%	45%
Malta	76%	0%	46%	50%	43%	8%
Netherlands	60%	30%	75%	44%	41%	15%
Poland	75%	8%	56%	35%	24%	41%
Portugal	74%	2%	54%	43%	30%	27%
Romania	98%	2%	67%	33%	22%	45%
Slovakia	91%	3%	52%	21%	36%	43%
Slovenia	77%	6%	72%	18%	32%	50%
Spain	77%	3%	35%	33%	31%	36%
Sweden	39%	0%	54%	38%	31%	31%
United Kingdom	63%	18%	85%	57%	29%	13%
EU-28	**65%**	**22%**	**42%**	**40%**	**31%**	**29%**

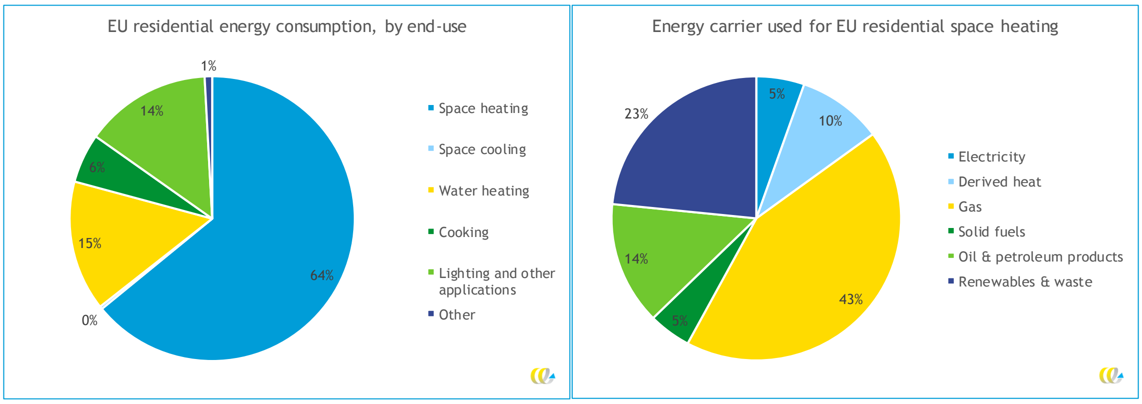
Source: (Eurostat, 2020c; Housing Europe, 2017).

The energy consumption of the residential built environment also varies substantially across EU member states. This is due to a wide range of factors, including the availability of heating fuels and government policies, but one factor stands out as having a major influence on heating and cooling demand: climate, which in our context can be described and quantified using the heating degree days index and the cooling degree days index[1]. A higher heating degree days index corresponds to a higher heating demand and a higher cooling degree days index to a higher cooling demand.

As Figure 1 (left) shows, space heating accounts for almost two-thirds of the energy consumption of the European residential sector, followed by water heating (15%) and electrical appliances (14%). In most member states apart from a few Southern European countries, cooling contributes only marginally to total residential energy use. Figure 1 (right) shows that natural gas is the fuel most widely used for residential space heating, although in several Northern and Eastern European countries this role is played by renewables and waste (in most cases wood).

[1] The heating degree days index is calculated by summing the temperature difference between outside and inside (in the present context: 18°C) for all days with a temperature below 15°C. The cooling degree days index is calculated by summing the temperature difference between outside and inside (here: 21°C) for all days with a temperature above 24°C (Eurostat, 2020c).

Figure 1 - EU residential energy consumption in 2018, by end-use (left) and energy carrier used for space heating (right)



Source: (Eurostat, 2020c).

Table 2 summarises, for each member state, the main characteristics of residential energy use, including the cited climate indicators.

Table 2 - Characteristics of residential energy consumption in 2018 and climate indicators in EU-28

Country	Share of space heating in total energy use	Main energy carrier used for space heating	Heating degree days/year	Cooling degree days/year
Austria	70%	Renewables and wastes (33%)	3,373	27
Belgium	74%	Gas (47%)	2,594	24
Bulgaria	54%	Renewables and Wastes (57%)	2,439	172
Croatia	69%	Renewables and wastes (65%)	2,250	155
Cyprus	*Not available*	*Not available*	626	747
Czech Republic	69%	Renewables and wastes (34%)	3,185	26
Denmark	63%	Renewables and wastes (41%)	3,102	5
Estonia	*Not available*	*Not available*	4,160	9
Finland	66%	Derived heat (34%)	5,408	3
France	66%	Gas (35%)	2,306	60
Germany	67%	Gas (46%)	2,915	25
Greece	56%	Oil & petroleum products (48%)	1,501	335
Hungary	74%	Gas (53%)	2,640	110
Ireland	59%	Oil & petroleum products (48%)	2,724	0
Italy	68%	Gas (60%)	1,798	243
Latvia	66%	Renewables and wastes (53%)	3,970	10
Lithuania	70%	Renewables and wastes (43%)	3,784	12
Luxembourg	79%	Gas (51%)	2,836	30
Malta	44%	Oil & petroleum products (54%)	391	638
Netherlands	64%	Gas (87%)	2,584	17
Poland	66%	Solid fuels (45%)	3,234	22
Portugal	39%	Renewables and wastes (73%)	1,199	260
Romania	63%	Renewables and wastes (54%)	2,861	108
Slovakia	68%	Gas (64%)	3,125	47
Slovenia	64%	Renewables and wastes (59%)	2,725	57
Spain	43%	Renewables and wastes (37%)	1,709	275

Sweden	55%	Derived heat (50%)	5,169	2
United Kingdom	62%	Gas (74%)	2,926	1
EU-28	**64%**	**Gas (43%)**	**2,998**	**95**

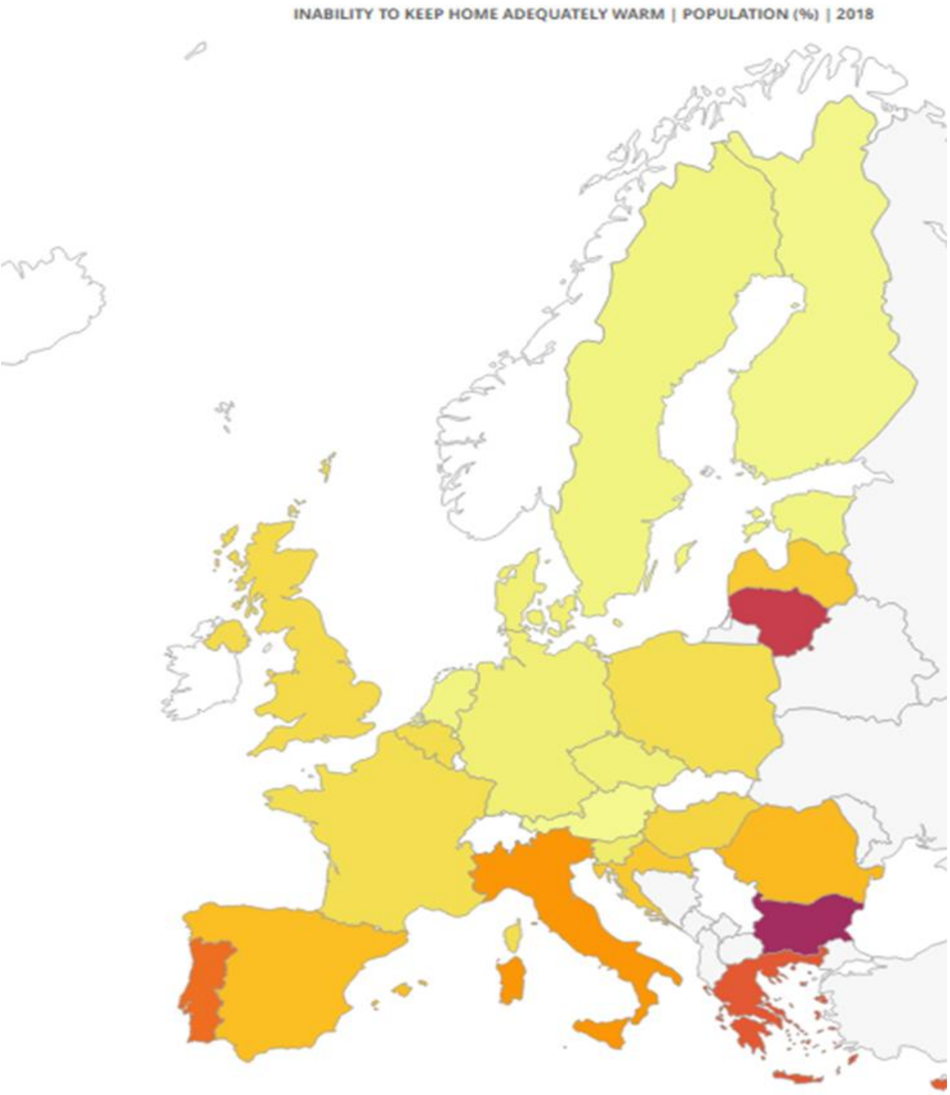
Source: (Eurostat, 2020c).

2.2 Energy poverty

Energy poverty, i.e. a household's inability to afford to pay for its energy needs, derives from a combination of high energy prices, lack of adequate building insulation and low income. Rates of energy poverty differ across the EU: in certain Southern and Eastern European countries, over 20% of households are unable to keep their homes properly warm, while in Northern and Western European countries this is less than 5% (EU Energy Poverty Observatory, ongoing).

When elaborating policies, due allowance must be made for the fact that energy poverty varies by country as well as within countries, so national governments need to take measures accordingly. Policies that impose higher costs on residents should thus be supported by measures to mitigate energy poverty.

Figure 2 – Share of households unable to afford to keep their home adequately warm (2018)



Source: (EU Energy Poverty Observatory, ongoing).

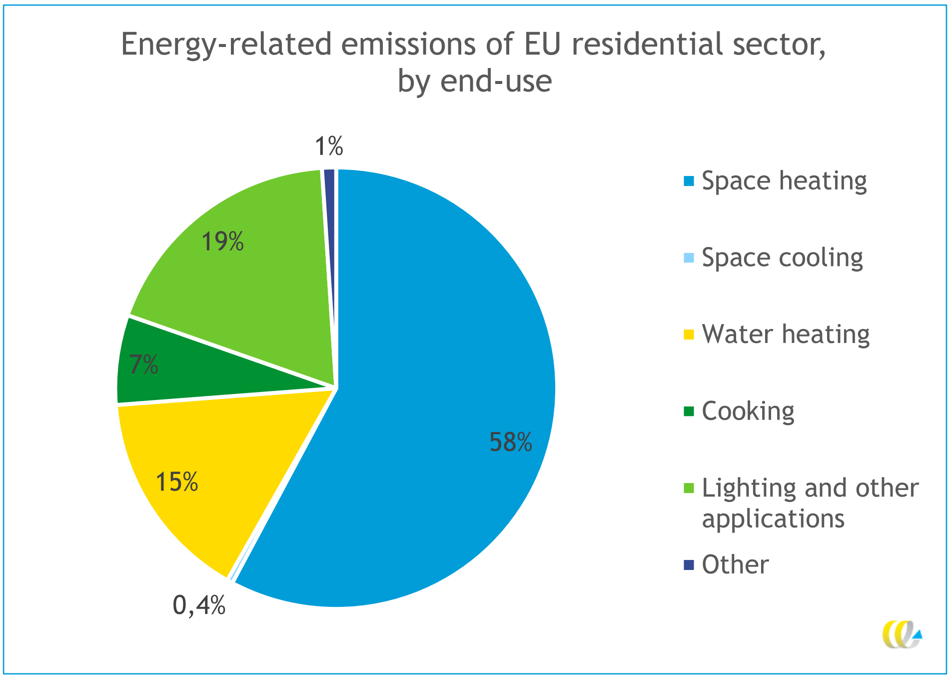
2.3 Emissions of the residential sector

The greenhouse gas emissions of the residential sector are of two types: emissions related to domestic energy use and emissions embedded in construction materials.

Emissions related to energy use

Residential energy use falls into two categories: heating (space heating, water heating, cooking) and electricity use (appliances, lightning, cooling). As we have seen, space heating accounts for almost two-thirds of residential energy demand in the EU and is consequently the main source of GHG emissions. The contribution of the various end-uses to the total GHG emissions of the residential sector is roughly equal to their share in total energy use, though there are minor differences due to different fuel mixes being used for end-uses.

Figure 3 – Energy-related emissions of EU residential sector, by end-use (direct and indirect), calculated using PRIMES data (EC, 2016a) and Eurostat (2020c)



Energy-related emissions vary strongly across countries, owing to both differences in heating demand (climate and building quality) and the heating fuels used. The direct CO_2 emissions per unit energy are highest in countries using primarily fossil fuels like natural gas.

Business-as-usual emissions in 2050

The EU reference scenario of the PRIMES model is a business-as-usual (BAU) scenario for estimating the future development of CO_2 emissions. It is a benchmark model built around predicted development of the EU energy system, transport systems and GHG emissions based on implemented policy and market trends in 2016. The time horizon extends to 2050 and all EU-28 member states are included (EC, 2016a).

Although other scenarios are available, they are not as suitable as a BAU scenario:
- The EUCO scenarios do not model implemented policy, but rather the achievement of 2030 targets, and do not extend to the year 2050.
- The 'Clean Planet for All' Baseline scenario (2018) includes more recent legislation, but projects achievement of 2030 energy and climate targets. Furthermore, not all necessary data are available for this scenario.
- The European Commission has developed two scenarios, 1.5LIFE and 1.5TECH, outlining how net zero GHG emissions can be secured in the EU in 2050 (EC, 2018). In both scenarios the emissions of the residential sector reach zero by 2050, through a combination of demand reduction, electrification and fuel switch. These are not BAU scenarios but ambitious exploratory scenarios.

The PRIMES reference scenario encompasses all energy policies implemented up to 2016 and so does not include the 'Clean Energy for all Europeans' package and, in particular, the new Buildings Performance and Energy Efficiency Directives concluded in December 2018. As this is the most complete scenario in terms of implemented policy and data, however, it has been adopted here as the BAU scenario. The cited limitations should be kept in mind, though. Table 3 compares the available baseline scenarios.

Table 3 – Comparison of EU energy and climate scenarios

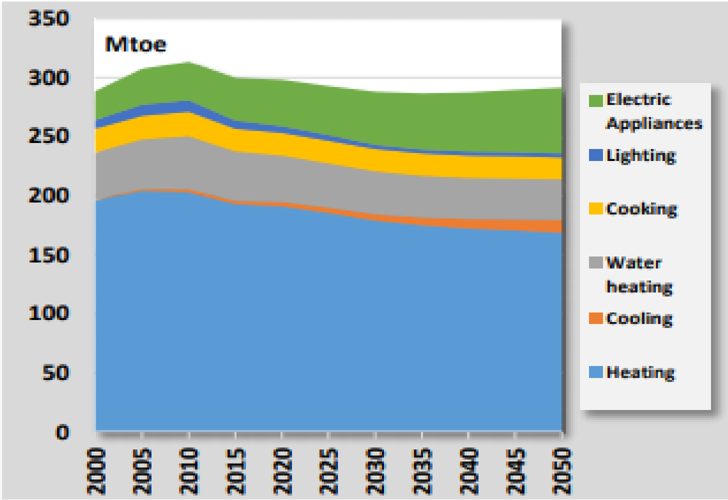
Scenario	Year	Policy assumptions	Available data	Final year	Emissions of residential sector (Mt)[2]		Total emissions (Mt)	
					2020	2030	2020	2030
EU Reference 2016 scenario	2016	Implemented policies, technological and macro-economic developments taken into account. Assumes achievement of 2020 GHG and RES targets.	Sectoral GHG emissions and energy use of all member states (as dataset). Trends in fuel mix and share of residential sector in total energy use (in report).	2050	384	326	4,275	3,732
EUCO 3232.5	2019	Assumes achievement of 32.5% energy efficiency target and 32% renewable energy target, as per Clean Energy for All Europeans Package.	Sectoral GHG emissions and energy use of all member states (in report). No information on fuel mix or share of residential sector in total energy use.	2030	385	213	4,264	3,132
Clean Planet for All, Baseline scenario	2018	Builds on 2016 Reference scenario, but with technology assumptions updated and agreed legislation included. Assumes achievement of 2020 energy and climate targets.	Sectoral CO_2 emissions (not total GHG emissions) and energy use of EU as a whole (in report). No information on individual member states, nor on fuel mix or share of residential sector in total energy-use.	2070	212	177	4,178	3,166

Source: (EC, 2016a; EC, 2018; EC, 2019b).

According to the 2016 reference scenario, the total final energy consumption of the EU residential sector will not change dramatically between 2020 and 2050, decreasing by around 2%. There are small changes in the energy demand of individual end-uses, though: energy use for space heating decreases slightly owing to improved home insulation, while energy use for cooling and electrical appliances increases somewhat.

[2] In the Clean Planet for All Baseline scenario non-CO_2 emissions are not included, but these are included in EUCO 3,232.5, which means the emissions of residential sector cannot be directly compared. For total emissions, non-CO_2 emissions are omitted.

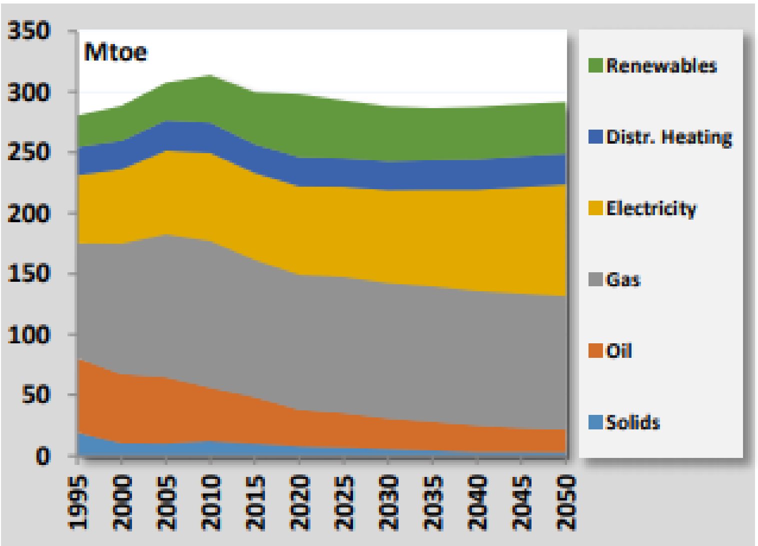
Figure 4 - EU residential energy consumption, by end-use (megatonnes oil-equivalent)



Source: (EC, 2016a).

As Figure 5 shows, besides the limited reduction in overall energy use, the reference scenario also assumes a limited decrease in use of fossil fuels (gas, oil and solids). It also still assumes substantial use of natural gas in the residential sector.

Figure 5 - Projected trends in fuel mix of EU residential sector (megatonnes oil-equivalent)



Source: **(EC, 2016a)**.

