OECD Economics Department Working Papers No. 1751

Home, green home: Policies to decarbonise housing

Peter Hoeller,

Volker Ziemann,

Boris Cournède,

Manuel Bétin

https://dx.doi.org/10.1787/cbda8bad-en

OECD

Organisation for Economic Co-operation and Development

ECO/WKP(2023)4

Unclassified **English - Or. English**

14 March 2023

ECONOMICS DEPARTMENT

HOME, GREEN HOME: POLICIES TO DECARBONISE HOUSING

ECONOMICS DEPARTMENT WORKING PAPERS N° 1751

By Peter Hoeller, Volker Ziemann, Boris Cournède and Manuel Bétin

All Economics Department Working Papers are available at www.oecd.org/eco/workingpapers

JT03514279

ABSTRACT / RESUME

Home, Green Home: Policies to Decarbonise Housing

The housing sector is one of the main sources of CO_2 emissions in OECD countries, accounting for over a quarter of the total. Robust and rapid action is required to reach the net zero emission target by 2050. Decarbonising housing involves halting the use of fossil fuels in homes, ensuring that electricity is generated from carbon-free sources, using high-energy-efficiency appliances and heating systems, ensuring effective insulation and encouraging behavioural changes. This paper discusses which policy instruments can prompt this transformation of the housing sector, ranging from carbon pricing through energy labelling requirements to green housing finance.

Keywords: Housing, decarbonisation, energy efficiency, insulation

JEL codes: F64, H23

****

Foyer, vert foyer : Des politiques publiques pour décarboner les logements

Le secteur du logement est l'une des principales sources d'émissions de CO_2 dans les pays de l'OCDE, représentant plus d'un quart du total. Des mesures énergiques et rapides sont nécessaires pour atteindre l'objectif de zéro émission nette d'ici à 2050. Pour décarboniser le secteur du logement, il faut cesser d'utiliser des combustibles fossiles dans les habitations, veiller à ce que l'électricité soit produite à partir de sources sans carbone, utiliser des appareils et des systèmes de chauffage à haut rendement énergétique, assurer une isolation efficace et encourager des changements de comportement. Le présent document examine les instruments politiques susceptibles de favoriser cette transformation du secteur du logement, qu'il s'agisse de la taxation du carbone, des exigences en matière d'étiquetage énergétique ou du financement des logements verts.

Mots-clés : Logement, décarbonisation, efficacité énergétique, isolation

Codes JEL: F64, H23

Table of contents

Tables

Figures

Boxes

Home, Green Home: Policies to Decarbonise Housing

By Peter Hoeller, Volker Ziemann, Boris Cournède and Manuel Bétin[1]

1. Introduction and main findings

1. In 2020, the residential sector accounted for more than a quarter of the total CO_2 emissions in the OECD. Emissions emanate from space and water heating, cooling, ventilation, lighting and the use of appliances and other electrical plug loads. Also, the construction of homes is emission-intensive. A step-change is needed to reduce emissions drastically to reach the net zero emission target by 2050. Apart from developing decarbonisation strategies, policy must go well beyond environmental matters and encompass economic, social, innovation, tax and spending policies, as well as governance arrangements, to drive transformational change.

2. Policy options for more rapid decarbonisation of housing include:

- Decarbonisation strategies should ensure consistent carbon pricing across sources, sectors and over time. Carbon pricing – including properly calibrated taxes on fossil fuels used in homes or emission trading – offers an effective and cost-efficient way of creating carbon-saving incentives. Carbon pricing is key to underpin the needed large-scale changes, including avoiding the rebound of emissions that can follow other measures if they are unaccompanied by pricing.
- Effective carbon rates are currently low in most countries, and rates differ across sectors. Not even half of the OECD countries apply explicit carbon taxes to direct emissions from buildings, while excise taxes, which are generally misaligned with the carbon content of fuels, still prevail.
- Various market imperfections specific to the housing sector call for going beyond carbon pricing with a well-coordinated mix of policies. This is the case, for example, of split incentives between landlords and renters to invest in energy efficiency improvements. Adjusting rent-setting rules to

[1] Peter Hoeller (consultant), Volker Ziemann, Boris Cournède and Manuel Bétin (OECD Economics Department) wrote this paper. They are indebted to Marc-André Buquet, Andoni Montes, Anastasia Tikhmyanova (OECD Economics Department at the time of preparation of this study) and Sean Dougherty (OECD Economics Department) for their contributions to this paper. Feedback by delegates to the OECD Economic Policy Committee Working Party No. 1 on Macroeconomic and Structural Policy Analysis is gratefully acknowledged. The authors thank Sebastian Barnes, Tobias Kruse, Luiz de Mello and Alain de Serres (OECD Economics Department), Nicolina Lamhauge (OECD Environment Directorate), Caroline Roulet (OECD Directorate for Financial and Entreprise Affairs), Ji-Soo Yoon (OECD Centre for Entrepreneurship, SMEs, Regions and Cities), Jonas Teusch and Luisa Dressler (OECD Centre for Tax Policy and Administration) for their comments and suggestions. Thanks go to Lillie Kee, Inés Gomez Palacio and Nathalie Bienvenu (OECD Economics Department) for technical assistance.

allow both landlords and renters to benefit from energy savings resulting from investments in energy retrofitting would strengthen incentives for renovation.

- Regulatory measures are important complements to carbon pricing. Energy performance certification should be extended to all properties and cover not only those for sale and rental, as is currently the case in most countries. Reliable information would raise awareness about the benefits of home improvements. Also, the energy efficiency standards on appliances and new buildings should be strengthened further to ensure full alignment with the net-zero emission target.
- Compensatory measures can be used to offset adverse effects on vulnerable social groups. Transfers should maintain incentives to reduce greenhouse gas emissions, for instance, by tying them to household income and property size while avoiding links to energy use.
- Public support programmes for energy efficiency improvements should focus on retrofitting the worst existing housing units, and subsidies should be paid depending on the actual energy efficiency gains and be capped and means-tested to avoid dead-weight losses. Countries should abolish the remaining subsidies for installing fossil fuel boilers.
- The social housing sector can play a leading role. Building new and retrofitting existing social housing units according to high environmental standards would directly contribute to housing decarbonisation, reduce the risk of energy poverty for social-housing tenants, and help to develop capabilities and capacity in the retrofitting business sector.
- Green housing finance remains in its infancy: a patchwork of mainly private-sector green building ratings initiatives using hard-to-compare criteria has hindered market integrity. Promoting greater international comparability and transparency of green building standards would facilitate the alignment of green real estate assets with the net-zero emission target.
- Housing and environmental policies are highly decentralised in many countries. Reforms and resources are needed to align incentives and agendas across levels of government. Local-level regulations, spending power and resources must be consistent with national decarbonisation goals.

3. The following section takes stock of recent trends in housing-related greenhouse gas emissions, targets and projections up to 2050. Section 3 reviews policy options available to meet housing emission reduction targets. Section 4 underlines the roles of technology and finance in housing decarbonisation. Section 5 discusses possible adverse effects on low-income earners and measures to tackle them. Section 6 addresses the changes required in governance for a successful emission transition in the housing sector. The paper builds on earlier OECD work on A Framework to Decarbonise the Economy (D'Arcangelo et al., 2022[1]), Decarbonising Buildings in Cities and Regions (OECD, 2022[2]), Effective Carbon Rates, (OECD, 2022[3]) the Taxation of Housing (OECD, 2022[4]), and Real Estate Finance and the Climate Transition (OECD, 2022[5])as well as IEA emission scenarios and energy efficiency analysis (IEA, 2022[6]).

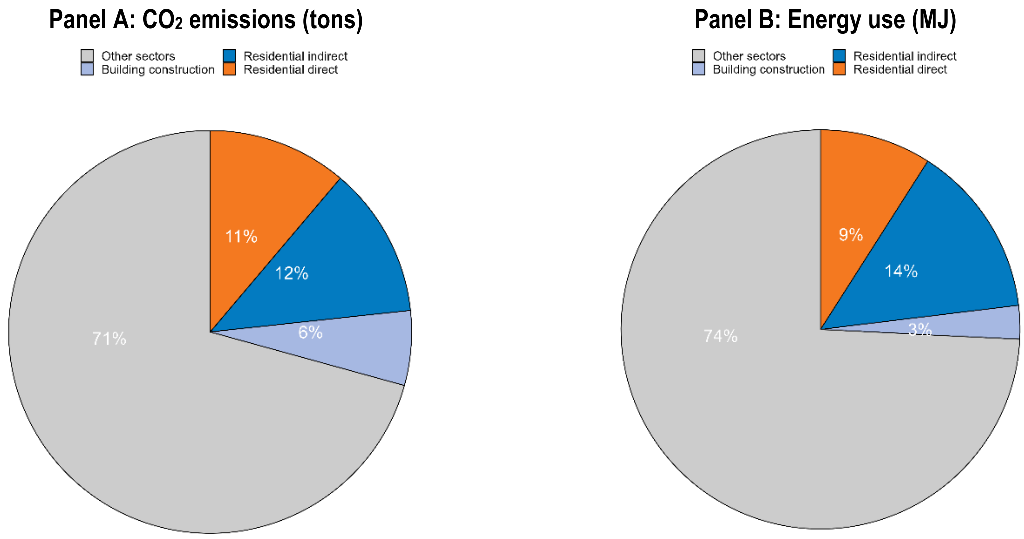
2. Track emission trends and the achievement of targets

Past trends and recent evolution of housing CO_2 emissions

4. In 2020, the residential sector accounted for 23% of total CO_2 emissions in the OECD (Figure 1). Emissions emanate from space and water heating, cooling, ventilation, lighting and the use of appliances and other electrical plug loads. The construction of homes contributes an extra 6% to total CO_2 emissions, largely reflecting the heavy use of concrete and steel in current building technologies.