Embedded emissions

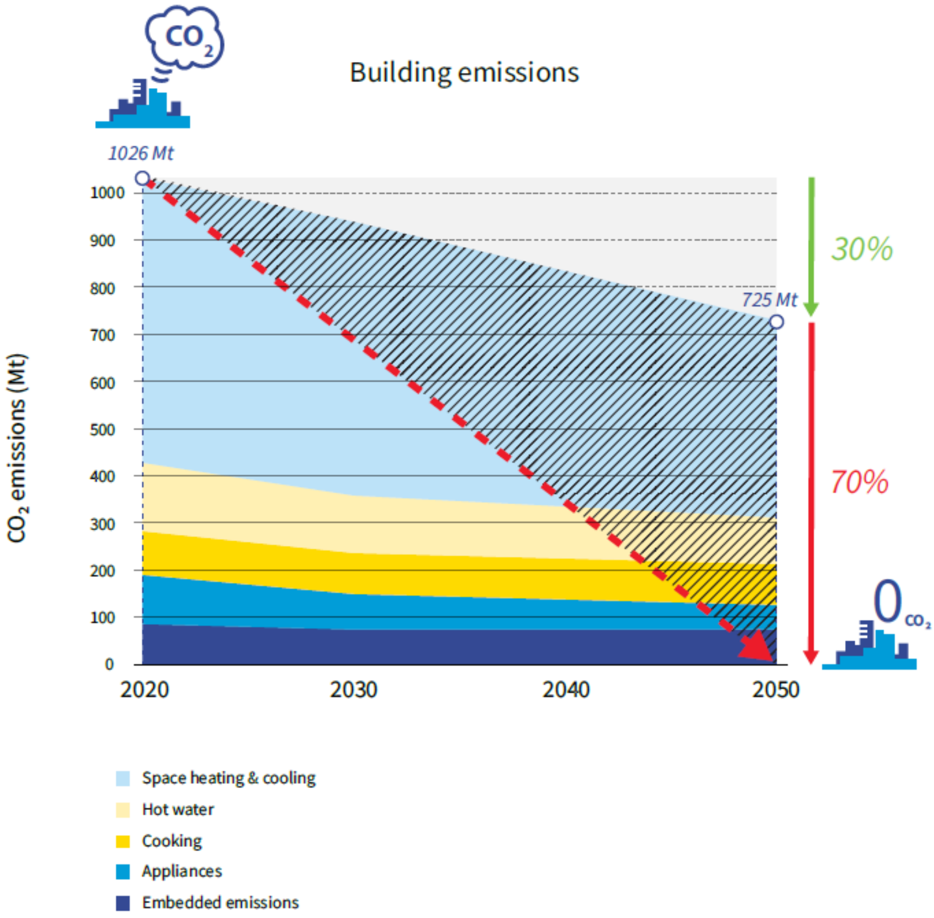
In our context, embedded emissions (also referred to as embodied emissions) are the GHG emissions associated with the materials and construction processes employed in the course of the entire lifecycle of a building or energy infrastructure. For buildings, these are associated largely with the production of building elements and construction materials, which is often very energy-intensive and therefore carbon-intensive.

At present, the embedded emissions of residential buildings are estimated to contribute 20% to total emissions (Röck, et al., 2020). The figure may be far higher for low-energy buildings, however. These low-energy homes have lower GHG emissions during their lifetime, even though the materials used to build them may come with a bigger carbon footprint in production.

Total emissions

Figure 6 provides a breakdown of the total CO_2 emissions of the residential sector by source, calculated using the EUCalc model (see Annex A.1). This is a combination of:
- the emissions related to energy use, based on the PRIMES reference scenario;
- the embedded emissions intensity of materials, based on various levels of renovation and energy standards of new buildings (Röck, et al., 2020).

Figure 6 – Baseline annual CO_2 emissions of residential sector (direct, indirect and embedded emissions), calculated with EUCalc based on (Röck, et al., 2020) and (EC, 2016a)



As can be seen, under this business-as-usual scenario with no additional policies in place, residential CO_2 emissions are projected to decrease by only 31%. To fully decarbonise this sector therefore requires far more vigorous action.

3 Decarbonisation pathways for the buildings sector

This chapter describes the potential for decarbonising the built environment and the technical means to that end.

3.1 Target areas for building decarbonisation

As outlined in Chapter 2, the GHG emissions of the buildings sector derive from a limited number of sources. Reducing these emissions requires a combination of *energy demand reduction* and *decarbonisation of energy carriers and materials*. For each of these 'emissions target areas', dedicated decarbonisation strategies will be required.

Table 4 – Decarbonisation strategies per emissions target area in residential buildings

Emissions target area	Decarbonisation strategy	
	Demand reduction	Decarbonisation of energy carrier/material
Heating	Improvement of building envelope	Heating fuel switch
Appliances and lighting	Appliance efficiency	Renewable electricity
Materials	Material efficiency	Decarbonisation of materials production

Demand reduction

Reducing energy demand is in line with the 'Energy efficiency first' principle introduced by the EU in 2016 in its Clean Energy for All Europeans package and requiring member states to consider energy efficiency in all their energy planning, policy and investment decisions; see the following textbox.

Article 2.18 of the Governance Regulation 2018:
'Energy efficiency first' means taking utmost account, in energy planning, policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions.
Recital 64
"Member States should use the energy efficiency first principle, which means to consider, before taking energy planning, policy and investment decisions, whether cost-efficient, technically, economically and environmentally sound alternative energy efficiency measures could replace in whole or in part the envisaged planning, policy and investment measures, whilst still achieving the objectives of the respective decisions. This includes, in particular, the treatment of energy efficiency as a crucial element and a key consideration in future investment decisions on energy infrastructure in the Union. Such cost-efficient alternatives include measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy. Member States should also encourage the spread of that principle in regional and local government, as well as in the private sector".

Besides its decarbonisation potential, energy efficiency is also important from a variety of other perspectives:
- Economic: Demand reduction reduces the need for energy generation. Efficiency measures can, to a certain extent, be more cost-efficient than supply-side measures.
- Technical: Low-temperature heating solutions (such as heat pumps and low-temperature district heating) require good insulation levels to achieve adequate comfort levels. Minimising demand peaks also mitigates the need for extra investments in electricity and gas grids.
- Social: Demand reduction is needed to reduce the monthly energy costs of consumers, especially in view of rising energy prices.
- Energy security: maximising energy efficiency will enable diversification of energy sources and supply and reduce energy import dependency (Stefan Scheuer SPRL, 2019).

Decarbonisation of energy carriers

Decarbonisation of the remaining energy demand is an essential step for achieving zero emissions in the buildings sector. Decarbonised energy carriers can, in theory, reduce emissions by 100% without any need for efficiency measures. This would require all energy carriers to be produced using zero-carbon technologies (i.e. renewable energy). However, there is a cost trade-off between energy efficiency and renewable energy production, and total system costs can be minimised through judicious combination of energy efficiency and zero-carbon supply. The precise point at which energy efficiency comes at a higher cost than zero-carbon supply is beyond the scope of this study, however.

Decarbonisation of materials

As with energy, decarbonising material use also has two sides: demand reduction (material efficiency) and decarbonising production (including construction and end-of-life processes). These two strategies will be discussed together here, as both the quantity and the quality of materials used in buildings is triggered by the buildings sector.

Hereafter, we outline the measures available for decarbonising the respective emissions target areas in Table 4.

3.1.1 Building envelope

A key step in decarbonising the buildings sector is reducing heating demand by upgrading the building envelope (insulation).

Renovation depth and rate

Building envelope measures are an important element of building energy renovation, along with improvements to the heating system. The amount of energy saved as a result of such measures is referred to as the renovation depth, defined in (EC, IPSOS, Navigant, 2019) as the non-renewable primary energy savings achieved in a specific calendar year, on the following scale:
- below threshold ($x < 3\%$ savings);
- light renovation ($3\% \leq x \leq 30\%$ savings);
- medium renovation ($30\% < x \leq 60\%$ savings);
- deep renovation ($x > 60\%$ savings).

The rate at which the energy performance of the building stock improves can be expressed as the annual reduction of its primary energy consumption. This weighted energy renovation rate for the EU currently stands at about 1%. The rate at which 'deep renovation' is occurring is only around 0.2-0.3% (EC, IPSOS, Navigant, 2019).

Decarbonisation potential

JRC has developed a method to determine the cost-optimal energy renovation strategy per building type. The most cost-efficient level of envelope insulation depends on climatic conditions and available technologies; in other words, it differs per member state and region (Filippidou & Jimenez Navarro, 2019).

Fraunhofer ISI have estimated the potential of cost-efficient energy savings measures in EU residential buildings through to 2050. According to their analysis, final energy savings of 63% can be achieved compared with the baseline trend (Fraunhofer ISI, 2019). This issue is discussed further in Section 3.2.

The EUCalc model (Kockat & Wallerand, 2019) includes renovation rate and renovation depth potentials that have been verified with stakeholders. The highest ambition level in the model assumes an average building renovation rate of 3% per annum and that renovated buildings consume on average 55% less energy than before renovation. This rate is considered necessary if the entire building stock is to be renovated between now and 2050 (Kockat & Wallerand, 2019).

Improving the building envelope is thus a crucial step for reducing emissions associated with heating. After (deep) renovation, most buildings will have a residual energy demand. The remaining emission reduction can then be achieved by switching to zero-carbon energy carriers.

Innovation

Innovation in the building envelope is required to reduce costs and improve renovation rate and depth. Besides better technologies and product innovation, improvements will also be needed in business models, social and cultural norms, financial structures and policy. These forms of innovation will be discussed further in Chapter 8.

Table 5 – Examples of innovation needed in the building envelope

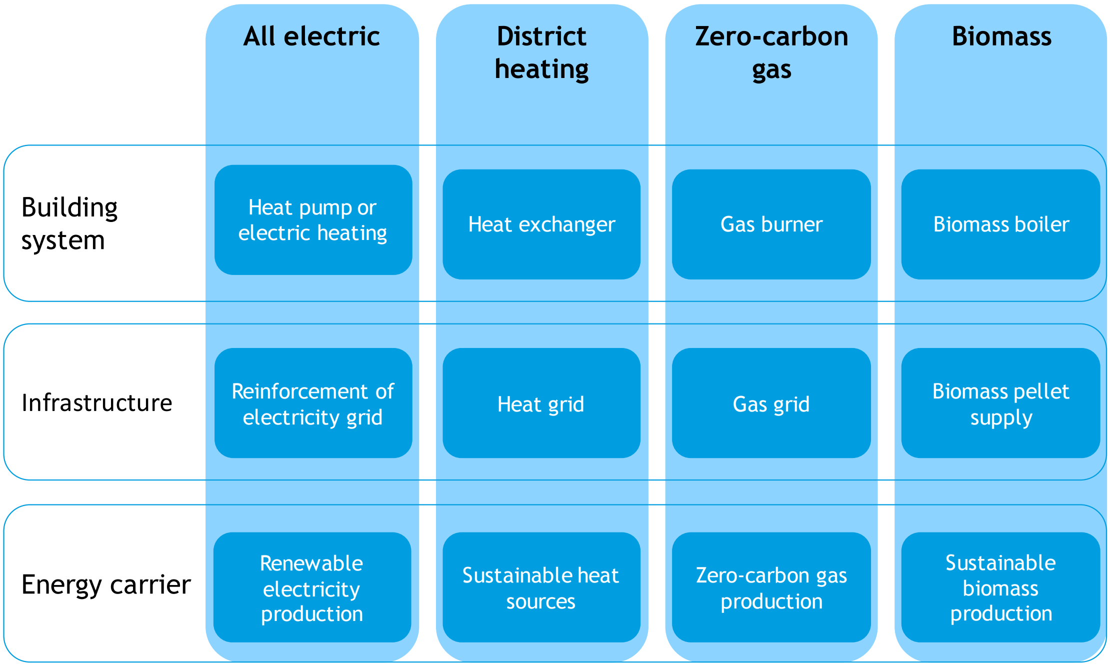
Innovation type	What is needed?
Technologies and products	– Vacuum insulation panels, gas-filled panels, aerogels, nano insulation materials – Prefabricated, modular technological components and packages (ECTP, 2019; EC, 2018)
Business models	– Integrative supply chains and business models delivering (deep) renovation packages (one-stop shops) – Digitisation of retrofit supply chain
Social and cultural norms	– Attractiveness/desirability of low-energy buildings (in general) – Acceptance of external appearance of renovated low-energy buildings (e.g. external wall insulation, window type, solar panels)
Financial mechanisms	– Building-related loans (financing as part of mortgage) transferrable to next owner

Innovation type	What is needed?
	– Financing models such as 'comfort as a service', 'pay-as-you-save' schemes (loans linked to repayment through utility bills) and green mortgages
Policy	– Energy efficiency-based property sales tax – Minimum efficiency standards for existing buildings – Valuation of efficiency measures through lifecycle cost analysis

3.1.2 Heating fuel switch

In the built environment, heating currently relies heavily on fossil fuels (gas, oil and coal). Switching to alternative energy carriers that can be decarbonised (electricity, district heating, zero-carbon gas[3], sustainable biomass) is therefore essential. This switch entails changes to the building system, energy infrastructure and energy production plant, which differ depending on the energy carrier; see Figure 7.

Figure 7 - Components of the energy system for heating



Owing to the wide diversity of building types, there is no 'one size fits all' heating solution for the whole EU or for entire countries. The feasibility and cost-effectiveness of the various heating strategies depends on many factors, including building type, existing energy infrastructure and climate. A combination of solutions is therefore needed that is tailor-made to the varied requirements of the buildings and their residents.

Because decarbonised energy carriers are, on average, still more expensive than fossil fuels, certain heating systems (such as heat pumps) work better with well-insulated buildings, and the total cost of the energy system can therefore be reduced by lowering energy consumption. In other words, the switch in heating fuels needs to go hand in hand with a reduction of heating demand through good insulation of the building envelope.

[3] Mainly biomethane and green hydrogen.

Against this background, for each energy carrier we now discuss:
- the measures required with respect to heating/cooling appliances, energy infrastructure and energy production plant;
- the type of building and location where a solution is typically cost-effective;
- cost distribution and which party needs to invest;
- main barriers and drawbacks for implementation.

Electric heating

Space heating of buildings can be fully electrified by using heat pumps (extracting heat from the soil or air) or other forms of electric heating. Electric cooling is also possible with heat pumps.

Electrification of heating will increase demand for electricity and in many areas the electricity network may therefore need to be reinforced. To fully decarbonise heating, the electricity itself must also be renewably sourced.

As heat pumps are most efficient at generating low-temperature heat, buildings need to be very well insulated. Heat pumps are therefore especially suitable for buildings and dwellings that are already reasonably to well-insulated (e.g. newer double glazing), including new constructions. For poorly insulated buildings and dwellings, this heating strategy will entail relatively high costs for either energy or insulation measures.

For this solution the main costs relate to insulation and heating appliances, which are borne by the building owner. Insulation costs depend strongly on the building type and initial level of insulation. Direct electric heaters have lower costs than heat pumps, but are less efficient, resulting in higher energy costs. Table 6 summarises the required measures and the parties to invest.

Table 6 – Measures and parties to invest for all-electric heating

Energy system component	Measure	Party to invest
Heating/cooling appliances	Heat pump or electric heater	Owner
Insulation	High level of insulation	Owner
Energy carriers	Renewable electricity production	Energy company (costs passed on to resident)
Energy infrastructure	Possibly reinforce electricity grid	Grid operator

The specific barriers and drawbacks for all-electric heating and cooling are:
- high up-front costs of insulation and heat pumps (partly compensated by lower energy bills);
- split incentive for insulation and appliances between renter/tenant and owner;
- resistance of owners/residents to home improvements due to inconvenience, disruption and aesthetics;
- implications of high peak electricity demand for the electricity grid and power sector (e.g. peak production and seasonal storage);
- increased electricity demand that needs to be supplied by renewable sources.

District heating

District heating is a collective form of heating, supplying hot water to buildings through heat grids. The heat is supplied to the building's central heating system via a heat exchanger.
The heat can be supplied from a variety of sources: many existing district heating systems utilise heat from natural gas-fired combined heat and power (CHP) plant. The main other sources are 'waste' heat from industry, geothermal heat, low-temperature 'waste' heat from data centres, solar thermal energy and collective heat pumps. District heating can be supplied at high temperatures of over 90°C, but other sources have lower temperatures and can be combined with low-temperature central heating or individual heat pumps.

District heating requires extensive, insulated hot-water distribution grids. Because of the costs and grid heat losses, district heating has greatest potential in areas that are densely populated as well as in close proximity to heat sources.

The costs of district heating lie mainly in the heat grids and renewable heat production. These investments are made by a district heating company and passed on to the consumer through connection fees, fixed fees and energy costs. Table 7 summarises the required measures and the parties to invest.

Table 7 – Measures and parties to invest for district heating

Energy system component	Measure	Party to invest
Heating/cooling appliances	Heat exchanger	Owner
Insulation	Only necessary for low-temperature heating	Owner
Energy carriers	Renewable heat production	Energy company (costs passed on to resident)
Energy infrastructure	Heat distribution grid	Grid operator

The barriers and drawbacks for district heating are:
- district heating cannot be implemented by individual households, but requires collective investment;
- high up-front costs of heat grid and renewable heat sources;
- resistance of owners/residents to collective heating due to monopoly of heat companies, high (perceived) costs, nuisance during construction and lack of control over comfort;
- absence of nearby renewable heat source.

Zero-carbon gas

There are currently two forms of 'zero-carbon gas': sustainable biomethane and (green) hydrogen. Sustainable biomethane is upgraded biogas produced from sustainable biomass sources. Although it is already being produced, the availability of sustainable biomass for this purpose is very limited. Estimates of the total potential sustainable biomethane output vary from 7% of current natural gas demand (ICCT, 2018) to 18% (Navigant, 2019).
Besides limited production potential, the availability of biomethane for buildings is also constrained by demand from other sectors with fewer alternatives, such as industry and transport, and this demand may drive up its price.

Zero-carbon hydrogen can be produced via electrolysis of water (green hydrogen) or by combining steam reforming with carbon capture and storage (CCS) (blue hydrogen). The latter production method results in residual GHG emissions and associated methane emissions upstream. Neither form of hydrogen production is up and running on a commercial scale, and given demand from other sectors it is uncertain to what extent hydrogen will become available for the built environment in the future and at what price. Hydrogen can potentially play an important role in balancing peaks in electricity production, however, and for this reason is included in many scenarios.

Despite the limited availability and potentially high price of zero-carbon gas, there may be a few situations in which it is an attractive means to decarbonise heating. Owing to the high-temperature heat delivered by gas boilers, there is no need for extensive insulation to achieve an acceptable comfort level, as is the case with heat pumps. Zero-carbon gas may therefore be a 'last resort' solution in buildings that cannot be adequately insulated, such as historic buildings.

Zero-carbon gas can be distributed through (existing) gas grids and converted in gas boilers, hybrid heat pumps or innovative appliances such as fuel cells. Renewable biomethane can replace natural gas and make use of the energy infrastructure already in place. The only additional cost is for the production of sustainable biomethane, the price of which may also be driven up by high demand from other sectors and limited production capacity.

For hydrogen, changes are required to the gas grid and building appliances, but the impact of these changes is relatively limited compared with other heating/cooling options if the gas grid is in good condition (Northern Gas Networks; Wales&West Utilities; Kiwa; Amec Foster Wheeler, 2016) (Kiwa, 2018). The total costs of converting from natural gas to hydrogen derive from modifying the gas grid (depending on its current state), modifying or replacing gas boilers and production of the hydrogen itself.

Table 8 summarises the required measures and the parties to invest.

Table 8 - Measures and parties to invest for zero-carbon gas heating

Energy system component	Measure	Party to invest
Heating/cooling appliances	Gas boiler	Owner
Insulation	Not strictly necessary	Owner
Energy carriers	Renewable biogas or hydrogen	Energy company (costs passed on to resident)
Energy infrastructure	Retrofit existing gas infrastructure for hydrogen	Grid operator

The barriers and drawbacks for gas-fuelled heating are:
- limited availability of sustainable biomethane and zero-carbon hydrogen;
- competing demands from other economic sectors (hydrogen for industry, as a shipping fuel, etc.);
- high cost of producing green hydrogen;
- cost of modifying gas grid and appliances for hydrogen;
- cooperation between government, gas suppliers and grid operators;
- safety and public perception challenges regarding use of hydrogen in homes.