Figure 1. Housing accounts for a large share of overall CO_2 emissions

Sectoral decomposition of OECD CO2 emissions and energy use, 2020

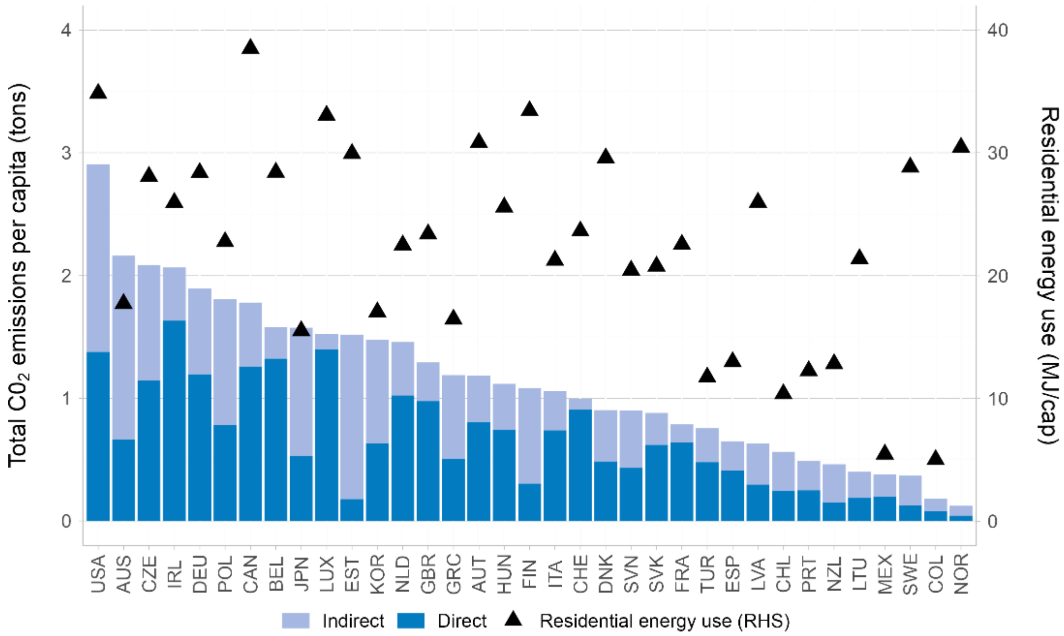


Note: Data are unavailable for four OECD countries (Colombia, Costa Rica, Iceland and Israel). 2019 data were used for 12 OECD countries (Argentina, Austria, Canada, Denmark, Estonia, Greece, Lithuania, the Netherlands, Poland, Slovakia, Spain and Sweden). Building construction refers to the direct and indirect (embodied) emissions corresponding to the ISIC 41 sector classification. The residential sub-sector includes all energy-using activities in apartments and houses, including space and water heating, cooling, ventilation, lighting, and the use of appliances and other electrical plug loads. The breakdown between direct and indirect emissions is based on the proportion of final residential energy used from electricity and district heating. Indirect emissions are calculated as follows: Energy_use *(p_e+p_dh)*EF where p_e=proportion of energy generated by electricity, p_dh=proportion of energy generated by district heating, and EF is the emission factor for electricity and district heating.
Source: Energy Efficiency Indicators database (IEA, 2021[7]), Emission Factors database and OECD calculations.

5. CO_2 emission levels vary considerably across countries, ranging from nearly three tonnes per capita in the United States to almost zero in Norway (Figure 2). The vast differences demonstrate that harsh climatic conditions are not obstacles to achieving low emission levels. Indeed, high-income countries with high heating needs, such as the Nordic countries, achieved a low carbon footprint in their residential sector primarily through electrification of energy consumption at home coupled with a surge in carbon-free electricity production. More generally, the correlation between energy use and CO_2 emissions is low, illustrating the effect of different choices regarding the split between direct and indirect emissions, the carbon content of fuels combusted directly by households and the carbon content of primary energy sources used to produce electricity or district heating (indirect emissions).

Figure 2. Several countries have high home energy needs, but low CO_2 emissions

Total CO_2 emissions and energy use of the residential sector, 2020



Note: The breakdown between direct and indirect emissions is based on the proportion of final residential energy used from electricity and district heating. Indirect emissions are calculated in the following way: Energy_use *(p_e+p_dh)*EF, where p_e=proportion of energy generated by electricity, p_dh=proportion of energy generated by district heating, and EF is the emission factor for electricity and district heating.
Source: Energy Efficiency Indicators (IEA, 2021[7]), Emission Factors database (IEA, 2021[8]), and OECD calculations.

6. In the OECD area, 75% of direct housing energy consumption is used for space and water heating or cooling and around 12% for electric-powered appliances. Consequently, most of the reduction of direct residential CO_2 emissions will need to come from heating and cooling energy efficiency gains. Appropriate management of the thermal fluids used in heat pumps and cooling systems will be required to avoid leakage of these non-CO_2 greenhouse gases into the atmosphere during and especially after the lifetime of these pieces of building equipment.

7. In 2020, around 25% of the final energy supply to the residential sector still originated from individual gas-powered systems, 10% from oil combustion, 3% from coal combustion and 15% from biomass and waste combustion. As much as 40% of the residential sector's energy use was supplied by electric power generation (30%) and district heating (less than 10%), generating no direct CO_2 emissions. Differences across countries are considerable (Figure 3).

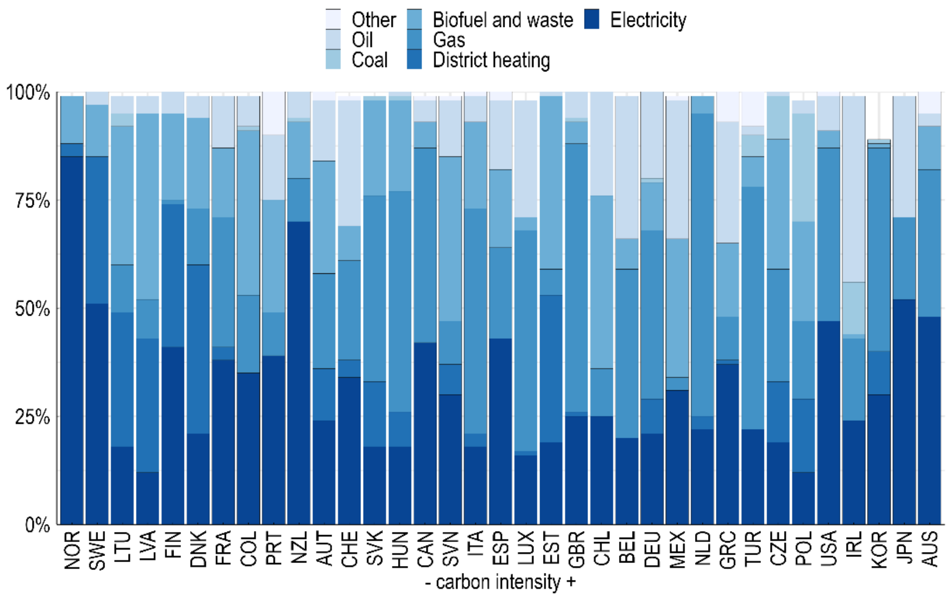
8. Some countries such as the United States, the Czech Republic or Germany combine high per capita energy use and extensive reliance on fossil fuels, resulting in high emissions per capita. The Nordic countries, in contrast, display low emissions despite high per capita energy consumption. Other countries, such as Australia, Japan and Korea, have relatively high emissions despite comparatively low energy consumption per capita. The discriminating feature is the carbon content of the energy used. Coal has the highest carbon content, followed by oil and gas.

9. In Norway and New Zealand, the residential sector is mostly electrified (around 70% of energy use) and is carbon-free mainly because of the prevalence of hydropower plants. But electrification does not guarantee a low carbon footprint, as illustrated by Australia, Korea and the United States, where

electricity is mainly produced by fossil fuels. As a result, these countries display a very high carbon intensity despite a high level of electrification (Figure 3). Except for Estonia, countries with a high share of district heating show a low carbon intensity, showcasing the technology's ability to introduce renewable energy sources when producing heat.

Figure 3. Carbon intensity depends on the extent of direct emissions and the energy mix

Share of total energy consumption, 2020 or latest available data



Note: 2019 data were used for 13 countries (Austria, Canada, Colombia, Denmark, Latvia, Lithuania, the Netherland, Norway, Slovenia, Colombia, Chile, Spain and Greece). Countries ranked by increasing carbon intensity (emissions per unit of energy used),
Source: Energy Efficiency Indicators (IEA, 2021[7]) and OECD calculations.

Where and how are CO_2 emissions trending down?

10. The OECD-wide total CO_2 emissions of the residential sector have declined by 17% from 2000 to 2020, notwithstanding an increase in population and the number of dwellings (Figure 4, Panel A). The energy efficiency of homes and appliances has improved, and many countries have successfully started to reduce the carbon content of the energy supplied. By contrast, in non-OECD countries, total CO_2 emissions from the buildings sector have risen considerably (IEA, 2021[9]), reflecting strong economic growth, fast urbanisation and limited progress in reducing CO_2 intensity, as coal and other fossil fuels remain central to the energy mix of many emerging economies including the largest non-OECD member countries (Huo et al., 2021[10]).