Biomass

Biomass is derived from organic matter such as trees, plants and agricultural and urban waste and is usually distributed in the form of pellets. For biomass to be an effective means of reducing GHG emissions, it must be sustainably produced, ensuring all lifecycle emissions are accounted for, including indirect land use change (ILUC). As with biomethane, the production potential of sustainable biomass is very limited and there is competing demand from other sectors. Current regulations provide insufficient guarantee that the biomass used is indeed sustainable (Norton, et al., 2019).

Owing to the limited availability of sustainable biomass, its use for residential heating should be seen as a 'last resort' option for situations where electrification and district heating are unfeasible, where there is no existing gas grid or it is unavailable, and where there is minimum nuisance from odours, such as rural areas with low population density and scattered buildings.

Using biomass for heating means having a biomass-fuelled boiler. Modern boilers are connected to a central heating system and have filters to reduce particulate matter emissions.

The costs for this solution lie mainly in the production of renewable biomass. Table 9 summarises the required measures and the parties to invest.

Table 9 - Measures and parties to invest for biomass heating

Energy system component	Measure	Party to invest
Heating/cooling appliances	Biomass heater	Owner
Insulation	Not strictly necessary	Owner
Energy carriers	Renewable biomass production	Biomass producer (costs passed on to resident)
Energy infrastructure	No extra infrastructure needed	–

The barriers and drawbacks for biomass heating are:
- limited availability of sustainable biomass and competing demand for woody biomass;
- spatial competition: low density of production (low power density) implies major land requirements, interfering with other types of land use;
- air pollution, related health effects and smell of biomass burning;
- transport of biomass to buildings needs to be done by owner/resident.

Overview of heating/cooling solutions

Table 10 gives an overview of the heating/cooling solutions discussed.

Table 10 - Overview of energy carriers for heating/cooling

Energy carrier	**Electricity**	**District heating**	**Zero-carbon gas (hydrogen or biomethane)**	**Biomass**
Heating/cooling appliances	– Heat pump or electric heater – Air conditioning or heat pump	– Heat exchanger	– Gas burner or hybrid heat pump-gas system	– Biomass burners
Energy infrastructure	– Electricity grid (reinforced)	– District heating grid	– Gas grid	– Individual transportation of biomass
Production of energy carrier	– Renewable electricity production	– Waste heat, geothermal heat, collective solar	– Sustainable biogas or hydrogen production	– Sustainable biomass production
Built environment characteristics *(in what types of country/area/building is the solution cost-efficient?*	– New constructions – Well-insulated buildings – Low heating demand	– Urban areas – Concentrated heating demand – High heating demand	– Existing gas infrastructure – High heating demand/poorly insulated buildings	– Rural areas – Low heating demand – Lacking/downgraded gas/electricity infrastructure
Costs and distribution *(building, energy infrastructure, heating/cooling appliances, source)*	– Insulation costs relatively high – Reinforced electricity grids	– Operational costs high for distributor – Costs low for households	– Hydrogen currently too expensive for built environment – Gas infrastructure can be repurposed: low costs	– Appliance costs low – Infrastructure costs unknown
Main barriers and constraints	– High up-front costs of insulation and heat pump – Resistance of owners/residents due to inconvenience, disruption and aesthetics – Increased electricity demand and high peak demand; impact on grid and renewables production	– Collective investments needed – High up-front costs of heat grid and renewable heat sources – Resistance of owners/residents due to monopoly of heat companies, high (perceived) costs, nuisance during construction, lack of control over comfort – Absence of nearby renewable heat source	– Limited availability and competing demands from other sectors Hydrogen: – High cost of green hydrogen production – Costs of modifying gas grid and appliances for hydrogen – Public perception challenges regarding use of hydrogen in homes	– Limited availability of sustainable biomass and competing demands from other sectors – Air pollution and related health impacts

Innovation

Innovation in heating is needed to improve the uptake and performance of zero-carbon energy carriers and heating appliances. Besides better technologies and product innovation, improvements will also be needed in business models, social and cultural norms, financial structures and policy. These forms of innovation will be discussed further in Chapter 8.

Table 11 – Examples of innovation needed in heating

Innovation type	What is needed?
Technologies and products	– Scaling-up and cost reduction of decarbonised heating appliances (heat pumps, solar thermal water heaters) – Developing and scaling up of zero-carbon gas production, storage, infrastructure and heating appliances – District heating grids (lower temperature, geothermal sources, waste heat, pipeline design, control systems (CORDIS, 2019b) – On-site heat and electricity storage systems and control systems (Rosenow & Lowes, 2020) (RHC-ETIP, 2020) – Modelling, software and monitoring tools for new and future buildings and for retrofitting old and historical buildings (RHC-ETIP, 2020)
Business models	– Connecting stakeholders in the heating value chain – Facilitating utilisation of waste heat – Appliance-as-a-service (leasing) for heating appliances such as heat pumps – Valuation of demand-side flexibility and storage for heating (Rosenow & Lowes, 2020)
Social and cultural norms	– Acceptance of collective/community solutions: building owners often do not consider 'community solutions' such as district heating – Training, education, certification and technology awareness for installers in buildings (RHC-ETIP, 2020)
Financial mechanisms	– Financial solutions for neighbourhood energy systems – Economic policy instruments: CO_2-pricing of heating fuels – Time-variant electricity prices to encourage flexible use of heat (Rosenow & Lowes, 2020)
Policy	– Local governments assigning areas for collective heat systems, with citizen engagement process – Integrative energy planning of neighborhoods

Relative deployment of heating solutions and policy relevance

As described earlier, decarbonisation of heating and cooling will require a combination of demand reduction and a choice of a decarbonised energy carrier with appropriate infrastructure and appliances. The cost effectiveness and feasibility of the measures in member states, regions and neighbourhoods depend on many factors, including building type, current energy supply infrastructure and climate.

When identifying possible policy levers it is important to realise that a *combination* of heating solutions, determined by local factors, imposes the lowest overall cost to society. In other words, there is no one single solution, such as electric heat pumps, that will be best for all buildings; rather, a combination of electrification, district heating, gas and biomass will be necessary. Although steering towards just a single solution is feasible, this implies higher costs to society. Policymakers should therefore be wary of incentivising specific energy carriers and heating appliances at the expense of others. Only if a particular energy carrier plays a prominent role in the country should it be prioritised via policy.

3.1.3 Home appliances and lighting

Besides heating and cooling, household energy demand also derives from the use of electrical appliances like computer equipment, TVs, white goods (refrigerators, freezers, washing machines, dishwashers, dryers), small electrical goods, lighting and sometimes cooking units.

Since non-renewable electricity is currently the main source of GHG emissions, full decarbonisation of home appliance use has three elements:
- improved energy efficiency of the appliances;
- decarbonisation of the electricity supply (green electricity);
- improved materials use/embedded emissions in the appliances.

Appliance efficiency increases as old appliances are replaced by new, more efficient ones, which may also have lower embedded emissions, depending on the materials used. However, there may also be a negative impact on decarbonisation, if new types of appliances are introduced, a greater number are used, or the materials have higher embedded emissions or are harder to recycle.

Innovation

Innovation is needed to improve the energy efficiency of home appliances and increase the uptake of smarter, more efficient designs. Besides better technologies and product innovation, improvements will also be needed in business models, social and cultural norms, financial structures and policy. These forms of innovation will be discussed further in Chapter 8.

Table 12 - Examples of innovation needs for home appliances and lighting

Innovation type	What is needed?
Technologies	– Smart homes: Demand response, smart meters, sensors to integrate user behaviour, building-automation control systems – Next-generation LEDs
Business models	– Appliance-as-a-service/leasing business models

3.1.4 Building materials

In our context, embedded emissions are the GHG emissions associated with the materials and construction processes employed in the course of the entire lifecycle of a building or energy infrastructure. With growing renovation and declining energy consumption in pursuit of decarbonisation, as time progresses the share of embedded emissions in the residential buildings sector will rise.

Embedded emissions can be reduced through reduction and re-use of materials and use of materials with lower carbon footprints and longer lifetimes (Material Economics, 2019). Decarbonisation of key building materials like steel, concrete and glass needs to take place at the production stage (WGBC, 2019b). The materials used in new buildings, insulation and appliances need to move towards zero-carbon in the production phase, by using recycled or bio-based materials, for example. Finally, the assembly and end-of-life stages must also be decarbonised, leading to circular value chains.

Because of the increasing relevance of embedded emissions in the residential sector, policies stimulating sustainable use of materials are essential to achieve net-zero emissions in this sector. Policies should target operational and embedded emissions ('whole-life carbon') in an integrated manner, to avoid having a situation where requirements on embedded emissions disincentives efforts to tackle operational emissions (WGBC, 2019a): certain products may have more embedded carbon than an alternative (for example, double glazing versus single glazing), but reduce total lifecycle emissions.

Innovation

Innovation in building materials is needed to reduce the emissions of production, decrease raw materials use and improve recyclability. Besides better technologies and product innovation, improvements will also be needed in business models, social and cultural norms, financial structures and policy. These forms of innovation will be discussed further in Chapter 8.

Table 13 – Examples of innovation needed in building materials

Innovation type	What is needed?
Technologies	– Materials with reduced embedded emissions – Bio-based building materials, also for multi-storey (wood, cross-laminated timber) – Bio-based and recyclable insulation materials (CORDIS, 2019a) – Integration of construction and demolition waste in new constructions (ECTP, 2019)
Business models	[-]
Social and cultural norms	– Acceptance of different appearance of buildings
Financial mechanisms	[-]
Policy	– Carbon passports for materials – Building passports detailing the materials used in a building

3.1.5 Lifestyle and societal trends

Changes in lifestyle and societal trends influence comfort demand and consumer behaviour, generally leading to either decreased or increased energy demand.

Comfort demand refers to the energy and material demand of people's lifestyle, determined by preferred indoor temperature, area (number of rooms) heated and number and type of appliances used. Comfort demand correlates strongly with how people live, e.g. home occupancy and the living space per house or per occupant, in turn strongly linked to social norms. For example, urbanisation contributes to reduced living areas, while more single-person households increases the average living and heating area per person.

Behavioural change relates to how people interact with energy-consuming appliances, e.g. switching them on and off. Behavioural change can be stimulated by certain business models and technologies, such as platform-as-a-service (PaaS), decentralised power generation, thermostats, smart meters and sensors (building automation). These new developments may raise consumer awareness of the value of energy and the personal (carbon) footprint, leading to reduced energy use.

Fraunhofer ISI (2019) estimate that a combination of societal trends — such as building automation and interconnection of appliances, but also increased comfort levels — could reduce final energy demand in the buildings sector by up to 35% by 2050, but could also increase it by as much as 45%. Societal trends thus have major potential for reducing energy demand, but unless appropriately steered may equally well lead to substantially higher demand.

Innovation

Innovation in lifestyle and social norms is needed to induce low-carbon behaviour.
While there is certainly a role for technology and product innovation in steering behavior (e.g. smart meters), innovation may need to be more on the cultural and policy level. These forms of innovation will be discussed further in Chapter 8.

Table 14 - Examples of innovation needs in lifestyle and societal trends

Innovation type	What is needed?
Technologies	— Smart meters — Demand response technology for utilising self-produced energy
Social and cultural norms	— Acceptance of lower-temperature heating
Policy	— Information/labelling of efficiency of appliances and buildings, and carbon content of energy carriers and building materials — Building efficiency standards

3.2 Decarbonisation potential

These technical and lifestyle measures vary in their relevance for the different emissions target areas and in their decarbonisation potential.

The total techno-economic potential for energy savings in the residential sector, defined as the cost-effective and near-cost-effective technical potential, was estimated in (Fraunhofer ISI, 2019) at 63% of the PRIMES baseline final energy demand in 2050 (see Table 15). These reduction potentials result from building envelope measures in existing and new buildings and the use of higher-efficiency heating, hot-water and home appliances and lighting.

Further reductions can be achieved if more efficient lifestyles and behaviours are adopted. The cited study assesses that changes in lifestyle and societal trends can either increase or reduce final energy demand. The most efficient scenario indicates a further reduction potential of 7% of total energy use due to heating and cooling (we assume this also applies to hot water) and 4% due to home appliances and lighting.

Table 15 – Final energy savings potentials compared with PRIMES baseline trend for 2050

Emissions target Area	Source of energy savings	Savings potential (% of baseline energy use, 2050)
Heating/cooling (incl. hot water)	Building envelope – Existing buildings 25% – New constructions 12%	37%
	Efficiency of heating systems – Efficiency of heating appliances 13% – Efficiency of hot-water appliances 4%	17%
	Lifestyle trends	7%
Home appliances and lighting	Efficiency – Lighting 3% – Electrical appliances 4%	7%
	Lifestyle trends	4%

Source: (Fraunhofer ISI, 2019).

The energy use remaining once these efficiency measures are in place needs to be decarbonised as well. For heating and cooling, this will usually require a switch to a heating system that can use zero-carbon energy carriers, such as switching from gas or coal boilers to heat pumps or district heating. Finally, all energy carriers (including gas, electricity and district heating) must be produced using renewable production methods. In theory, emissions can be reduced by 100% by switching to zero-carbon energy carriers, while demand reduction via building envelope measures can reduce emissions by 37% and efficient heating systems by 17%. For reasons of cost effectiveness, though, a combination of demand reduction and zero-carbon energy carriers is required.

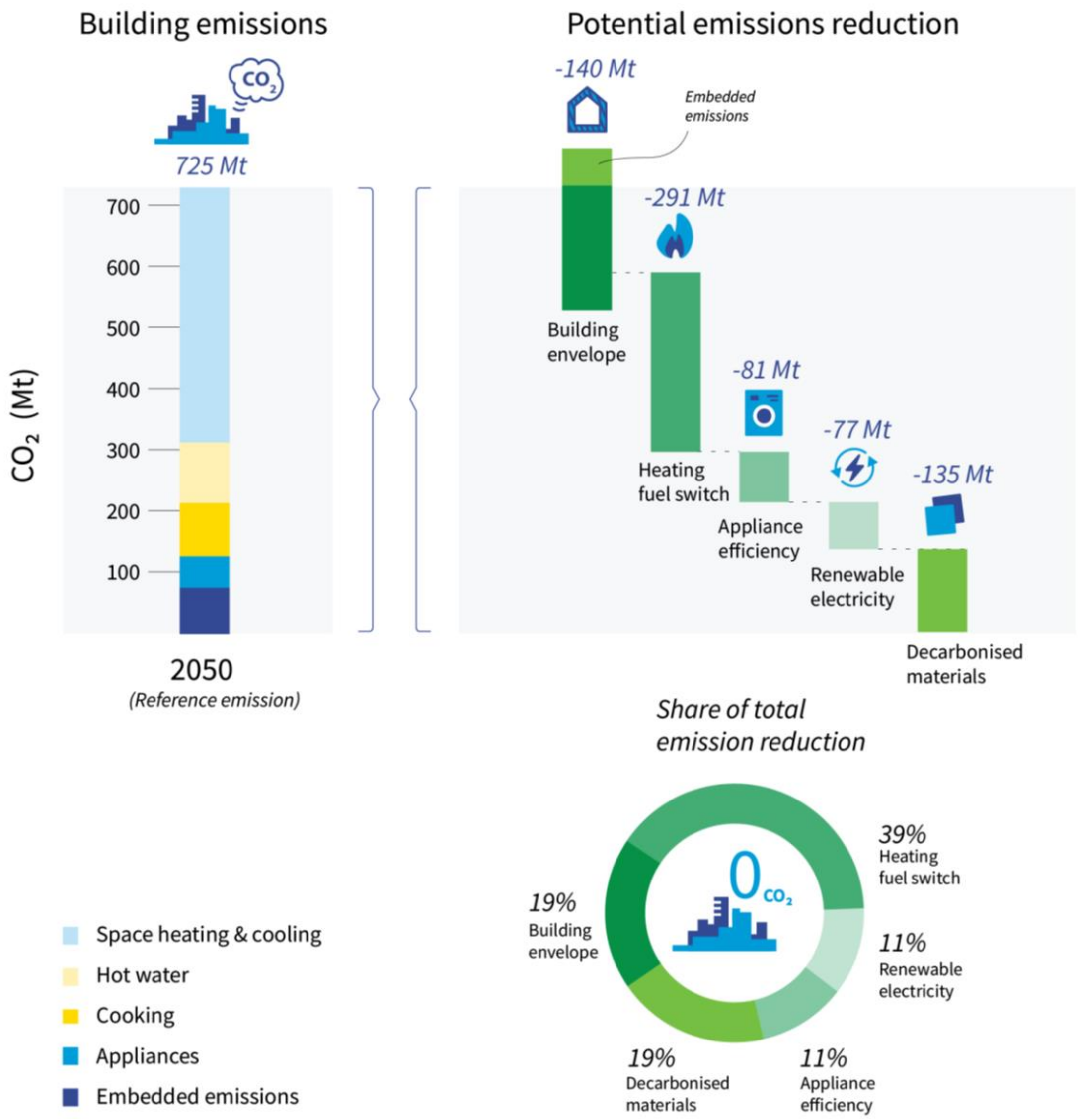
To assess the potential contributions of the various measures, a zero-carbon scenario was developed by Climact using the EUCalc model. This is a model of emissions at the European level, based on user-defined ambition levels for different levers influencing emissions. For the present study, the highest ambition levels were taken for all the levers in the buildings sector[4] and additional assumptions made on decarbonising power generation and industry to arrive at a zero-emissions scenario for 2050 (see Annex A.2).

Embedded emissions were based on the carbon intensities of construction and renovation materials (Röck, et al., 2020). The embedded emissions associated with home appliances, energy infrastructure and renewable electricity were not included. Reductions in embedded emissions from decarbonised industry (production and end-of-life) were counted as annual emissions reductions so they could be compared with operational emissions.

The levers were grouped into the five main areas where buildings sector emissions can be targeted. Figure 8 shows the respective potential of these steps towards full decarbonisation, set off against the 2050 baseline scenario.

[4] Except for the demolition rate, which was reduced from 1 to 0.4% per year.

Figure 8 - Annual GHG emissions in 2050 reference scenario and net reduction potential of emissions target areas, based on EUCalc



As can be seen in this figure, to achieve 100% decarbonisation of the residential building sector requires policies in all five target areas:
— building envelope;
— heating fuel switch;
— appliance efficiency;
— renewable electricity;
— decarbonised materials.

3.3 Timeline of investments

The timing of decarbonisation measures affects the cost of the transition for society, as well as the ease with which the changes are made. Determining the optimum timing of measures can therefore help in establishing a policy roadmap in which the measures are taken in a timely and cost-efficient manner.