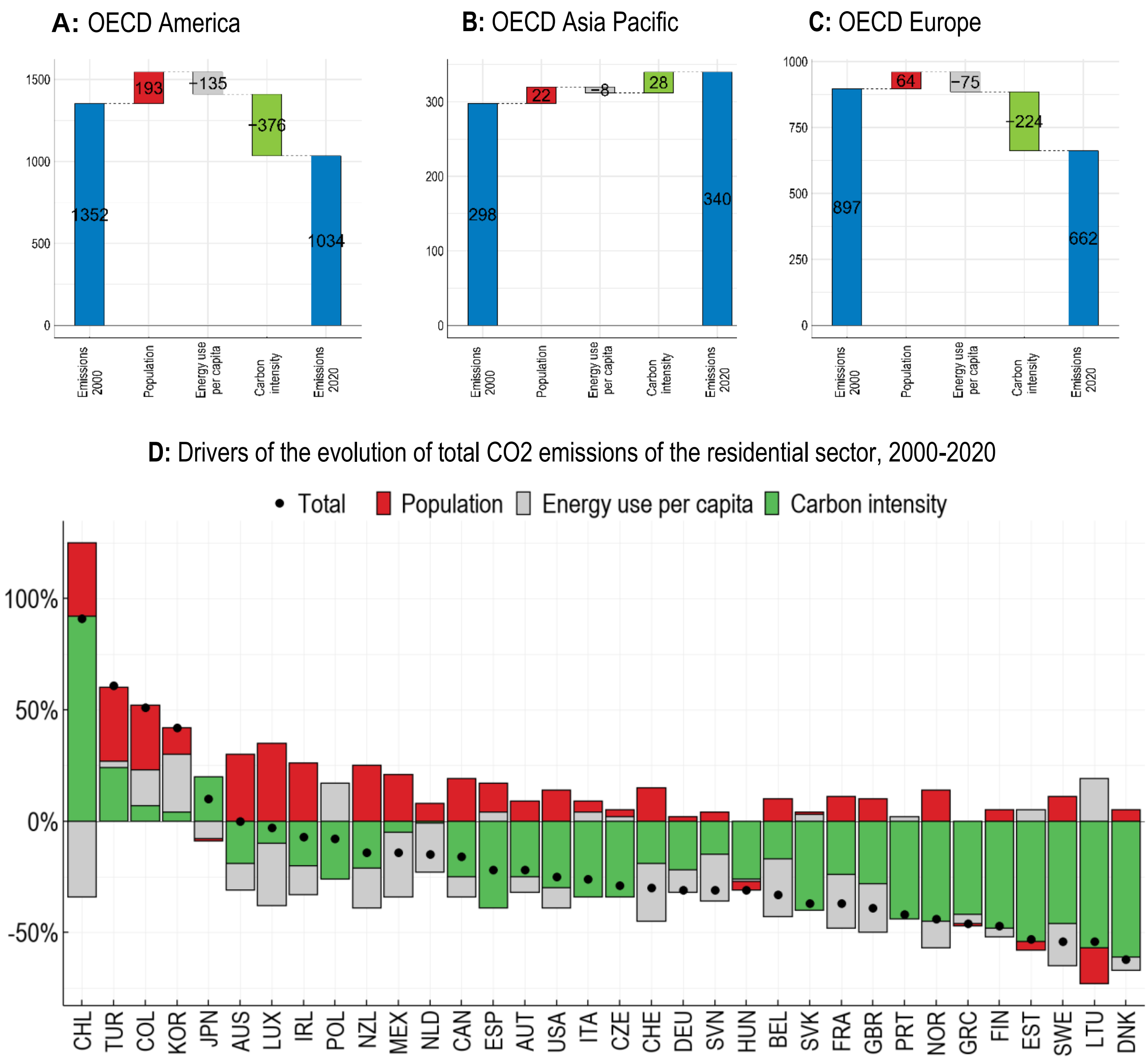
11. The gentle OECD-wide average decline over the last 20 years hides a wide variation in cross-country performance. In Denmark, Estonia, Lithuania and Sweden, emissions have declined by more than 50%, while they have risen by more than 50% in Chile, Colombia and Türkiye (Figure 4, Panel B).

12. Denmark exhibits the steepest decarbonisation of the residential sector as CO_2 emissions have declined by more than 60% in the last 20 years (Figure 4, Panel B). This drop is explained by a drastic reduction in carbon intensity, mainly due to a shift from coal and natural gas to carbon-free heat generation systems relying on electricity production via renewable resources such as wind power. Since the late 1990s, Denmark has also pioneered gas-powered district heating networks, recently upgraded at a relatively low cost to biomass and waste-powered primary energy sources (Menu, 2021[11]).

13. Chile, in contrast, displays the highest increase in residential CO_2 emissions, mainly because of a rising carbon intensity due to the extensive use of oil, natural gas and coal combustion by households. In addition, wood and biomass combustion is still used by about ¼ of the households (Cristián Yáñez O., 2019[12]) and accounted for nearly 40% of total energy demand in 2019 (Figure 3). Similarly, indirect emissions have tended to increase due to the fast expansion of coal-powered electricity plants. In addition to Chile, Australia, Colombia, Japan, Korea and Türkiye are the other OECD countries where emissions from the residential sector increased from 2000 to 2020.

Figure 4. Drivers of the evolution of total CO_2 emissions of the residential sector

Drivers of the evolution of total CO_2 emissions of the residential sector, 2000-2020, MT CO_2/year



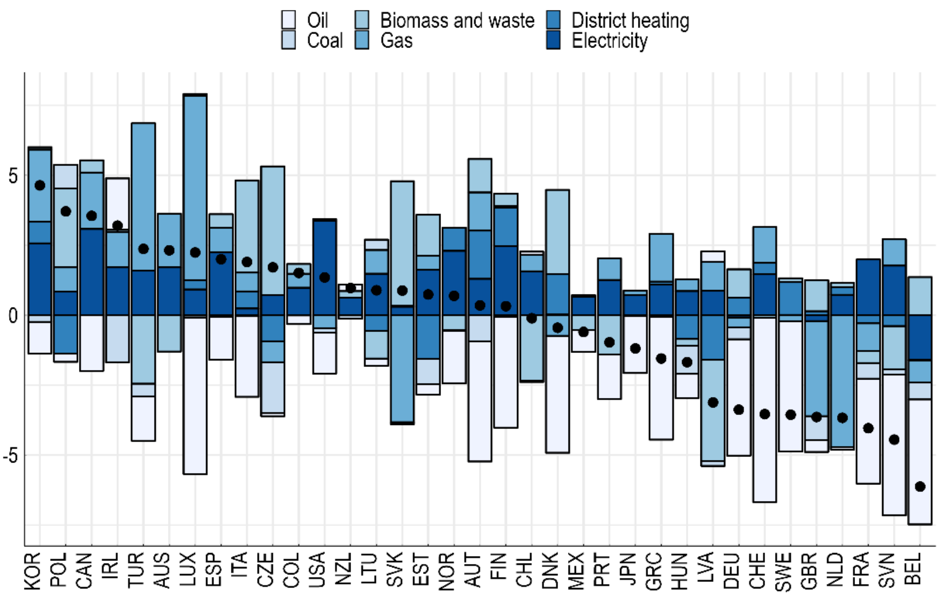
Note: Black circles represent the total CO_2 emission change between 2000 and 2020. Carbon intensity refers to CO_2 emissions per unit of energy used. Data are unavailable for three OECD countries (Costa Rica, Iceland and Israel). 2019 data were used for nine countries (Argentina, Austria, Canada, Colombia, Denmark, Spain, Estonia, Lithuania, and the Netherlands).
The decomposition follows the additive index decomposition (LMDI) method pioneered by (Ang, 2015[13]).
Source: Energy Efficiency Indicators (IEA, 2021[7]), World Energy Outlook (IEA, 2021[14]), and OECD calculations.

14. Energy use per capita and carbon intensity – CO_2 emissions per energy unit – have declined on average in the OECD area. The average fall in energy use per capita, however, masks that this variable increased in nearly half of the OECD countries. By contrast, the reduction in carbon intensity, which is determined by the CO_2 content of the fuels used, has been more uniform.

15. The decline in the direct use of coal by households, the most carbon-intensive fuel, was minor in recent years in most countries because it had been largely phased out prior to 2000 (Figure 5). The use of oil, the second-most carbon-intensive fuel, has declined in all countries (except in Ireland), substantially so in many of them, and replaced by lower-carbon sources. The phase-out of oil boilers is partly policy driven. Some countries, such as Austria, Finland, France and Spain, have mainly replaced oil products by less-carbon intensive or carbon-free energy sources (electricity and district heating). In Belgium, the Czech Republic, Denmark, Italy, Slovakia and the United Kingdom, the substitution is mainly due to the more extensive use of biofuels and waste combustion. Canada, Korea, Luxembourg, and Türkiye are countries that have switched from oil to gas, which reduces the carbon intensity at the margin but prolongs fossil fuel dependency and has been creating acute energy price pressures for households after the Russian invasion of Ukraine and the reduction of Russian gas deliveries to Europe.

Figure 5. The change in the residential sector energy mix has been far from uniform across countries

Change in residential energy use per capita (GJ), 2000-2020



Note: Black dots represent total change in energy use per capita.
Source: Energy Efficiency Indicators (IEA) and OECD calculations.

Achieving net-zero emissions will require strategies and policy reforms

16. Most OECD countries have committed to achieving net-zero emissions by 2050, with a few countries having committed to reaching the target earlier. National climate plans differ in the detail they provide about measures for particular sectors, such as housing, and the specific requirements for sub-national entities (see section 6), households or firms. In particular, 16 OECD countries have explicit climate targets and commitments for the housing sector: Australia, Austria, France, Germany, Hungary, Ireland,

Italy, Japan, South Korea, New Zealand, Portugal, Slovenia, South Africa, Spain, the United Kingdom, and the United States (Appendix B).

17. An example of a national plan focussing on the buildings sector is Japan's 2050 Carbon Neutral Goal, which aims for zero emission buildings through better insulation, low carbon power generation and an energy reduction of 20% in the residential sector and 50% in the commercial sector (Ministry of Economy, 2020[15]). Germany is another country that has set sector-specific targets in its Climate Action Plan. For the buildings sector, it has drawn up a roadmap to reach a virtually climate-neutral building stock and sets a goal to reduce emissions by two-thirds by 2030 compared to 1990. Among the measures to achieve this goal, Germany has introduced zero-emission standards for new buildings and for the existing building stock to undergo extensive retrofitting. Implementation will be closely monitored (BMUB, 2016[16]).

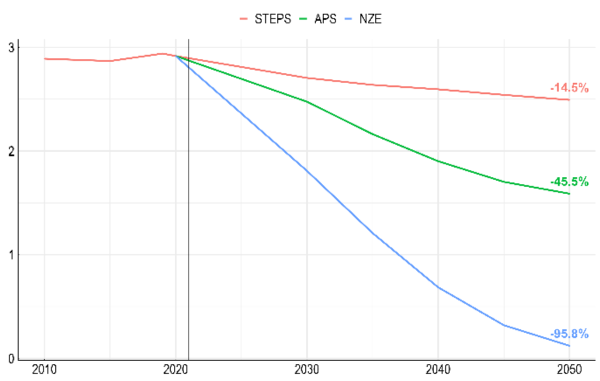
18. Housing-sector targets accompanied by policy plans have benefits such as providing guidance for developing implementation plans and providing a basis for accountability. However, housing-sector emission targets that are not just guiding but also binding could imply different degrees of effort per tonne of carbon compared with other sectors, which would be cost-inefficient and imply lower greenhouse gas emission reductions than what could be achieved for the same cost with homogenous marginal costs (Blanchard and Tirole, 2021, p. 135[17]).

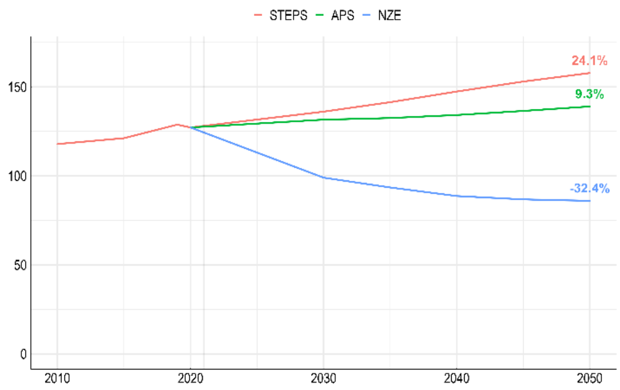
19. The IEA Net Zero Emissions (NZE) framework (IEA, 2020[18]) provides scenarios that draw a normative path for the emission reduction targets set in the Paris Agreement. Figure 6 illustrates that, under current policies, world CO_2 emissions in the buildings sector would only decrease by 14.5% from 2020 to 2050 on the back of a 24.1% increase in energy consumption. In strong contrast, the reduction reaches 32% of energy use and 95.8% of CO_2 emissions by 2050 in the IEA NZE scenario. Even already announced but not yet implemented policies would cut 2050 emissions only by nearly half from the 2020 level, showing the large gap separating current policy pledges from what is required to reach net zero emissions by 2050.