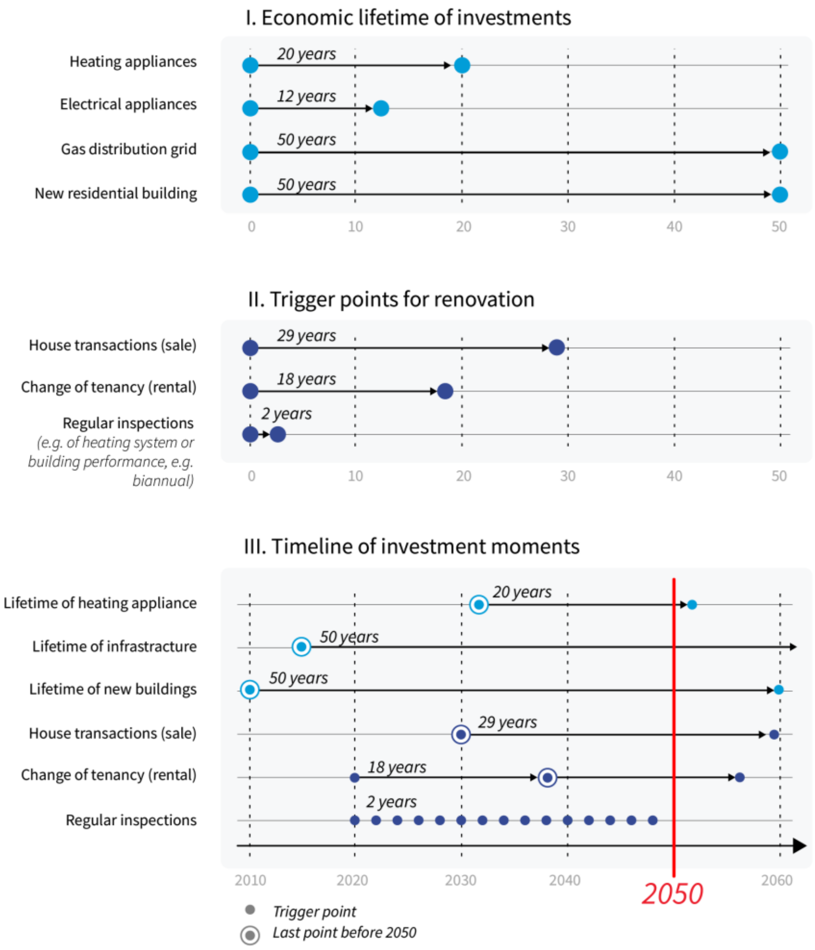
Lowest cost: Utilise technology investment cycles

The first consideration is that the timeline on which measures are implemented affects the total cost to society. Most measures require replacement of an existing technology/solution by a zero-carbon alternative: replacing gas boilers by heat pumps, for example. In a least-cost scenario, new investments are made at the end of a technology's lifetime. If the investment is made before the end of the economic lifetime, there will be extra costs due to the premature write-downs (stranded assets) of the existing technology.

IRENA (2017) estimates that, globally, the costs of stranded assets associated with decarbonisation of the buildings sector will double if policy action is delayed from 2020 to 2030. An example of stranded assets would be the additional cost of installing gas-fired boilers and later replacing them with heat pumps, versus installing heat pumps in the first place. By comparison, stranded assets do not occur if building equipment is replaced when it has reached the end of its lifetime.

Figure 9, based on (Agora Energiewende & Agora Verkehrswende, 2019), shows the lifetime of investments for a number of technologies. Some technologies have lifetimes of over 30 years. This means that between now and 2050 there is only one natural investment moment, which, if not utilised, will lead to higher costs to society. These considerations hold for new residential buildings as well as distribution grids.

Figure 9 - Trigger points for investment



Difficulty of change: Utilise trigger points for renovation

Trigger points for renovation are key moments in a building's lifetime when carrying out energy renovations is less disruptive and more economically advantageous than at other times (BPIE, 2017). These specific moments have major potential for increasing renovation rate and depth. Trigger points include the sale or change of tenancy of a home, non-energy upgrades (e.g. new kitchen, upgrading of external façade, adding an extension), a change in the number of occupants (e.g. a new baby, child moving out, renting a room), as well as regular (mandated) building inspections. Property transfers are good occasions to undertake deep renovation, because new owners often want to make changes to their new home anyway and may not yet have moved in, thus exposing them to less inconvenience. Figure 10 shows the average frequency of some of these trigger points[5].

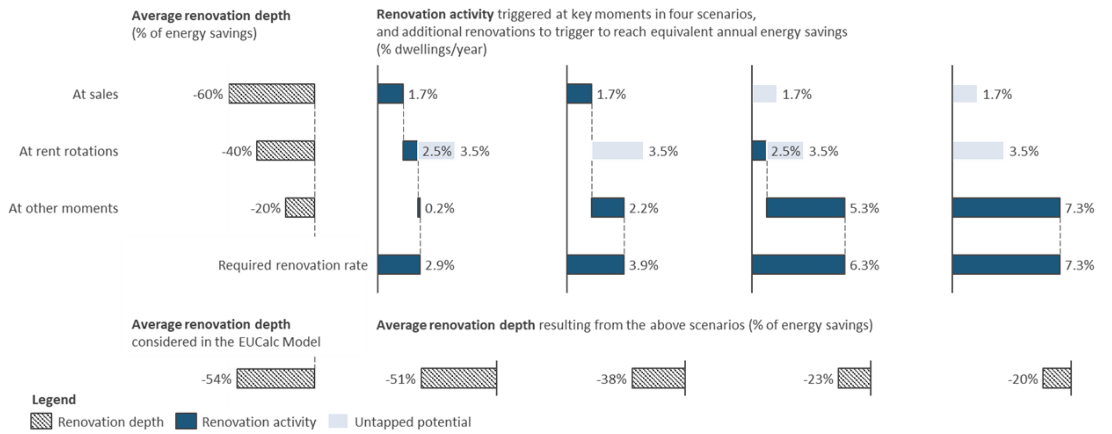
These trigger points are occasions to trigger the building owner or other investor to make the decision to renovate or invest in decarbonisation measures. Figure 11, illustrating how

5 Frequency of sales based on 221 million households in EU (Eurostat, 2020a), 65% of homes are owner-occupied (Housing Europe, 2017) and approximately 5 million house transactions per year (ECB, ongoing). Frequency of change of tenancy based on 25-44% of tenants moved in five years (Eurostat, 2017). Regular inspections are an example of biannual inspections.

the various trigger points might occur in the run-up to 2050, shows the urgency of utilizing these occasions to trigger change, with some of them occurring only once between now and 2050. If the occasion is not used, measures taken at a later date will incur higher costs and greater disruption.

Utilizing renovation trigger points is a key factor in increasing both the rate and depth of renovation. To achieve a 54% average reduction in energy demand through renovation (as assumed in the EUCalc model) requires an average annual renovation rate of 3% through to 2050, with every renovation leading to 54% reduction. There are many scenarios for reaching this average, though, as illustrated in Figure 10. For example, if there is 60% reduction at every sales moment (at a frequency of 1.7% of dwellings per year), other renovations such as at rent rotation and outside key moments do not require such a high renovation depth.

Figure 10 – Necessary renovation rate and depth at key moments to reach an average of 51% energy savings in four scenarios

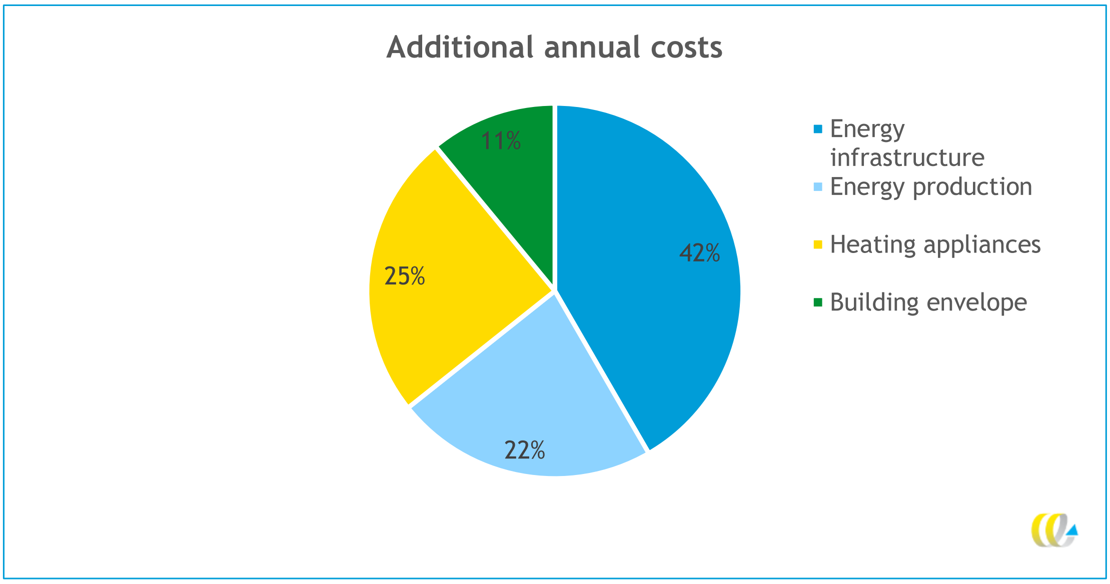


3.4 Cost of measures

To secure the EU's current 2030 targets of 32% renewable energy and 32.5% energy efficiency improvement requires average additional annual investments of around 260 billion EUR, approximately 125 billion EUR of which in the residential sector (EC, 2019c). Given that there are around 221 million households in EU (Eurostat, 2020), this translates to an average additional annual investment of about 600 EUR per dwelling. This underlines the need to make maximum use of trigger moments, so costs can be absorbed at point of sale or other trigger points.

In a modelling study of the most cost-efficient measures for decarbonising heating and cooling in the Netherlands, CE Delft calculated the average additional cost to be approximately 1,000 EUR per building-equivalent (residential and non-residential buildings) per year (CE Delft, 2018). This includes investments as well as operational costs.
The distribution of these costs across energy infrastructure, energy production plant, heating appliances and building envelope is given in Figure 11. This average amount and its distribution will differ among member states.

Figure 11 – Distribution of additional annual costs for cost-efficient decarbonisation of heating and cooling in the Netherlands



These costs are the total costs to society and will be incurred by a variety of different actors: infrastructure costs by grid operators and energy production costs by electricity generators, zero-carbon gas producers and district heating operators. These costs will eventually be passed on to consumers through energy and grid tariffs. On the other hand, costs relating to the building envelope and heating appliances will usually be incurred directly by the building owner.

3.5 Barriers to decarbonisation

Implementation of decarbonisation measures will face a number of barriers. Based on a series of recent studies (WGBC, 2019b; Trier, et al., 2018; D'Oca, et al., 2018) (Beillan, et al., 2011; Zahradnik, 2016; Bean, et al., 2017; BPIE, 2013; Rosenow, et al., 2016) these can be categorised under the following headings:

1. Lack of consumer knowledge and awareness of benefits.
2. Lack of economic incentive or business case.
3. Inability to invest.
4. Fragmentation of market solutions and suppliers.
5. Lack of skilled labour.
6. Split incentive between landlord and tenant.
7. Custom and habit, leading to inaction even when other barriers are absent.

These barriers focus on the consumer. Other barriers not included in these main categories include inconvenience, technical barriers, political barriers, lack of physical space, insufficient diversity of buildings, difficulty in decision-making processes and lack of examples.

To overcome these barriers requires changes in people’s behaviour, the market, technology costs and societal norms. Policy and innovation are notable ways to steer these changes. While this is obviously an extremely broad challenge, it can be addressed by judicially chosen policy measures and through smart innovation strategies.

In the next three chapters we review the existing policy framework, identify gaps in current EU policy and present the contours of a policy roadmap towards full decarbonisation.
In Chapter 7 we consider the policies already in place in three EU member states.
In Chapter 8 we then turn to the issue of innovation, technical and otherwise.

4 Policy framework

To achieve full decarbonisation of the residential buildings sector will demand wise use of the full range of policy instruments (financial incentives, pricing, regulatory instruments, financing instruments, information) in combinations specifically tailored to each of the five target areas identified. On their own, financial incentives will not be enough; pricing and regulatory instruments will also be required.

In this chapter we describe the various policy instruments and their strengths and weaknesses, provide a framework for analysing decarbonisation policies and visualise what a comprehensive set of policy measures would look like.

4.1 Types of policy instrument

There are a range of policy instruments available to address the barriers identified in Section 3.5. We distinguish the following:
- financial support;
- pricing instruments;
- regulatory instruments;
- financing instruments;
- informative instruments.

Financial support and pricing are both economic instruments, with the former reducing the market price via a financial stimulus and the latter increasing it by imposing a levy. Table 16 summarises the objectives of the various types of policy instrument and provides several examples.

Table 16 – Types of policy instrument

Type of policy instrument	Examples	Objectives
Informative instruments	– Energy performance labelling of products – Energy Performance Certificates for buildings	– Increase awareness – Enable informed decision-making
Financial support	– Subsidies for renovation measures or appliances – Tax deductions for renovation measures or appliances – Support programmes for research and innovation	– Create demand – Reduce investment costs – Stimulate innovation
Financing instruments	– Public loans for decarbonisation measures – Guarantees for businesses	– Steer public and private capital towards investing in decarbonisation measures
Pricing instruments	– CO_2 pricing or taxation – Tax incentives, e.g. increase of property taxes over time if a building is not renovated	– Create level playing field for decarbonisation measures

Type of policy instrument	Examples	Objectives
Regulatory **instrument (obligations)**	– Building codes – Appliance efficiency norms – Standards	– Break through custom/habit and split-incentive barriers – Create new norms and standards in society – Set a minimum threshold

4.2 Review of the policy instruments

These five types of policy instrument have different strengths and weaknesses, which we now review.

Informative instruments

The aim of informative instruments is to raise awareness of the benefits of measures to create demand for them. Merely informing actors does not guarantee they will actually change their behavior, though, making the effectiveness of such instruments uncertain.

The strengths and weaknesses of informative instruments are as follows:

Strengths	Weaknesses
– Raises awareness of need and benefits	– Uncertain effect – Most effective in combination with other measures

Financial support

Financial support is an economic stimulus and can take the form of a subsidy, a tax deduction or a government guarantee. Its aim is to create demand for a measure by lowering the amount to be invested. This support measure can be provided to home owners as well as private funders, for example, or to the private sector, such as energy companies. Financial support may be directed towards the building envelope (e.g. insulation measures), appliances (e.g. subsidies for heating or electrical appliances) and production of energy (e.g. biogas) or materials (e.g. circular materials).

The level of support can be calculated to cover, fully or in part, the difference between the investment and the expected savings or willingness to pay. While the extent of uptake will certainly be influenced by the subsidy level, ease of implementation is also an important factor. In particular, administrative procedures for applying for the support should not be limiting.

An advantage of financial support as a policy measure is government control over total expenditure. It also stimulates the economy and, as a secondary effect, creates government income in terms of tax revenue.

An important drawback of financial support measures is the limited response: not everyone responds (price inelasticity), nor is everyone able to do so (e.g. lack of access to finance) or eligible (e.g. split incentive).

When implementing these policies it is important to address equity issues. For example, subsidising insulation measures benefits homeowners, especially those already able to invest. If well-designed, though, financial support can also improve social equity by providing support to low-income groups. Measures should also be designed so as not to favour suboptimal technologies.

Finally, policies can be designed to stimulate market innovation, for example by introducing performance-based standards rather than technology standards, and pricing CO_2 rather than energy carriers in general.

The strengths and weaknesses of financial support are as follows:

Strengths	Weaknesses
– Reduces investment costs – Possibility to address energy poverty/compensate lower-income groups – Stimulates market innovations and cost reduction – Socially acceptable – Government control over total expenditures	– No full response due to price inelasticity and non-economic barriers – High government costs if maximum effect is desired – Risk of unnecessary market distortion – Free riders/oversubsidising

Financing instruments

Financing instruments *facilitate* the use of public or private capital for decarbonisation measures, for example by providing loans for renovation, or by requiring banks to do so.

Financing instruments only become relevant once there is a need or wish to invest. As such, then, it is a supporting policy that does not of itself influence consumer behavior, but needed on top of economic and regulatory instruments.

The strengths and weaknesses of financing instruments are as follows:

Strengths	Weaknesses
– Creates access to finance	– Becomes relevant only after there is need and/or wish to invest

Pricing instruments

Pricing is an economic instrument that imposes a levy, thus internalising external costs and creating a level playing field for decarbonisation measures. Examples are an energy tax (like that already mandatory under the Energy Taxation Directive), a CO_2 tax on energy carriers (fuels and electricity), or a property sales tax levy for poorly insulated buildings. Any pricing mechanism can be introduced low at first and subsequently increased if emission targets are not met.

Pricing sends cost signals to the market, incentivising adoption of the most cost-efficient options. These signals can act to drive rational economic choices, for example in a business case for investment in a district heating system. However, many investments must be made by building owners, where the business case is not the sole driver. As with financial support, then, response is limited: not everyone responds to financial measures (price inelasticity), not everyone is able to (e.g. lack of access to finance) and not everyone is eligible (e.g. split incentive).

An important weakness is that pricing policies can aggravate inequality and energy poverty, owing to increased costs and the fact that not everyone is able to invest in measures. In addition to pricing policies, therefore, flanking policies will need to be taken to mitigate these effects, such as financial support, requirements for rented properties and general poverty alleviation measures.

The strengths and weaknesses of pricing are as follows:

Strengths	Weaknesses
– Creates level playing field – Low administrative costs if system can be tied to existing tax system	– No full response due to price inelasticity and non-economic barriers – Risk of investing in unsustainable solutions without CO_2 pricing – Risk of increased energy poverty

Regulatory instruments

Regulatory instruments are based on legal (regulatory) provisions and are mandatory. Examples include technical requirements in the form of legal standards or terms for contractual agreements. More specifically:

- Energy performance standards regulate the CO_2 emissions of the total building envelope, appliances and energy infrastructure. For new constructions, the standards must be fulfilled to obtain building permits. Existing buildings may be required to meet them on certain occasions (most logically, when leasing or selling the building through a notary), thus making the renting or selling party responsible. The builder (in the case of new constructions) or owner (for existing buildings) is thus made responsible for complying with the standard by adopting decarbonisation measures prior to the build, delivery, lease or sale of the building.
- A cap on the GHG emissions of the energy carriers sold by an energy company (electricity, gas, district heat). To ensure 100% reduction of carbon emissions, this cap is gradually reduced to zero. By targeting energy companies, the number of parties involved in executing the policy is limited. The additional cost of the decarbonisation measures needed to meet this cap is passed on to the consumer, who will incur higher energy costs. This incentivises demand reduction on the consumer side, as well as a switch to decarbonised energy carriers/heating solutions, and thus stimulates the market for efficiency measures. However, these higher energy costs aggravate energy poverty.
- A final example are efficiency requirements for new appliances.

In the implementation and design of regulatory policies it is important not to skew the direction of measures towards non-optimal outcomes, but instead give freedom to choose cost-effective and desirable measures. For example, performance regulations that steer CO_2 emissions and energy use give the market the freedom to choose cost-efficient measures.

The strengths and weaknesses of regulatory instruments are as follows:

Strengths	Weaknesses
— Known impact on decarbonisation	— Risk of implementing less cost-efficient measures — Risk of imposing high costs if alternatives are expensive

Assessment of policies and barriers

The strengths and weaknesses of the various types of policy are summarised in Table 17.

Table 17 - Strengths and weaknesses of different types of policy

Type of policy	Strengths	Weaknesses
Informative instruments	— Raises awareness of need and benefits	— Uncertain effect — Most effective in combination with other measures
Financial support	— Reduces investment costs — Possibility to address energy poverty/compensate lower-income groups — Stimulates market innovations and cost reduction — Socially acceptable — Fixed cost for government	— No full response due to price inelasticity and non-economic barriers — High government costs if maximum effect is desired — Risk of unnecessary market distortion — Free riders/oversubsidising
Financing instruments	— Creates access to finance	— Becomes relevant only after there is need and/or wish to invest
Pricing instruments	— Creates level playing field — Low administrative costs if system can be tied to existing tax system	— No full response due to price inelasticity and non-economic barriers — Risk of investing in unsustainable solutions without CO_2 pricing — Risk of increased energy poverty
Regulatory instruments	— Known impact on decarbonisation	— Risk of implementing less cost-efficient measures — Risk of imposing high costs if alternatives are expensive

Based on these strengths and weaknesses, an assessment can be made of the policy instruments best suited for addressing the barriers to decarbonisation measures in each of the five target areas (Table 18).