Figure 6. Global IEA scenarios to 2050 underscore the magnitude of required changes

Residential and commercial buildings

Panel A: World CO_2 emissions (GT) | Panel B: World Energy use (EJ)



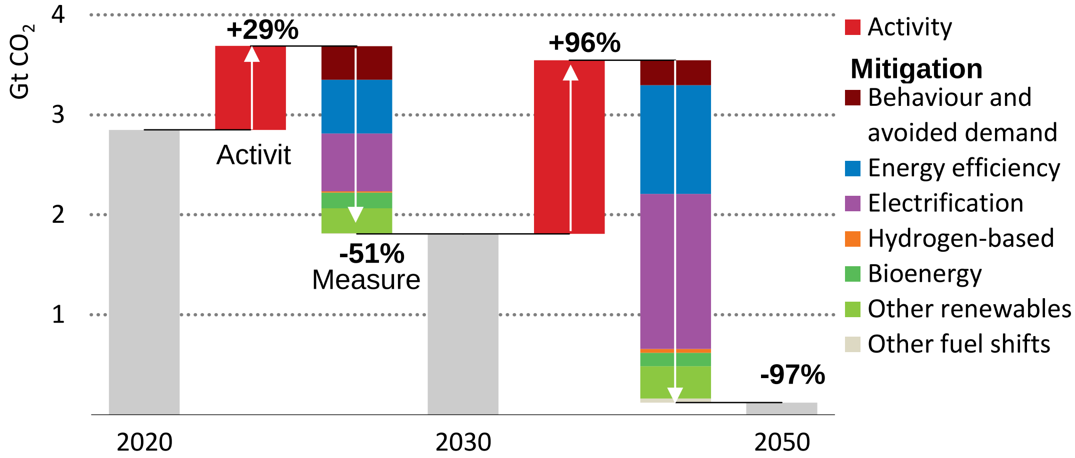


Note: The Stated Policy Scenario (STEPS) projects energy consumption and emissions under currently implemented or firmly announced policies. It assesses on a sector-by-sector basis the different pledges made by governments. Some announced policies that are unlikely to be implemented in due time are not incorporated. The Announced Pledges Scenario (APS) is a variant of STEPS and assumes that all pledged policies are fully enacted into policies. Policies in countries that have not yet made a net-zero emission pledge are assumed to be the same as in the Stated Policies Scenarios. The Net Zero Emissions (NZE) scenario sets out a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. Variables are only available at the world level. No regional or country detail is provided by the IEA.
Source: World Energy Outlook 2021 (IEA, 2021[14]) and OECD calculations.

20. In addition to electrification and decarbonised energy supply, around 40% of the reduction is expected to come from lower energy use (Figure 7). The reduction in energy use comes from the higher environmental quality of new buildings, retrofits of existing buildings and more efficient technologies supplemented by behavioural changes such as warmer target indoor temperatures in the summer and cooler ones in the winter (IEA, 2020[18]).

21. To shrink direct building-sector emissions by more than 95% by 2050, the IEA highlights the need to reduce carbon intensity drastically through a massive transition from fossil fuel combustion to carbon-free electricity generation and the use of renewables (Figure 7). In the NZE scenario, both oil and gas combustion are phased out by 2050: this stands in stark contrast with current policies, under which fossil fuels would still represent around 40% of the energy supply by 2050.

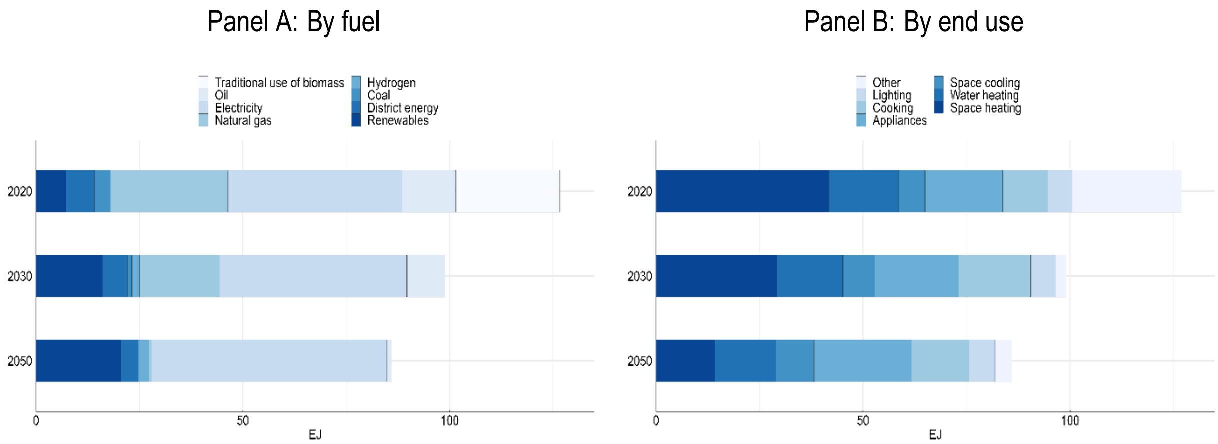
Figure 7. Decarbonising housing requires mass electrification and strong energy efficiency gains