Table 18 - Synopsis of policies best suited to addressing barriers to decarbonisation measures

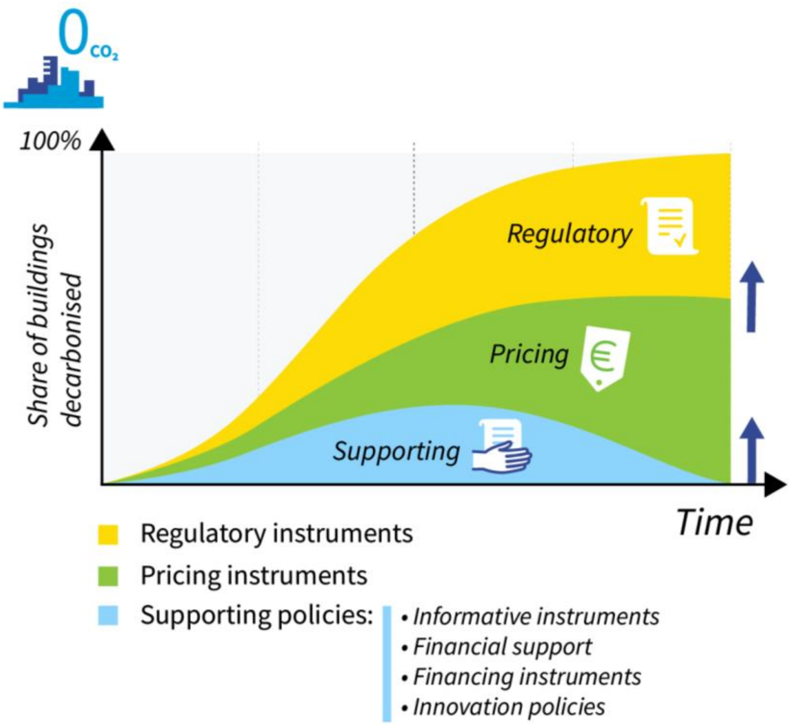
Barrier	Financial support	Pricing instruments	Regulatory instruments	Financing instruments	Informative instruments
Lack of knowledge					X
Lack of economic incentive	X	X			
Inability to invest				X	
Fragmentation of market	X		X		
Lack of skilled labour	X				
Split incentive	X		X		
Custom and habit			X		

As the Table 18 shows, to address all the barriers a mix of policy instruments is needed:

1. **Informative instruments** to address the lack of knowledge and information.
2. **Financial support and pricing instruments** to provide an economic incentive, create a level playing field and stimulate the market.
3. **Financing instruments** to address the inability to invest.
4. **Regulatory instruments** to address split incentive, custom and habit, ensuring that the full potential is utilised (backstop policies).

When combined in a comprehensive policy package, these policy instruments can enable, incentivise and ensure full decarbonisation. Together, the policies form a comprehensive pathway towards decarbonisation of the residential building sector, as shown schematically in Figure 12.

Figure 12 - Decarbonisation policy package



4.3 Policy framework

To make full use of the potential for decarbonisation, appropriate combinations of policies need to be developed for each of the target areas identified in the residential buildings sector, viz.:
- building envelope;
- heating fuel switch (incl. heating appliances and energy carrier used for heating);
- home appliances and lighting;
- electricity;
- building materials.

The policy matrix in Table 19 provides an indication of how the various types of policy instrument can best be matched to these target areas. *The cited measures are merely examples and the matrix is not intended as a comprehensive overview*. The examples are cited, moreover, regardless of whether they are already implemented, at either the EU or national level.

Table 19 – Matrix of policy instruments and target areas, with examples (*for illustrative purposes only*)

Type of Instrument	Building envelope	Heating fuel switch	Home appliances	Electricity	Building materials
Informative instruments	Renovation passport or efficiency labels for buildings	Efficiency labels for H/C appliances	Product labelling	Carbon labelling of energy carrier	Carbon passport for materials
Financial support	Financial support of energy efficiency measures (demand reduction)	Subsidy of H/C appliances	Subsidy of electrical appliances	Subsidy of decarbonised energy carrier & infrastructure	Subsidy of zero-carbon building materials
Financing instruments	Financing for renovation	Financing for H/C systems	Financing for appliances	Financing for renewables & infrastructure	Financing for materials & recycling
Pricing instruments	Energy performance-based property taxation	Energy pricing	Energy pricing	CO_2 pricing or taxation of energy carrier	CO_2 pricing of materials
Regulatory instruments	Technical requirements for building envelope/ efficiency	*Efficiency standards for heating systems* Targeted obligation for district heating	Efficiency standards for appliances	Requirements for decarbonisation of energy carrier(s)	Requirements for low-carbon materials use

Given the respective strengths and weaknesses of each type of policy, a combination of the various instruments — with regulatory instruments as a backstop — is needed in every target area to achieve full decarbonisation of the residential buildings sector.

5 Gaps in existing EU policy

The policy roadmap developed in this study encompasses policies at the EU, national and local levels. In this chapter we describe the EU policies currently in place and the areas they target, mapping them onto the matrix developed at the end of the last chapter to identify gaps in each of the target areas. In the next chapter we draw conclusions on what is additionally required — at the EU, national or local level — to bridge these gaps.

5.1 Overview of existing EU policy

The EU directives and other provisions most relevant to the residential built environment are as follows:

- **The Energy Performance of Buildings Directive (EPBD)** is directed at energy savings in buildings. It requires all new buildings to be Net Zero Energy Buildings (NZEB) from 2021 onwards, and requires member states to set up Long Term Renovation Strategies (LTRS) (translating ideally to an investment plan and implementation) and implement Energy Performance Certificates (EPC) for all existing buildings. Minimum energy performance standards are required for major renovations, if they are cost-effective.
- **The Energy Efficiency Directive (EED)** sets a 32.5% energy savings target for 2030 and mandates national energy savings of at least 0.8% of annual final energy consumption. Member states can choose which policy instruments are used to reach this target. One possible implementation is energy efficiency obligation schemes (EEOS) that require energy companies to incentivise, finance, require or otherwise deliver energy savings at final customers. Member states can also opt for alternative instruments such as energy or CO_2 taxes, financial incentives and voluntary agreements. The EED also requires each member state to carry out an assessment of the national potential of district heating and cooling.
- **The Renewable Energy Directive (RED)** sets a target of 32% of renewable energy in 2030, with all sectors included. A specific target of 1.3% increase per year has been set for the share of renewables used for heating and cooling, which includes the use of waste heat in buildings.
- **The Energy Taxation Directive (ETD)** lays down a minimum tax rate for energy carriers such as heating fuels and for electricity. The ETD is currently being revised to include a CO_2 element, allowing member states to apply a CO_2 tax.
- **The EU Emissions Trading Scheme (ETS)** sets a price on carbon emissions through a cap-and-trade system for industrial producers, including electricity generators.
- **The Effort Sharing Regulation (ESR)** sets national, binding, annual GHG emission reduction targets for sectors outside the scope of the EU ETS, including buildings.
- **The Ecodesign Directive** sets minimum mandatory requirements for the energy efficiency of numerous product groups, including for heating, cooling and electrical appliances.
- **The Energy Labelling regulation** prescribes energy labels for household and commercial product groups.
- **The Construction Products Regulation (CPR)** provides a common technical language to assess the performance of construction products.
- **The EU Governance Regulation** sets out requirements for planning, reporting and monitoring of energy and climate goals.

Recent developments

Two recent developments that may impact these directives in the short term are the European Green Deal and the Circular Economy Action Plan.

The European Green Deal (EGD) (EC, 2019d) has broad aims, one of which is to initiate a ‘renovation wave’ to increase the building renovation rate. Key actions outlined in the EGD are:

- Rigorously enforcing the EPBD.
- Reviewing the Construction Products Regulation, to ensure that buildings are designed in line with the needs of the circular economy and leading to increased digitisation and climate-proofing of the building stock.
- Introduction of innovative financing schemes under InvestEU, targeting housing associations or energy service companies that could roll out renovation. An essential aim would be to organise renovation efforts into larger blocks so as to benefit from better financing conditions and economies of scale.

The Circular Economy Action Plan (CEAP) (EC, 2020b) sets out to launch a comprehensive Strategy for a Sustainable Built Environment, addressing construction and renovation of residential buildings. Key elements are:

- Assessing sustainability performance of construction products in the context of the revision of the Construction Product Regulation, including possible introduction of recycled content requirements for certain construction products, taking into account their safety and functionality.
- Developing digital logbooks for buildings.
- Using Level(s), a voluntary reporting framework to assess the sustainability of buildings, to integrate life cycle assessment in public procurement and the EU sustainable finance framework.
- Possible revision of the material recovery targets laid down in EU legislation for construction and demolition waste and its material-specific fractions, including insulation materials.
- Reviewing the Ecodesign Directive and widening it to product groups such as electronics, ICT, textiles, furniture and high-impact intermediate products like steel and cement.

Matrix of policy instruments

In Table 20 the matrix presented in Table 19 in Section 4.3 is used to summarise the relevance of the policy instruments already in place under existing EU directives for the various target areas.

As some of the provisions of the EU directives, like RED and EED targets, are implemented in national policies using a wide variety of policy instruments in such cases national targets are cited separately. Because of the freedom of choice that member states have in implementing the EED, this directive is slotted into multiple cells and marked with an asterisk. Financing instruments are not included, as they are considered secondary to the other types of instruments.

Table 20 - Matrix of policy instruments and target areas

Type of policy instrument	Building envelope	Heating fuel switch	Home appliances	Electricity	Building materials
National targets	– ESR – EED	– ESR – RED – LTRS		– RED	
Informative instruments	– EED* – EPBD (EPC) – EPBD (LTRS) – LTS	– EPBD – LTS – RED II	– Energy labelling – EED (smart meters)		– CEAP (digital logbooks)
Financial support	– EED* – EGD				
Pricing instruments		– EED* – ETS – ETD – EED (EEOS)		– ETS – ETD	– ETS
Regulatory instruments	– EED* – EPBD (new buildings; major renovations)	– EPBD	– Eco-design	– RED – EPBD (electricity prosumers)	– CPR – CEAP (revision of Ecodesign)

5.2 Trajectory of emissions reduction under current policies

According to the European Environment Agency, with existing and additional planned national policies and measures Europe is not on track to meet the 40% GHG emissions reduction target for 2030 (EEA, 2019a). As described in Section 2.3, projections of emissions from residential buildings paint a similar picture. With the policies in place as of 2016 (PRIMES EU reference scenario), emissions from residential buildings are expected to decrease by only 30% between 2020 and 2050. In the 'Clean Planet for All' baseline scenario, which assumes achievement of the 2030 targets, emission cuts in residential buildings in 2050 are taken to be approximately 45% compared to 2020 (EC, 2018).

In summary, then, current and planned policies will not be effective in achieving full decarbonisation of the residential buildings sector.

5.3 Gap analysis of EU policy framework

The types of policy instruments that follow from current EU directives strongly vary for each target area. A high-level assessment of these policies yields the following review of the scope of EU legislation for each target area, and where there are gaps to be filled at the EU, national and/or local level.

– The building envelope is targeted by the Energy Performance of Buildings Directive (EPBD), which introduces minimum energy performance requirements for new buildings. It also sets minimum energy performance standards for major renovations of existing buildings. In addition, most member states seek to secure part of the target of 0.8% annual reduction of energy use under the Energy Efficiency Directive (EED) with measures targeting building renovation (building envelope or heating appliances), but the types of policy instrument adopted differ per member state, varying from mandatory schemes to energy or CO_2 taxes, financial incentives and voluntary agreements. Regulatory policy instruments are not often chosen (Rosenow, et al., 2015).

- Switching to decarbonised heating fuels is to some extent covered by the Renewable Energy Directive (RED) in the form of an indicative target to increase renewable energy for heating. There are no major pricing or regulatory policies at the EU level that help achieve this target, however, member states are responsible for implementing measures to this end.

- Appliances are subject to the energy efficiency standards under the Ecodesign Directive and they are also included in the Energy Labelling Regulation.

- Decarbonisation of electricity is targeted by the RED and the EU Emissions Trading Scheme (ETS). The Energy Taxation Directive (ETD) sets a minimum tax for energy, but this does not yet incentivise decarbonisation of energy carriers, as it is not based on their carbon intensity. The current revision of the ETD aims to set a framework for CO_2 taxation.

- Building materials are included in the Construction Products Regulation (CPR). The Circular Economy Action Plan (CEAP) considers adding circularity and carbon footprint requirements; this will be developed further in the coming years.

Thus, some target areas are addressed by legislation at the EU level, while others are not, in which case appropriate policy action Is up to member states. These gaps in current EU legislation for each target area are summarised in Table 21, with the focus on regulatory policy instruments.

Table 21 - Gaps in EU regulatory policy in each target area

	Building envelope	Heating fuel switch	Home appliances	Electricity	Building materials
Existing EU policy	Performance requirements for new buildings and major renovations		Efficiency requirements for new appliances	Cap on emissions (ETS)	Cap on emissions from ETS sectors
Gaps	Performance requirements for existing buildings	Cap on emissions for heating fuels Obligation or ban of heating systems Ban on fossil fuel in new constructions			Lifecycle emissions requirements

As the table shows, home appliances and electricity are subject to binding regulations under current EU directives, while these are lacking in three important areas:
1. Building envelope of existing buildings.
2. Heating fuel switch.
3. Building materials.

This lack of regulatory instruments means there are no regulatory policies in place at the EU level to ensure decarbonisation takes place, nor that the targets under the Effort Sharing Regulation, Renewable Energy Directive and Energy Efficiency Directive will be met. Thus, it is currently up to each individual member state to implement strong financial, pricing and regulatory policies in these areas to achieve decarbonisation in buildings.

6 Policy roadmap for full decarbonisation

As we saw in the last chapter, under current EU policies the building envelope of existing buildings, energy carriers for heating and building materials are not comprehensively addressed by means of pricing or regulatory instruments, while in Chapter 3 (Figure 8) we concluded that these are precisely the areas with the greatest emissions reduction potential. It follows that if these areas are addressed by vigorous policies at the EU, national and local level, emissions can be reduced on a much steeper trajectory.
This chapter identifies priority areas for improving the policy framework for decarbonisation of residential buildings with respect to these three areas, for the EU and/or national governments, taking into account country-specific circumstances.

6.1 Building envelope for existing buildings

The Green Deal acknowledges that the renovation rate needs to be increased in order to achieve the full emission reduction potential by 2050. Current financial support and financing schemes are having insufficient effect and regulatory policies are therefore needed. Current building standards cover new buildings only. Although EPBD sets minimum energy performance standards for major renovations, these do not generally increase either the rate or depth of renovation.

The reach of these **minimum energy performance standards** can be increased by utilising trigger points for renovation. For privately owned buildings, standards can apply to the moment of sale, while for (commercial) rental they can apply to the moment the building gets new tenants (new rental), or at a time announced well in advance. If a building or apartment does not conform to the standard, it will be ineligible for sale or rental. For social housing, standards can additionally be linked to renovation plans required by the (national) government according to pre-determined timelines. In some cases, buildings will not change ownership or tenancy frequently enough before 2050.Energy efficiency requirements may therefore need to encompass buildings during ownership or rental as well, with an obligation to decarbonize the remaining energy demand.

Price signals can also be used as a possible policy instrument to incentivise renovation. Property taxes or sales taxes can be based on a building's energy performance, providing a financial incentive for improvement. Energy taxes and CO_2 taxes also create an incentive for energy efficiency (see hereafter).

6.2 Switching to decarbonised heating fuels and appliances

Residential space heating relies heavily on fossil fuels (gas, oil and coal) and switching to non-fossil energy carriers and heating systems is therefore absolutely indispensable for achieving full decarbonisation. The RED imposes an indicative target for renewable energy in heating, leaving it up to member states to achieve it through national policies.

This indicative target of 1.3% annual increase in renewable energy in heating is not binding, however, nor is it by any means sufficient to arrive at full decarbonisation by 2050[6].

There is a major policy gap when it comes to the energy carriers used in the built environment, with no provisions in place to ensure the required switch from gas, oil and coal to renewable alternatives and sustainable appliances. Matters are most complex for heating and cooling, because measures are needed in the entire value chain (appliance, infrastructure and production)[7] and by different actors. Owing to the long lifetime of new investments in heating systems, infrastructure and energy generation, regulatory policies geared to decarbonising the energy carriers for heating are needed as a matter of priority. The great majority of any future investments in fossil heating systems and infrastructure (natural gas, oil, coal) will be in place until after 2050 and should thus be avoided at all cost.

CO_2 pricing

To address the energy switch for heating, a combination of CO_2 pricing and regulatory instruments will be needed to reduce the cost of decarbonised energy carriers relative to fossil heating fuels and thus create a level playing field. Pricing an energy carrier (electricity, gas, oil, coal) means imposing a price or tax on its carbon footprint, incentivising a switch to decarbonised energy carriers as well as efficiency measures. Electricity production falls under the ETS, while gas, coal and district heating do not, and would be very complex to include and lead to unwanted effects (CE Delft, SQ Consult & Cambridge Econometrics, 2014). The current energy taxation system (Energy Taxation Directive) is based on energy content, while some countries have successful experience with a CO_2-based tax (CE Delft, 2019). The current review of the ETD will include a framework for CO_2 taxation.

Switching to a taxation system based on CO_2 emissions would stimulate the production of renewable energy carriers for heating as well as the switch from fossil-based systems to zero-carbon solutions, e.g. from natural gas boilers to electric heating (CE Delft, 2019). A CO_2 price works best if it is imposed on all energy carriers (in particular, both electricity and gas). The tax can be levied either close to the producer or at the end user, but in both cases it will ultimately be consumers pay, via their energy bill. Carbon pricing will incentivise both reduction of energy demand and a switch to renewable energy carriers. In the case of gas, for example, a CO_2 tax would increase the price of natural gas but not of renewable options, creating a more level playing field for alternatives such as renewable electricity, district heat or biomethane. Calculations for the Netherlands show that energy efficiency, alternative heating strategies and renewable energy incentives would be a financially attractive means of halving natural gas use at a CO_2 price of 43 €/tonne (CE Delft, 2019).

Pricing is most effective if the price increase is announced well in advance, so the market can take it into account in long-term investment decisions.

[6] To move from 10 to 100% via a 1.3% annual increase would take 77 years.

[7] With the exception of buildings that currently have electric heating.

Preventing energy poverty

A drawback of carbon pricing is that it can lead to an increase of energy poverty unless appropriate flanking measures are taken to protect vulnerable groups. Energy poverty can be alleviated or prevented through deliberate policy measures, including:

- Financial support of building efficiency measures targeted towards lower-income groups, such as modernisation plans for multi-family blocks and free provision of insulation measures.
- An energy allowance, e.g. via energy tax deduction.
- Progressive energy taxation, with a low tariff (or exemption/deduction) for low consumption to compensate lower incomes, and a higher tariff for higher consumption.

These energy poverty policies should be implemented on top of pricing and regulatory measures and should be embedded in a national policy framework that makes due allowance for the particularities of the national situation.

Regulatory policies

Owing to price inelasticity, split incentives and a range of other factors, response to economic instruments is never complete, which means regulatory policies are also needed if full decarbonisation is to be achieved. Such policies can be used as a backstop if decarbonisation falls behind the required trajectory.

Regulatory instruments to decrease space heating emissions can be directed towards energy companies. For example, a cap (permit) could be imposed on the GHG emissions associated with its energy sales (electricity, gas, district heat, coal, oil), with this cap being reduced in increments to zero. These emission permits could be traded among energy companies. The additional costs of the decarbonisation measures needed to meet this cap would be passed on to energy consumers, for whom the effect would be the same as for carbon pricing. This system resembles the EU ETS, but requires a separate emissions cap, as buildings sector emissions are part of the Effort Sharing Regulation and inclusion in the EU ETS would have unwanted side effects, as described in (Cambridge Econometrics, 2020).

CO_2-based pricing and legislation are examples of technology-neutral policy instruments that leave it up to consumers to choose the most appropriate technology in their situation. For heating/cooling, in particular, these types of instruments deserve priority, because different solutions will be cost-efficient in different situations and stimulating or prescribing specific technological solutions could therefore lead to (substantially) higher costs. In addition, the lowest cost for society is often not reflected in the business case for the supplier or consumer. This is especially true for district heating, which requires collective action. The choice for an optimal heating solution, and steering towards it with dedicated policies, can be supported by local and regional governments developing heat plans at their scale, first analysing the building stock to determine where certain solutions are most cost-efficient from a societal perspective. Local and regional governments should then be given the requisite instruments to provide (e.g. facilitate, tender, or construct) district heating services for these specific, locally determined groups of buildings.

The EED requires each EU member state to carry out an assessment of the national potential for district heating and cooling. This potential needs to be elaborated into local, specific areas and regional or local authorities need to be provided with the instruments to assign and implement district heating in those areas.

Once alternative heating solutions are available and affordable, in the longer term legislation can be introduced to prohibit fossil fuel-based heating systems such as gas or coal burners entirely, or even gas grids in specific areas. A first step in this direction is to implement increasingly strict standards for heating appliances. It should be borne in mind, though, that an outright ban on gas grids excludes the possibility of using existing gas infrastructure for zero-carbon gas such as biogas and hydrogen in the future. Such policies should therefore be limited to areas without existing gas infrastructure or cases where alternatives for zero-carbon gas are more attractive.

6.3 Reducing embedded emissions of building materials

The current EU ETS includes production facilities for construction materials like steel and concrete, thus imposing an industry-wide cap and a price on the GHG emissions from production of these materials. Despite this trading scheme, however, emissions from industry (including materials production) are still significant and are not on track for the EU's emissions reduction target (EEA, 2019b). In addition, not all the materials used in buildings fall under the EU ETS.

Further decarbonisation of production can be driven by imposing additional legislation on producers, by further strengthening the EU ETS, for example. This is beyond the scope of the present study, however.

Decarbonising materials and industry also needs to be driven by policies targeting the demand side, by introducing requirements for the buildings and construction sector that create a market for materials and products that are dearer than conventional alternatives. These requirements should target both operational and embedded emissions ('whole life carbon') in an integrated manner, to avoid situations where requirements on embedded emissions disincentivise efforts on operational emissions (WGBC, 2019a). While geared to the overall objective of decarbonisation, they should leave scope for different approaches rather than prescribing specific solutions (such as targets for a certain percentage of recycled materials, or timber buildings). To facilitate this building-level approach the Level(s) framework was developed: a voluntary reporting framework on building sustainability that is currently being tested (EC, 2020a).

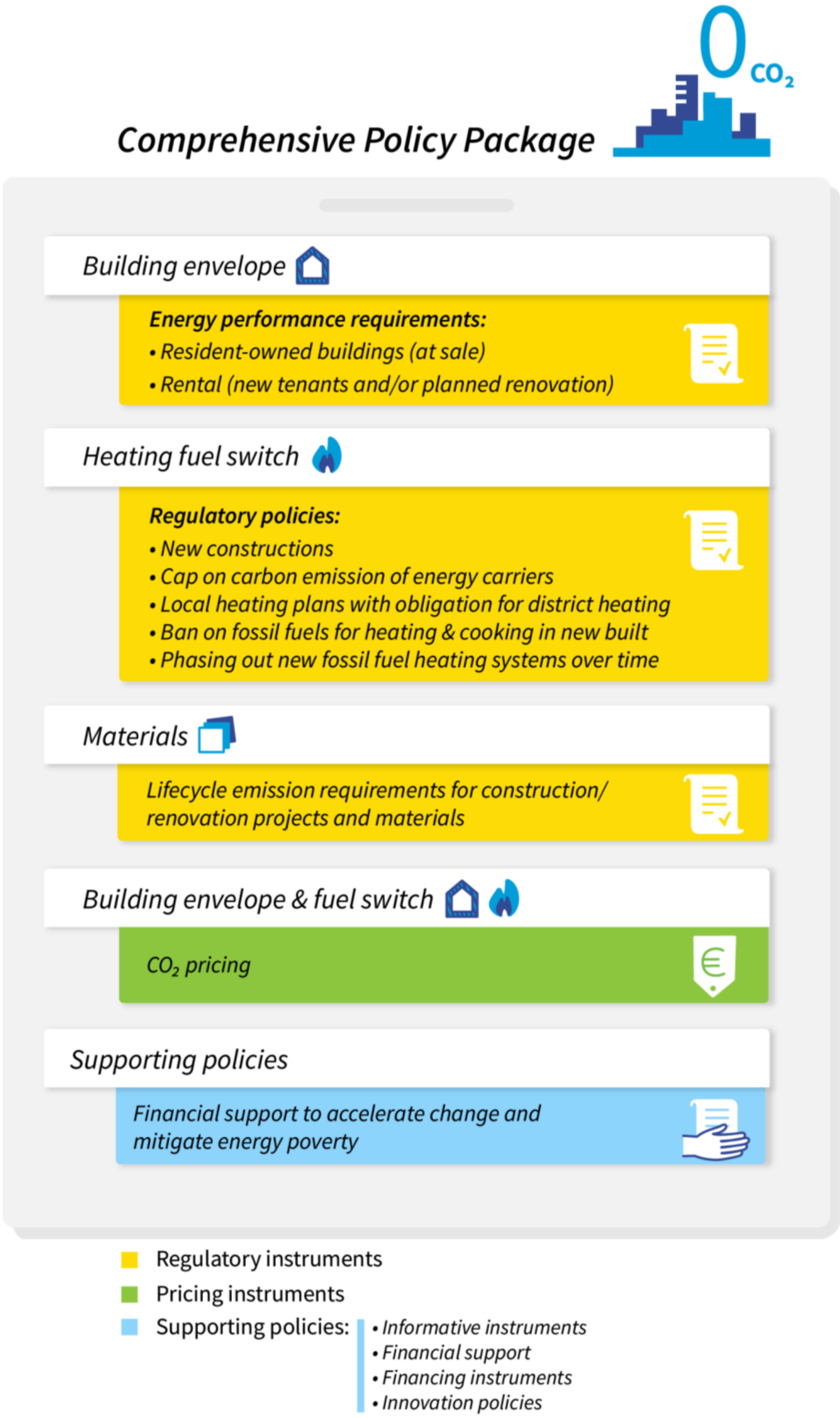
A first step towards including whole life carbon in requirements is to explore how this can be used in procurement, as described in the EU Circular Economy Action Plan.

There are a number of ways requirements on embedded emissions can be included in existing EU directives. Under the Circular Economy Action Plan (CEAP) consideration is being given to adding circularity to the Construction Products Regulation (CPR); this could be expanded to include definitions for embedded emissions. In addition, the CEAP intends to expand the Ecodesign directive to include intermediate products such as cement.
The Energy Performance of Buildings Directive (EPBD) provides an opportunity to set building-level requirements for the climate performance of buildings. Its scope could be extended to set criteria for both operational and embedded emissions in the transition to net-zero-carbon buildings. This can ensure that lifecycle GHG emissions are considered in the design of new buildings and major renovations.

6.4 Summary of policy recommendations

The main policy recommendations described above are summarised in Figure 13 as a comprehensive policy package.

Figure 13 – Synopsis of policy instruments in comprehensive policy package



6.5 Timeline

Given the long lifetimes of investments associated with all the emissions target areas identified in the residential buildings sector and the infrequency of other trigger moments, as explained in Section 3.3, there is an urgent need for pricing and regulatory policies to ensure these investment cycles can be utilised.

Pricing and regulatory instruments need to start at a low level and be announced well in advance to allow the market and consumers to plan for change. In parallel, financial support is needed to facilitate the transition. After implementation, the price levels, requirements and standards will need to be strengthened by setting intermediate objectives in line with EU targets, to reach 100% decarbonisation by 2050. This timeline, too, should be announced in advance.

7 Case studies

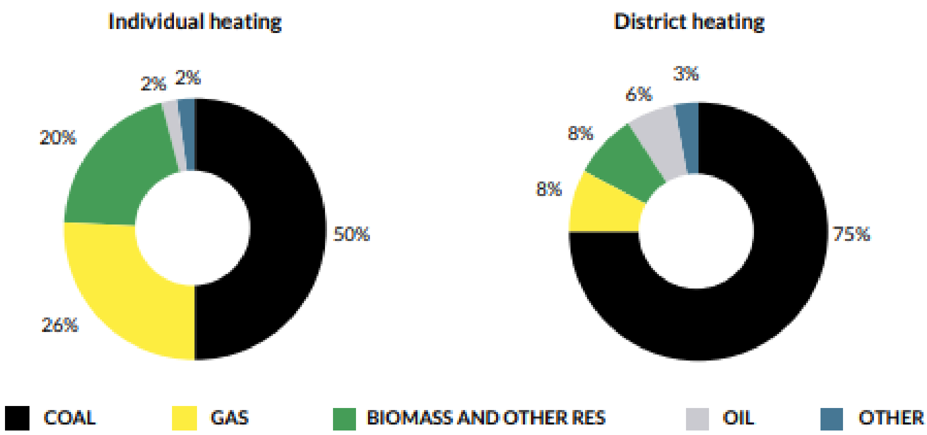
In this chapter we consider three country case studies: Poland, Spain and the Netherlands. In each, examples are discussed of policies that address the two priority areas for emissions reduction: energy carriers for heating, and the building envelope of existing buildings.

7.1 Case study: Poland

7.1.1 Country context

In Poland residential energy consumption is dominated by space heating (66%) and water heating (16%), for which there is high reliance on fossil fuels. Coal is often used, since it is cheap and mined domestically. However, Polish coal is becoming more expensive and supply is declining, leading to growing import dependency (National Energy Conservation Agency ; Institute for Structural Research, 2019). Over half of domestic heating demand is covered by coal (National Energy Conservation Agency ; Institute for Structural Research, 2019), which is used for both individual heating and district heating, which in Poland supplies approximately 20% of residential heating (Eurostat, 2020c). The heating energy mix is shown in Figure 15.

Figure 14 – Energy mix for heating in the Polish residential sector

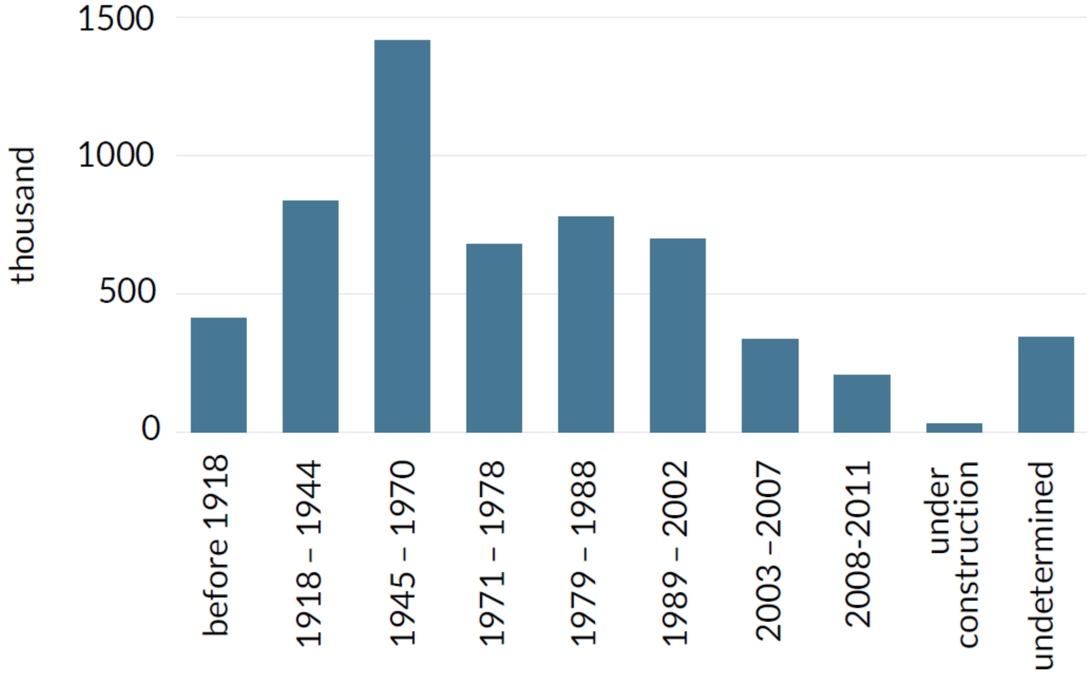


Source: (National Energy Conservation Agency ; Institute for Structural Research, 2019).

The high share of coal in the energy mix leads to high CO_2 emissions, as well as air pollution with sulphates, nitrogen and particulate matter. Polish cities are among the most polluted cities in the European Union, with 40,000 people dying prematurely each year because of poor air quality (National Energy Conservation Agency ; Institute for Structural Research, 2019). In Poland air pollution is the strongest driver for switching to different energy carriers for domestic heating.

Just over half of Polish citizens live in single-family houses (56%) and the majority of homes are owner-occupied (see Section 2.1). Most residential buildings in Poland were built between 1945 and 1970, but a significant share are older and these have the lowest level of insulation. It is estimated that 30% of buildings in Poland are uninsulated (National Energy Conservation Agency ; Institute for Structural Research, 2019).

Figure 15 - Construction date of Polish residential buildings (National Energy Conservation Agency ; Institute for Structural Research, 2019)



Source: (National Energy Conservation Agency ; Institute for Structural Research, 2019).

Almost 10% of Polish households are affected by energy poverty (National Energy Conservation Agency ; Institute for Structural Research, 2019). These energy-poor households often live in energy-inefficient buildings and use inefficient coal-fired heating systems owing to the low cost of coal. Switching to a different energy carrier for heating would increase energy poverty, since alternatives are more expensive.

7.1.2 Policy examples

The country's National Energy and Climate Plan, NECP (MAP, 2020), includes a number of policies of relevance for the built environment. First of all, there are several policies promoting use of renewable energy, such as the auction system for large-scale renewables and feed-in tariffs for small-scale renewables. Furthermore, the NECP formulates ambitions for the promotion of district heating and use of high-efficiency combined heat and power (CHP) plants. For new buildings there are minimum standards for energy use and thermal insulation (Minstry of Transport, Construction and Maritime Economy, 2013). Innovation is stimulated by the Intelligent Development Operational Programme, which incentivises R&D on low-emission heating technologies (Narodowe Centrum Badań i Rozwoju, 2019). Finally, there are policies encouraging renovation of existing buildings: the Thermal Renovation Fund and the Clean Air Programme. These latter two will now be highlighted, as they are the most relevant for the residential sector and their approach is unique in the EU.

Thermal Renovation Fund (1998-present)

In the mid-1990s the Polish government introduced a Thermal Renovation Fund to increase the energy efficiency of the residential sector, which was used mainly for renovating multi-family buildings. A share of the credit for this 'thermal modernisation' is awarded as funding, with the remainder provided as a loan.

Between 1999 and today, over 45,000 multi-family buildings have received subsidies and loans for thermal modernisation and a total of 2.7 billion PLN has been credited.
The programme has thus contributed significantly to improving the energy efficiency of the Polish residential sector. Recent years have seen a decline in the subsidies and loans granted, however.

Clean Air Programme (2018-present)

To address Poland's air quality issues, the Clean Air Programme came into effect in 2018. Its main aim is to replace inefficient coal-fired boilers, the main source of air pollution in the residential sector. It also incentivises thermal modernisation of buildings to reduce energy demand. The programme is dedicated to existing single-family houses, since these buildings often use old boilers and low-quality fuels and have the highest potential for improvement.

Prior to introduction of the Clean Air Programme, there was no large-scale programme in place geared to renovation of single-family buildings. The Clean Air Programme is a long-term effort that will continue through to 2029. The budget is 103 billion PLN, equivalent to 22 billion Euro. In theory this budget is enough to subsidise the replacement of over 2.8 million coal-fired boilers or the renovation of 2 million single-family buildings[8].
At present the Programme is publicly funded, but the government is looking into involving commercial banks.

The Clean Air Programme consists of a mix of instruments: subsidies, loans and standards. Home-owners can apply for grants and loans for both replacement of their heating source and insulation of their homes. In the first year 80,000 applications for grants and loans were submitted and over 46,000 subsidies have been granted[9].

The subsidy for replacing heating equipment depends on the new type of unit, the highest subsidy being awarded for replacing a coal-fired boiler by a heat pump[10]. Subsidies are also awarded for replacing old, inefficient coal-fired boilers by modern, more efficient coal-fired units, which must then meet efficiency and fuel quality standards. Five emission classes are distinguished for coal-fired boilers, with new units having to meet the requirements of the highest class (class 5). These boilers are over 90% less polluting than old models[11].

[8] These numbers are merely indicative. They correspond to the total budget of the Clean Air Programme divided by the maximum subsidy per boiler/building. In reality, part of the budget is used for replacing the heating source and part for thermal modernisation of buildings.

[9] Ministry of Climate : The Clean Air programme was launched a year ago

[10] Program Czyste Powietrze: Czyste powietrze- dofinansowania

[11] Czyste Ogrzewanie : Normy emisji dla domowych kotłów – Ecodesign i PN-EN 303-5:2012

The subsidy for housing insulation takes the form of an income tax deduction, possibly combined with an additional subsidy[12].

There are special provisions for energy-poor households. Under the Clean Air Programme municipalities can receive grants to help energy-poor single-family households invest in home insulation and replace their heating system. One solution available to municipalities is to provide connection to district heating[13].

Gaps and good practices

Because of the major amount of funding involved, the Clean Air Programme has the potential to contribute significantly to decarbonising the Polish building sector. It is still too early to assess whether it will indeed be successful, though, as it was implemented only two years ago and is still being improved and extended. The first signs are promising, however, with over 80,000 applications being submitted in the first year.

The Clean Air Programme is focused on single-family buildings, since these are the main source of air pollution in the Polish residential sector. There is consequently great potential for emissions reduction. In the long term, however, there also needs to be renovation of multi-family buildings, which are not presently targeted.

The Clean Air Programme comprises loans and grants for home-owners and this financial support will lead to a decrease in the number of coal-fired boilers. On its own, though, this is not enough to achieve a full phase-out of such boilers, since not all home-owners will make use of these funds. Regulation will therefore also be necessary as a backstop, and it is important that this be introduced as soon as possible, to make use of end-of-lifetime natural investment moments.

Intelligent Development Operational Programme

The Intelligent Development Operational Programme is a major innovation subsidy scheme that stimulates research and development. It is co-financed by the European Regional Development Fund. It includes a subsidy programme of 200 mln PLN (48 mln EUR) for research institutions, consortiums and SMEs to develop low-emission heating technologies (Narodowe Centrum Badań i Rozwoju, 2019). This grant scheme provides a stimulus for coal boiler manufacturers to develop low-carbon heating appliances.

7.2 Case study: Spain

7.2.1 Country context

Because of the climate, the average heating demand of the residential sector in Spain is among the lowest in the European Union. Within the country there are major regional differences in climate, however: regions in southern Spain have only 850 to 1,100 heating degree days per year[14], while some regions in northern Spain have over 2,750, comparable to countries like Belgium and the Netherlands. In total, Spain has six different climatic

[12] Program Czyste Powietrze : Ulga termomodernizacyjna

[13] Program Czyste Powietrze : Stop Smog

[14] The number of Heating Degree Days index is calculated by summing the temperature difference between outside and inside (in this case 18°C) for all days with a temperature below 15°C.

regions (Ministerio de Fomento, 2017). These interregional climatic differences mean there are substantial differences in the heating demand.

Because of the low average heating demand, total residential energy consumption is among the lowest in the EU. In Spain the average energy consumption per m^2 of a residential building is 103 kWh/m^2/year, compared with 184 kWh/m^2/year for the EU-28 (Ministerio de Fomento, 2017). Consequently, space heating accounts for a smaller share of residential energy demand: only 43%, compared with 64% for the EU as a whole. Demand for space cooling, on the other hand, is higher than the EU average (Eurostat, 2017b). Nevertheless, it contributes only marginally to the total energy demand of the residential sector (< 1%).

In Spain just over half of heating demand is covered by fossil fuels: roughly 30% by petroleum product and 25% by natural gas. There is also substantial use of biomass (Eurostat, 2017b). In this country solar thermal energy offers major potential for decarbonising water heating demand, which accounts for almost 20% of total residential energy demand.

The vast majority of homes in Spain, almost 80%, is owner-occupied, with less than 15% privately rented. In contrast, in the EU-28 as a whole only 65% of homes are owner-occupied and over 20% privately rented. Furthermore, the majority of people in Spain live in multi-family buildings: around 65% (Housing Europe, 2017), most of them organized in home-owners' associations, which means decisions on renovation are often a collective process requiring unanimous agreement. This makes the decision-making process more complicated than in countries with predominantly single-family dwellings (Ministerio de Fomento, 2017).

Approximately 9% of Spanish households are characterised as energy-poor, slightly above the EU average of 8% (Eurostat, 2020c). The share of energy-poor households has increased in recent years (Ministerio de Fomento, 2017).

7.2.2 Policy examples

The Spanish National Energy and Climate Plan (MITECO, 2020) and the country's long-term renovation strategy (Ministerio de Fomento, 2017) include several policies relevant for the residential sector. First of all, Spain has implemented policies to stimulate deployment of renewable energy systems, including an auction system for renewables and incentives for citizen energy projects. There are also several policies geared to improving building envelopes. For existing buildings, a renovation fund (PAREER/PAREER-CRECE) has been established, while new buildings are subject to the technical building code. These policy instruments are now discussed in more detail.

Renovation fund (PAREER/PAREER-CRECE)

The Spanish government has the ambition to renovate 1.2 million dwellings before 2030[15]. The main instrument to this end is the PAREER programme, initiated in 2013 and extended in 2015, when it was renamed PAREER-CRECE. This national programme provides government support for thermal modernisation of existing buildings and is managed by IDAE, a national energy agency.

The PAREER-CRECE programme is a fund which grants financial aid and repayable loans to projects that improve a building's energy performance. This can entail improvement of the energy performance of the thermal envelope and/or the heating or lighting systems or

[15] In 2016 Spain had 25.5 million dwellings (EC, 2016b).

changing from a conventional heating source to biomass, solar or geothermal energy. The projects eligible for financial aid are chosen on a competitive basis (Ministerio de Fomento, 2017).

Apart from financial aid, the PAREER-CRECE programme also provides technical expertise, help with procedures and help with identifying potential partners. This means a single operator can assist with the entire renovation process, making it easier for investors.

Gaps and good practices

The PAREER programme is successful because it provides support during the entire process. This is important since financial aspects are not the only factors that can hold back renovation projects. The PAREER programme is therefore a good example of an integrated approach.

The PAREER programme has the potential to contribute significantly to the Spanish government's ambition of 1.2 million renovated dwellings before 2030. To achieve this aim, however, would require roughly 24 billion EUR funding (assuming costs of approximately 20,000 EUR per building), far in excess of the 400 million EUR currently earmarked. The country's ambitions for 2020, set out in the Long-Term Renovation Strategy of 2014 (Ministerio de Fomento, 2014), were not met because of insufficient funding (Climate Strategy & Partners, 2020)[16]. If this failure is not to be repeated and the renovation ambitions for 2030 are indeed to be secured, there will have to be (far) more funding. At present there is only public funding available for renovation, so attracting private funding is a possible solution.

The programme is available in all Spanish regions, with regional authorities being responsible for implementation and able to factor in regional circumstances. Its success differs significantly from region to region, with the programme only proving able to deliver in a few regions. Almost 80% of PAREER funding has been awarded to projects in four of the country's seventeen regions: Asturias, Madrid, Navarro and País Vasco (IDAE, 2020) and it will need to be more vigorously implemented in other regions as well.

Technical Building Code (2013), including solar thermal requirements

In Spain new buildings must comply with the Código Técnico de la Edificación, or Technical Building Code, introduced in 2006 and most recently updated in 2013 (Ministerio de Fomento, 2013). Its requirements also apply to existing buildings that are renovated or extended. Certain buildings, such as monumental buildings and some non-residential buildings, are excluded from the requirements.

This code contains several energy-related requirements, including upper limits for a building's energy demand, requirements on heating equipment and a minimum requirement for use of renewable energy sources.

Requirement for solar water heating

What sets this Spanish building code apart from standards in other countries is the requirement for solar heating. Because of the high amounts of solar irradiation, solar heating has high potential in Spain. As solar heating is generally used for water heating, the

[16] The ambition was to renovate 1.1 million buildings before 2020, but only 150,000 were actually renovated.

Building Code makes it obligatory for new buildings to have a solar heating installation to (partly) cover water heating demand.

Regional specifications

Because of the substantial differences in climate across the country, the aforementioned requirements differ per climatic region. Buildings in colder regions have a higher heating demand, for example, so in these regions there is a higher upper limit on energy demand. Thermal envelope requirements are more stringent here, though.
In the case of solar heating requirements, the division of Spain into climatic regions is based on solar irradiation, since this affects potential solar thermal output. Five regions are distinguished, with regional requirements differing substantially. In climatic region I (solar irradiation < 1,387 kWh/m^2/year) solar heating must contribute at least 30% to water heating demand, while in climatic region V (solar irradiation > 1,825 kWh/m^2/year) the minimal contribution is 70%.

Gaps and good practices

The solar heating requirements in the Technical Building Code are unique in the EU. In other countries use of renewable heating sources is encouraged but not usually mandatory.

Furthermore, the acknowledgement of regional differences in the building code is unique. The large climatic differences in Spain affect heating demand and the potential for solar heating. It therefore makes sense to take climatic circumstances into account in technical requirements.

While the building code enables greater deployment of solar heating, it only applies to new constructions, with little deployment in existing buildings. To realise the full potential of solar (water) heating in the Spanish residential sector will require additional policies. Improved energy performance standards, phase-out of fossil-fueled water heaters and higher pricing of fossil heating fuels are among the options to increase the use of solar heating in existing buildings.

Furthermore, the Technical Building Code contains no penalties for non-compliance. Establishment of clear penalties and provisions for enforcement are essential to ensure compliance with the code.

7.3 Case study: Netherlands

7.3.1 Country context

The majority of homes in the Netherlands are single-family dwellings (75%). In total, 60% of homes are resident-owned and 30% social housing (Housing Europe, 2017). In this country approximately 64% of residential energy use is for space heating (Eurostat, 2020c), almost 90% of which is supplied by natural gas, thanks to the presence of Europe’s largest gas field in the north of the country. Since 2012 the occurrence of earthquakes triggered by gas production has led to a decline in public support for natural gas and to growing support and a sense of urgency for reducing the heating sector’s dependency on natural gas.

In 2018 the Dutch government announced that natural gas production would be scaled back and the subsequent national Climate Agreement (2019) sets the goal of making all 7 million residential and 1 million non-residential buildings independent of natural gas by 2050. To this end, 1.5 million residential buildings are to be taken off the gas grid by 2030. While many of the Netherlands' urbanised regions have potential for district heating, such systems are proving hard to develop, owing to a lack of business cases and difficulties with collective decision-making.

7.3.2 Policy examples

For the Netherlands we highlight four policy examples:
1. EPC standard for new buildings (1995-2020).
2. Energy taxation (1996-present).
3. Efficiency standard for existing office buildings.
4. Municipal heating plans and instrumentation (2018-in development).

EPC standard for new buildings (1995-2020)

The energy performance coefficient (EPC) standard is a minimum requirement for new buildings that was first introduced in 1995 and has been gradually increased to Nearly Zero Energy Buildings (NZEB) in 2020. The EPC is based on a building's estimated total primary energy consumption using a series of indicators for heating, ventilation, lighting and so on (adjusted to useful floor area) and the renewable energy produced by the building. Thus, the requirement can be met in different ways: through better insulation, better heating appliances or production of renewable energy, giving the developer flexibility in how to comply with the requirement under different circumstances, such as opting for insulation rather than solar panels for shaded buildings (Eck, 2016). A drawback is that the calculation is fairly complex, requiring a comprehensive study in order to comply with the legislation.

The energy performance calculation is part of the building permit application. Monitoring and enforcement are carried out by regional environmental services: agencies set up to enforce regulation on behalf of municipalities. Compliance is checked during construction. In case of non-compliance, a 'cease-work' order is issued and construction halted until the requirements are met.

In the 25 years that the policy has been in effect, the energy demand of new buildings has been reduced to nearly zero. The requirements have been gradually increased to an EPC of 0.4 in 2015 and NZEB requirements in 2020.

Gaps and good practices

The EPC standard has proven effective in bringing down emissions from new buildings, owing in part to its performance-based definition: it focuses on objectives (energy efficiency) and not on specific technologies.

In addition, this design allows for innovation: there are multiple ways to comply with the performance standard. Thus, innovation may lead to introduction of new technologies unknown when the policy was first introduced, but can nevertheless be used to achieve compliance.

Energy taxation (1996-present)

To incentivise energy efficiency, in 1996 an energy tax was imposed on the electricity and natural gas used by households and other small to medium-sized (non-ETS) consumers. Implementation is budget-neutral, by decreasing income tax by the same amount as revenue from the levy.
The tax is designed to regulate marginal energy consumption and to this end consumers are assigned an annually adjusted energy tax credit, thus exempting a certain energy use, as energy is deemed a primary need.

Ever since implementation, the level of the energy tax for households has been much higher than the minimum requirements under the European Energy Taxation Directive (PBL, 2014).

Gaps and good practices

In an evaluation of five policies for residential buildings between 1995 and 2002: the EPC standard for new buildings, three types of energy efficiency subsidy and the energy tax, the last of these was found to have the greatest impact in terms of emissions reduction.
Over that period the real price of natural gas and electricity increased by 7% per year as a result of the tax. Although consumers' response to the price signals (price elasticity) was found to be limited, this is the only instrument that applies to all three priority target areas: new buildings, existing buildings and home appliances (Ecofys, 2004).

However, the energy tax is not designed to incentivise the switch to renewable electricity or heating fuels, as it targets the energy content of the energy carrier rather than its CO_2 content. In addition, the current level of the energy tax is insufficient to create a business case for alternative heating strategies (CE Delft, 2018).

Energy performance standard for existing office buildings (2012-2023)

The Netherlands does not have energy efficiency requirements for residential buildings. However, in 2012 an energy performance requirement was introduced for office buildings. On January 1st 2023, all office buildings must have energy label C or they will no longer be allowed to be used for this purpose. Owing to a number of exceptions, only about 65% of office buildings are included in the obligation (RVO, 2020). In theory this regulation is easier to implement for office buildings than for residential buildings, because office buildings often have 5-year lease contracts (ING, 2016).

In 2016 52% of office floor space was estimated to have inadequate energy performance (EIB ; ECN, 2016). The necessary improvements were analysed to be mostly in appliances (LED lighting and air conditioning) rather than insulation measures.

As a result of this legislation, the Dutch National Bank requires Dutch banks to be aware of the energy performance of buildings in their portfolio, because they forecast that non-compliant buildings will decrease in value. Banks are actively looking to 'green' their portfolio by only offering new loans for buildings that comply with the standard or have a plan to improve performance (ING, 2016).

Municipal heating plans and instrumentation (2018-in development)

As part of the legislation package for existing buildings, municipal governments are required to develop a local heating plan ('transitievisie warmte'). These plans identify the most promising alternative heating solution in each individual neighborhood and must be based on the lowest total costs for society.

The national government assists in development of these plans with techno-economic modelling to determine the locally optimum heating strategy and insulation level. In addition, the national government provides subsidies for municipalities to implement a chosen heating strategy in selected neighborhoods. These subsidies are provided on a competitive basis.

These plans are part of a larger set of policy instruments still in development that will support local governments in realising these plans, extending further than the current subsidy schemes for neighborhoods. This includes district heating legislation (Warmtewet 2.0) that will enable local or regional governments to assign areas where district heating will eventually be mandated.

Gaps and good practices

The local heating plans are an important step towards defining a strategy for decarbonising residential heating and for communicating with residents. The current subsidy schemes have not yet resulted in significant implementation of the plans (Algemene Rekenkamer, 2020), as they were only implemented in 2018. Additional policy instruments are needed to ensure the success of these heating plans.

8 Innovation

To transition to a net-zero emissions economy by or before 2050, all the available technologies need to be scaled up and deployed at an exceptional pace. We will also need to rapidly increase the readiness and deployment of a next generation of low-carbon technologies, innovative and enabling business models and customer engagement. Through innovation, we could see renovation and decarbonised heating transformed and accelerated, much like what we have seen happen with solar PV and LEDs.

Innovation can lead to both cost and time savings and is thus also an important way to overcome barriers to decarbonisation, such as high up-front costs, inconvenience and lack of information. In addition, innovation can help secure other objectives besides decarbonisation, such as climate resilience and a circular economy.

To achieve this innovation in the buildings sector, clear policies are needed that go far beyond mere financing for research and innovation (R&I). Regulatory policies are needed to create a pull from the market. These policies will not only help decarbonisation with existing technologies and business models, but also create the need/market for new solutions.

8.1 Chapter structure

In each of the target areas for decarbonisation of the buildings sector that have been discussed throughout this report, innovation has an important role to play. Examples of innovation needs in each of these areas were given in Chapter 3. In this chapter we discuss innovation in an overarching way by answering the following questions:
- What types of innovation are needed to decarbonise the buildings sector?
- What barriers stand in the way of innovation in this sector?
- What kind of policy framework is needed to achieve this innovation?

Answers to these questions were sought based on a literature review and an expert consultation session.

8.2 Types of innovation

Innovation relates to more than just technology and product development. The ‘Net Zero 2050’ report on innovation (Climate Strategy & Partners, 2018) identifies different types, following a typical innovation breakthrough process:
- technology and product innovation[17];
- business model and services innovation;
- societal innovation.

In addition to these categories, we recognise two further types of innovation geared to creating the right framework conditions for innovation and decarbonisation, namely financial innovation and policy innovation.

[17] We combine technology innovation and product innovation here, because both comprise new or improved technical specifications and products.

Technology and product innovation

Technology and product innovation refers to the introduction and implementation of products, processes, goods and services that are new or significantly improved in terms of technical specifications, components, materials, incorporated software, user friendliness or other functional characteristics.

Examples relevant in the present context include (WEF, 2016):
- standardised, pre-fabricated components to boost construction and renovation productivity;
- (semi-)automated equipment (e.g. bulldozers);
- smart, digitised buildings for reduced energy use.

Business model and services innovation

Business model innovation refers to improvements in how the sector organises itself. This may involve an organisation changing its operating model, revenue model or value propositions to customers.

Examples:
- The Dutch 'Energiesprong' project halved the cost of net-zero-energy renovation by improving economies of scale and implementing 3D-printing technologies and prefabricated materials, as well as by moving from a product-centred approach to an industrialised, service-oriented approach that uses innovative technologies and business and/or finance models, such as selling products and services within an integrated framework (BPIE & i24c, 2016).
- The H2020 REFURB programme identified deep renovation packages as a 'one-stop shop' for home-owners.
- Digitisation and integration of the retrofitting supply chain using tools and models, such as online and map-based tools to explore dwelling characteristics, request a technical estimate online, obtain integrated offers from suppliers or financing.

Societal innovation

Societal innovation refers to a systemic change in social norms and culture.

Examples:
- acceptance of a different technology as a standard, such as electric cooking stoves;
- learning how to engage with low-temperature heating technologies in order to reduce energy use and provide comfortable heating;
- acceptance or appreciation of new exterior looks (aesthetics) of zero-energy buildings.

Financial innovation

Financial innovation in the context of decarbonisation of buildings refers to new or improved structures for financing decarbonisation measures.

Examples:
- Financial aggregation: financing packages and guarantees for major renovations involving multiple manufacturers and installers bundled together.
- Financial constructions for collective (neighborhood) energy systems, e.g. for a neighbourhood to collectively contract a loan for district heating.
- Loans or mortgages for building-related measures that can be transferred to the next house-owner.
- Blending of public and private financing for renovation and heating.
- Improved user journey for finance by providing assistance and financing packages.
- Classification of sustainable activities in the buildings sector to incentivise 'greening' of financial institutions' portfolios (Green Taxonomy). Besides EU or national rules for such classification, legal requirements for buildings (minimum energy performance standards) can also provide such an incentive, as with the Dutch EPC requirements for offices (see Netherlands case study).
- Pay-for-Performance (P4P), a subsidy design that rewards or finances end-users or aggregators for delivering energy savings against a business-as-usual (baseline) scenario. Such programmes use metering to determine actual savings, with the subsidy paid out based on this actual performance (RAP ; IEECP, 2020).

Policy innovation

Policy innovation is the introduction of new methods of public policy-making or new types of policy measures to incentivise innovation.

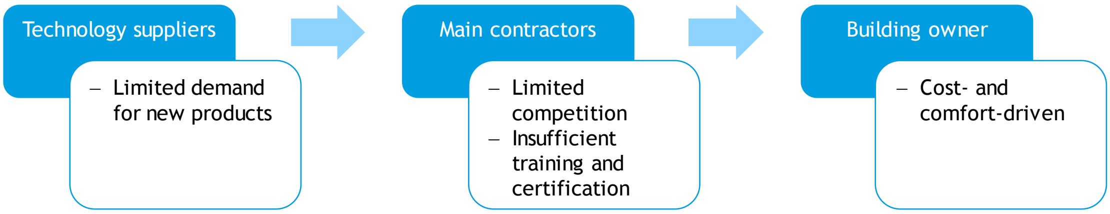
Examples:
- local heat plans: local governments assign areas for collective heat systems, with citizen engagement processes (see Netherlands case study);
- integrative energy planning that includes collaboration between energy planning and urban planning departments (CORDIS, 2018);
- energy efficiency-based property sales tax;
- minimum efficiency standards for existing buildings.

8.3 Barriers to innovation in the buildings sector

There are multiple barriers hampering development and uptake of innovative solutions.

- Market: There is no market for integrative business models for renovation or district heating.
- Fragmented value chain: Often, decarbonised solutions for the buildings sector go beyond innovative technology, requiring integration of the supply chain for construction and renovation, and including the energy system beyond the building. This supply chain (value chain) for energy efficiency and decarbonised heat is fragmented. There is no single actor that captures the full value of the benefits of a major renovation. Additionally, home renovation is a small project that nevertheless involves many actors.
- Conservative parts of the sector: Some parts of the supply chain of the construction and installation sector find it very difficult to innovate owing to their very local nature, consisting of local businesses and therefore not experiencing much competition, and also clients being driven mostly by cost and comfort (see Figure 16). This is especially true of major project developers or contractors. Although the producing sector is innovative, it is difficult to launch new products to the construction and installation sector. Thus, there needs to be a stimulus for major contractors, rather than just the production sector.

Figure 16 - Supply chain of building renovation and installation, with barriers to innovation



- **Training and certification**: the Installation sector has insufficient training and certification for new, innovative technologies.

8.4 Framework conditions for scaling up innovation

To scale up innovation, there needs to be an improvement in the conditions for innovation on the supply side, as well as market demand for innovative decarbonisation solutions.
To date, policies have focused on financing schemes for research and innovation, but have not changed the market to create the required demand. Financing schemes for the purchase of innovative products is one way to create demand, but these are not in themselves sufficient owing to limited response from the market.

What is therefore needed is regulation to trigger a ‘pull’ from the market and create a level playing field that makes innovative solutions competitive. A key example of such a policy instrument are the minimum energy performance requirements (MEPR) or Building Performance Standards (BPS) for existing buildings. These set a minimum standard every time a home is renovated, sold or rented out, or on some other occasion (as with the Dutch policy for office buildings; see Section 7.3.2). Standards can target the building envelope, heating appliances or a combination. Such standards need to be strengthened over time towards the necessary level for 2050.

On the supply side, innovation can be stimulated by traditional research and innovation funding, but can also benefit from measures that target specific barriers in the buildings sector:
- Innovation fund for the construction industry: The construction and renovation sector is dominated by small and medium enterprises (SMEs), which often have limited time and resources for innovation. These businesses therefore need financial support to innovate. Subsidies or tax incentives for businesses that work on collaborative tenders additionally help integrate the supply chain.
- Creation of innovation ecosystems: Innovation ‘hubs’ can connect different actors in the innovation value chain, including universities, technology suppliers and construction companies.

Regulatory policies can meet resistance if implemented abruptly, but backlash can be prevented in numerous ways. Policies and frameworks can be co-designed with citizens and market parties using citizen consultation practices. In addition, standards and other requirements can be introduced modestly at first and tightened over time. Besides, new constructions will help drive change in the construction sector. By demonstrating that buildings can be smarter, more efficient, more comfortable and healthier, new buildings can create demand for better existing buildings. At the same time, contractors and developers will develop the expertise to apply similar technologies in renovations.

If a demand is created for innovation in the buildings sector, a large market can be developed inside and outside the EU, with multiple co-benefits such as creation of (qualified) jobs, circularity and shorter supply chains. Innovation, as applied to this challenge, could consequently have a transformational effect, as it has had in other sectors. For this to be achieved, innovation needs to be stimulated, not only by financial support of R&I projects and demonstrators, but by setting the right kind of framework for deployment by means of regulatory policies.

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A Assumptions in EUCalc modeling

The emissions reduction in the reference scenario and the decarbonisation pathway was calculated by Climact using the EUCalc model. The main assumptions are given hereafter.

A.1 Business as usual scenario

The combination of lever positions under this scenario reproduces, as far as possible, the main sectoral assumptions and outputs of the EU Reference scenario as detailed in (EC, 2016a). The assumptions for embedded emissions from (Röck, et al., 2020) were integrated in the modeling.

A.2 Decarbonisation scenario assumptions

Area	EU Calc maximum	Decarbonised scenario
Renovation	– Rate: 3% p.a. – Depth: Renovated buildings consume on average 55% less energy than existing ones (70% of renovations lead to 60% energy savings and 30 to 40% savings)	– Rate reduced to 2.68% p.a. to ensure annual activity in 2050 representative of entire 2020-2050 period (i.e. full renovation of non-demolished buildings is achieved just by 2050, not before) – Depth: EE kept to EUCalc max.
New constructions	– 1% p.a. demolition – New constructions efficiency resulting from 30% of NZEB buildings and 70% of energy-positive new buildings	– Reduced to 0.4% p.a. demolition so as not to weaken the renovation narrative – EE kept to EUCalc max
DH andfuel Switch	– Individual heating systems, by 2050: – -95% gas/coal/heating oil – + 70% heat pumps/30% biomass – District heating, by 2050: – DH share from 8.4 to 16.5%, with 25% decentralised HP/34% biomass/28% Gas/9% Solar thermal/3% Geothermal	– Individual heating systems, by 2050: – fossil fuel phase-out kept to -95% – HP and biomass assumptions kept to EUCalc max. – Ad-hoc reduction: decarbonisation of remaining fuels (green gas and liquids) – Ad-hoc reduction: decarbonisation of cooking through electrification (70%) and green gas (30%) – Impact of ad-hoc calculations on power sector not modelled – District heating, by 2050: share of DH kept to EUCalc max. – Contribution of natural gas substituted by large-scale heat pumps consistent with other ECF study
Heating and ventilation efficiency	– Tech efficiency up by ~20% (from ~83% to 97% efficiency)	– Kept to EUCalc max.
Appliance efficiency	– Energy consumption from 100% in 2020 to ~30% in 2050	– Kept to EUCalc max.
Materials	– Up to 60% (substitution of concrete by timber	– Baseline embedded GHG emissions derived from (Röck, et al., 2020)

Area	EU Calc maximum	Decarbonised scenario
	— Smart product and material design, re-use of materials and circularity concepts of additive manufacturing, leading to 31% reduction in CO_2 emissions.	— Relative improvements kept to Industry levers in EUCalc max.
Power	— Coal phase-out, CC ratio, nuclear phase-out, wind, solar, hydro, geo, tidal, balancing strategies and charging profiles — See all power levers at the European Calculator Tool	— With EUCalc there is residual GHG intensity of power production even in the most ambitious decarbonation scenarios — Ad-hoc reduction: full decarbonisation via carbon-neutral flexibility solutions

B Examples of policies in each area

This appendix describes examples of financial support, pricing and regulatory policies in three different target areas (building envelope, heating fuel switch and appliances) and illustrates the strengths and weaknesses of these policies.

Financial support of energy efficiency (demand reduction) measures

Mechanism and effect

Subsidies for energy efficiency measures seek to improve building insulation/envelope by providing a financial incentive to the building owner or private funder. This can be a subsidy to a home-owner, a tax deduction or a government guarantee for a private funder.
The rate/extent of the subsidy may depend on the expected demand reduction.

The primary effect of improved building efficiency is reduced heating demand, yielding energy (and thus financial) savings for the building occupant. Reduced heating demand can also lower the temperature needed to heat the building, making it possible to utilise low-temperature appliances like heat pumps. The efficiency and effectiveness of the efficiency measures taken will thus depend on the decarbonised heating solutions being targeted.

Pros and cons

Advantages:
- energy demand is reduced;
- possibility to address energy poverty/compensate lower-income groups;
- market stimulus for new innovations.

Disadvantages and possible adverse side-effects:
- possibility of increased cooling demand;
- possibility of rebound effect: limited reduction in energy demand;
- possibility of use of insulation materials with high embedded emissions;
- ‘free riders’ effect: some measures would also be taken without subsidies;
- maximum effect of demand reduction is ~55%, so not 100% decarbonised;
- does not steer towards optimum mix of insulation-installation-infrastructure-production;
- no guarantee that all eligible measures will be taken;
- no trigger for collective measures;
- renovation rate of 3% implies high expenditure.

Financial incentive for heating/cooling appliances

Mechanism and effects

In this case subsidies target the appliances necessary to switch to decarbonised energy carriers. The subsidies target the building-owners. The switch to heating/cooling appliances with a different energy carrier will also lead to a higher demand for that carrier; however, decarbonisation of the energy carrier is not stimulated.

The subsidy levels can be set so as to (partly) cover the difference between the investment and the expected savings or willingness to pay. The extent to which the different measures are subsidised will influence the level of uptake.

For the various energy carriers for heating, the subsidies cover different technologies, as specified in the table.

Energy carrier	**Appliances subsidised**	**Effects on building envelope or energy carrier**
Electricity	Heat pumps Direct electric heaters	– Heat pump: increased building insulation due to temperature requirement – Increased load on electricity network – In case of existing gas grid: no longer needed
District heating	N/a	
Renewable gas	Hydrogen burners, fuel cells	
Biomass	Biomass/pellet burners	– In case of existing gas grid: no longer needed

Pros and cons

Advantages:
- socially acceptable;
- increased uptake of technologies may lead to innovation and cost reduction;
- opportunity to direct subsidies to energy-poor households.

Disadvantages:
- no guarantee that all eligible measures will be taken;
- no incentive for energy carrier to be decarbonised;
- risk of oversubsidising measures that would also be taken without subsidy;
- risk of favouring suboptimal measures;
- risk of subsidising mostly high-income groups;
- no decarbonisation of energy carrier;
- high knowledge level of home-owners, installers and regulators required.

Subsidy of decarbonised energy carrier and infrastructure

Mechanism and effects

Subsidy of decarbonised energy production, e.g. renewable electricity production. Government support for construction of district-heating and hydrogen grids. Subsidy or tax cuts on consumer energy bills for renewable energy.

CO_2 pricing

Mechanism and effects

This economic instrument entails putting a price on CO_2 in energy carriers related to the built environment, for example by taxation. This increases the cost of non-renewable energy and materials. The increased cost is passed on to the final energy consumer, incentivising demand reduction as well as a switch to a decarbonised energy carriers and (building) materials.

The CO_2 price can be introduced at a low level and increased whenever emission reduction targets are not met.
Energy consumers can reduce their energy costs by reducing their demand or by switching to decarbonised energy carriers. This creates a more level playing field for decarbonised heating solutions. Because of the increased cost of (non-decarbonised) energy carriers, energy poverty may be aggravated.

Pros and cons

Advantages:
- low administrative costs if system can be tied to existing tax system;
- creation of level playing field.

Disadvantages
- risk of energy poverty.

Building performance standards

Mechanism and effects

Regulatory instruments are based on a legal (regulatory) instrument: a mandatory measure, such as a technical requirement or contractual agreement. A building standard (like EPC) regulates the CO_2 emissions of the total building envelope, appliances and infrastructure. This standard must be fulfilled for new buildings, while existing buildings are required to meet it standard at certain points in time (most logically, when leasing or selling the building through a notary), thus making the renting or selling party responsible.

The standard can be a theoretical calculation or, for existing buildings, be based on actual performance (though this involve a multitude of factors). It can be made more stringent over time. The developer (in the case of new buildings) or owner (for existing buildings) is thus made responsible for complying with the standard by choosing decarbonisation measures prior to the build, delivery, lease or sale of the building.

A building standard creates an incentive for measures geared to efficiency/insulation, appliances and materials. The effect is limited to the building itself because the infrastructure and energy carrier are beyond the influence of the building-owner.
For decarbonisation of the energy carrier, additional instruments are needed.

Pros and cons

Advantages:
- opportunity to enforce policy at sale or change of tenancy.

Disadvantages:
- low-income home-owners do not have the means to comply with the standard;
- difficult to implement for existing buildings outside of sale or change of tenancy.

Requirement for decarbonisation of energy carrier

Mechanism and effects

This instrument imposes a cap (permit) on the GHG emissions of the energy carriers sold by an energy company (electricity, gas, district heat). The cap is reduced to zero over time. Imposing a cap on energy companies means a limited number of parties are involved and the knowledge level of these parties is high.
The level of the cap can be determined by past emissions (grandfathering) and emission rights can be traded. The system is therefore like the EU ETS for electricity, but expanded to also include other energy carriers (gas and district heating). Alternatively, different permits can be given for each carrier, with a different trading scheme for each.

The additional costs of the decarbonisation measures to meet this cap are passed on to energy consumers, increasing the cost of energy, possibly substantially. This incentivises demand reduction by consumers as well as a switch to decarbonised energy carriers/heating solutions, thus stimulating the market for efficiency measures. The higher energy costs increase energy poverty, however.

Pros and cons

Advantages:
- limited number of parties involved in implementing policy;
- 100% effectiveness possible.

Disadvantages:
- aggravation of energy poverty.

C Description of EU directives

This appendix describes the EU directives and policies of relevance for the residential built environment in more detail.

Energy Efficiency Directive (EED)

The EED aims for an energy efficiency target for 2030 of at least 32.5% (relative to the 2007 modelling projections for 2030). The EED allows for a possible upward revision of the target in 2023 if economic or technological developments permit substantial cost reductions.

Relevant measures for the buildings sector

- Annual reduction of 1.5% in national energy sales (until 31 December, 2020) and 0.8% in annual final energy consumption (from 1 January, 2021 to 31 December, 2030).
- EU countries carry out energy-efficient renovation of at least 3% of buildings owned and occupied by central government annually.
- EU countries prepare national energy efficiency action plans (NEEAPs) every three years.
- Final customers are provided with individual energy meters.
- Steps are taken to protect the right of consumers to receive easy and free access to energy consumption data.

Renewable Energy Directive (RED II)

In 2018 the renewed Renewable Energy Directive (RED II) came into force. It establishes a new renewable energy target for the EU for 2030 of at least 32%. Upwards revision of this target is possible in 2023.

Under the new Governance regulation, which is also part of the 'Clean energy for all Europeans' package, EU countries are required to draft 10-year National Energy & Climate Plans (NECPs) for 2021-2030, outlining how they will meet the new 2030 targets for renewable energy and for energy efficiency. The other new elements in the new directive need to be transposed into national law by member states.

Relevance for the buildings sector

- The RED II renewable energy targets apply to all sectors, including the residential sector, which means the amount of renewable energy used in this sector must increase as well.
- There is a further target specifically for the share of renewable energy in heating and cooling (1.3% increase per annum) and in district heating and cooling (1% p.a.).
- Under RED II, households may become energy self-consumers and producers, which is likely to lead to increased use of renewable electricity in households. They may also participate in energy collectives.
- Under RED II, consumers are entitled to be given full information about the costs, benefits and efficiency of renewable energy as well as full information on their energy consumption and the share of renewables in the energy they use.

Energy Performance of Buildings Directive (EPBD)

Together with the EED, the EPBD promotes policies that will help:
- achieve a highly energy-efficient and decarbonised building stock by 2050;
- create a stable environment for investment decisions;
- enable consumers and businesses to make more informed choices to save energy and money.

The **Directive** (EU, 2018) **amending the EPBD** (2018/844/EU) introduces new elements and sends a strong political signal on the EU's commitment to modernise the buildings sector in light of technological improvements and increase building renovations.

Relevant measures for the buildings sector

- EU countries must establish strong long-term renovation strategies aimed at decarbonising national building stocks by 2050, with indicative milestones for 2030, 2040 and 2050. The strategies should contribute to achieving the energy efficiency targets laid down in the national energy and climate plans (NECPs).
- EU countries must set cost-optimal minimum energy performance requirements for new buildings, for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls.
- All new buildings must be nearly zero-energy buildings (NZEB) from 31 December, 2020. Since 31 December, 2018, all new public buildings already need to be NZEB.
- Energy performance certificates must be issued when a building is sold or rented and inspection schemes for heating and air conditioning systems must be established.
- Electro-mobility is supported by introducing minimum requirements for car parks over a certain size and other minimum infrastructure for smaller buildings.
- An optional European scheme for rating the 'smart readiness' of buildings has been introduced.
- Smart technologies are promoted, including through requirements on installation of building automation and control systems and on devices that regulate temperature at room level.
- Health and well-being of building users is addressed, for instance through consideration of air quality and ventilation.
- EU countries must draw up lists of national financial measures to improve the energy efficiency of buildings.

Ecodesign

The Ecodesign Directive provides consistent EU-wide rules for improving the environmental performance of products, such as household appliances, information and communication technologies or engineering. The directive sets out minimum mandatory requirements for the energy efficiency of these products. The EU legislation on Ecodesign is currently applicable to 31 product groups, including lighting, heaters, fridges and freezers, vacuum cleaners, washing machines and driers, heating boilers and water heaters, air conditioners and fans, televisions and TV boxes, kitchen appliances and computers.

Relevance for the built buildings sector

Improved environmental performance of household appliances contributes to increasing the energy efficiency of such appliances when old appliances are replaced.

Energy labelling regulation

This regulation complements the Ecodesign requirements with mandatory labelling requirements. There are now 15 product groups requiring an energy label.

Relevance for the buildings sector

Improved environmental performance of household appliances contributes to increasing the energy efficiency of such appliances.

Energy taxation directive

The Energy Taxation Directive (2003/96/EC) (European Council, 2003) lays down rules for the taxation of energy products used as motor or heating fuels and for electricity.

Relevance for buildings sector

Evaluation of the ETD shows that rules on energy taxation no longer deliver the same positive contribution as when they first came into force in 2003. The ETD does not contribute to the new EU regulatory framework and policy objectives in the area of climate and energy, where technology, national tax rates and energy markets have all evolved considerably over the past 15 years. For example, there is no link between the minimum tax rates of fuels and their energy content and CO_2 emissions.

EU Emissions Trading Scheme (EU ETS)

The EU ETS puts a price on GHG emissions from energy-intensive installations (power stations and industrial plant) and airlines in EU countries plus Iceland, Liechtenstein and Norway. The system covers around 45% of the EU's greenhouse gas emissions. The carbon price is achieved through tradeable allowances for emissions and a cap on these emissions that is reduced over time.

Under the European Green Deal (see below), the Commission will present an impact-assessed plan to increase the EU's GHG emissions reduction target in a responsible way, including for the EU ETS.

Relevance for the buildings sector

Power generation is included in the ETS, creating a price incentive to decarbonise energy production. This also applies to the energy carriers used in the residential sector.

As production facilities for building materials like cement, glass and metals are included in the ETS, ETS also creates a price incentive for decarbonising building materials, thus lowering embedded emissions.

Construction Products Regulation (CPR)

The CPR lays down harmonised rules for the marketing of construction products in the EU and provides a common technical language to assess the performance of construction products. It ensures that reliable information is available to professionals, public authorities and consumers, so they can compare the performance of products from different manufacturers in different countries.

Regarding embedded emissions, the scope of the CPR is limited. The construction works must be designed and built in such a way that they will not have an exceedingly high impact, over their entire life cycle, on environmental quality or climate during construction, use and demolition, in particular as a result of any of the following:

a The giving-off of toxic gas.

b The emissions of dangerous substances, volatile organic compounds (VOC), **greenhouse gases** or dangerous particles to indoor or outdoor air.

Circular Economy Action Plan (CEAP)

2015 CEAP:

- Ecodesign Working Plan 2016-2019
- Fitness check of Ecolabel
- Action on Green Public Procurement: enhanced integration of circular economy requirements
- Demolition or Renovation of Buildings and Infrastructures
- Core indicators for the assessment of the lifecycle environmental performance of a building

2020 CEAP:

- Mandatory Green Public Procurement (GPP) criteria and targets in sectoral legislation and phasing-in of mandatory reporting on GPP (foreseen 2021).
- Mandatory requirements on recycled plastic content and plastic waste reduction measures for key products such as packaging, construction materials and vehicles (2022).
- Strategy for a Sustainable Built Environment (2021).
- Updating the Circular Economy Monitoring Framework to reflect new policy priorities and develop further indicators on resource use, including consumption and material footprints (2021).

European Green Deal

The European Green Deal is the roadmap for making the EU's economy sustainable, meaning that net emissions of greenhouse gases are reduced to zero by 2050, economic growth is decoupled from resource use and no person and no place are left behind.

The Green Deal outlines the investments needed and financing tools available, and explains how to ensure a just and inclusive transition.

Reaching the target of climate neutrality by 2050 requires action by all sectors of the economy, including:

- investing in environment-friendly technologies;
- supporting industry to innovate;
- rolling out cleaner, cheaper and healthier forms of private and public transport;
- decarbonising the energy sector;
- ensuring buildings are more energy-efficient;
- working with international partners to improve global environmental standards.

In 2020 the Green Deal will be translated into specific policies and is likely to impact multiple Directives.

Relevance for the buildings sector

As part of the Green Deal, the Commission has introduced a renovation wave for public and private buildings. It aims to take further action and create the necessary conditions for scaling up renovation and reaping the significant saving potential of the buildings sector.