Note: No OECD or country breakdown are available for the IEA NZE scenario. Activity refers to change in energy service demand related to rising population, increased floor area and income per capita. Behaviour refers to change in energy service demand from user decisions, e.g., changing heating temperatures. Avoided demand refers to change in energy service demand from technology developments, e.g., digitalisation.
Source: "Net Zero by 2050 – A Roadmap for the Global Energy Sector", (IEA, 2020[18]).

Figure 8. The fuel mix will be dominated by electricity complemented by home renewables

Global final energy consumption (EJ) by fuel and end-use application in buildings in the IEA net-zero scenario



Note: No OECD or country breakdown are available for the IEA NZE scenario. Other includes desalination and traditional use of solid biomass which is not allocated to a specific end-use.
Source: "Net Zero by 2050 – A Roadmap for the Global Energy Sector", (IEA, 2020[18]).

3. Reflect housing and local specificities in decarbonisation strategies

Tackle market failures and imperfections

22. Individual housing decisions can generate adverse environmental externalities, notably CO_2 emissions and air pollution. Specific market failures and imperfections complicate greenhouse gas emission reductions in the housing sector. For instance, people do not know how poorly insulated their homes are, and buyers have difficulties observing the energy efficiency of homes they consider purchasing. Many demand-side behavioural biases have been identified, such as myopia, bounded

rationality, hyperbolic discounting or dynamic inconsistencies (Gerarden, Newell and Stavins, 2017, p. 1007[19]). Market imperfections imply that owners and tenants do not undertake privately profitable investments, for instance, to raise energy efficiency (Fowlie et al., 2015[20]). Even with programme assistance and information campaigns, the take-up of zero out-of-pocket energy efficiency investments remains low, as non-monetary costs and rational inattention are major obstacles to home improvements (Sallee, 2014[21]).

23. The complexity of the housing market also arises because there are homeowners, landlords, tenants, housing associations and a non-market social housing segment. The tenure structure differs considerably across countries, so that also the policy issues, mix and design will differ. A particular problem is the split incentives problem: Tenants usually have limited options to react to higher energy costs. If landlords invest in raising energy efficiency, tenants enjoy the benefits in terms of lower energy costs or greater comfort. And, there are often only limited options in rental contracts to pass on investment costs into higher rents (de Mello, 2023[22]).

24. Moreover, homeowners have a longer time horizon for energy-saving investments, whereas tenants focus on the short-term benefits of home improvements (Kholodilin, Mense and Michelsen, 2017[23]). Incentives for energy savings are sharper for homeowners because they face the costs and benefits of their decisions. Allcott and Greenstone (2012[24]), de Mello (2023[22]) and Gerarden et al. (2017, p. 1504[19]) review the evidence on the split incentives problem and find that owner-occupiers are considerably more attentive to energy-saving opportunities than renters. Similar problems arise for houses with several apartments, including those built and managed by non-profit housing associations (Box 1).

Box 1. Multi-ownership, housing associations and CO_2 abatement decisions

The tenure structure differs considerable across countries, regions and cities. In Paris, for instance, 95% of buildings are in multi-ownership, and housing associations own 30% of the Dutch housing stock. In the case of multi-ownership, typically, a building management company is charged with the maintenance and repair of common areas, the building envelope and utility installations while also coordinating decisions by the owners about energy efficiency improvements. While maintenance and repair decisions are usually paid out of an accumulated fund, other decisions need voting by the apartment owners on an investment proposal by the building management company.

In the Dutch case, for instance, 70% of the occupants need to agree on such a proposal, and then financing has to be secured, even though the rent may not exceed a certain threshold (Van Oorschot, Hofman and Halman, 2016, p. 391[25]). However, subsidies from national and local governments exist for the retrofitting of apartments, including in the case of tenants who need to move out (de Feijter, van Vliet and Chen, 2019[26]). Strict voting and financing arrangements also exist in many other countries (Table 1). Some countries have eased the voting rules recently: Belgium reduced the required voting shares from ¾ of the votes to a 2/3 majority, while Austria reduced a 2/3 majority to a simple majority or a 2/3 majority of the votes that cover at least 1/3 of the owners.

Table 1. Voting requirements to approve retrofitting of multi-owner properties

	Maintenance	Renovations	Participation in vote
Australia	Simple majority	Simple majority	All management committee members
Austria	Simple majority	Simple majority or two thirds of a third of the owners	The owners
Belgium	Not specified	Communal parts: 2/3 majority	Not specified, votes calculated on the basis of share values

		Mandatory work to comply with standards: simple majority Other works: 4/5 majority	
Finland	No majority requirements	Simple majority	All property shareholders
Germany	Simple majority	3/4 majority	Not specified
Netherlands	70% majority	70% majority	All tenants
Poland	No majority requirements	Unanimity or majority (depending on the community)	All property shareholders, votes calculated on the basis of share values
Portugal	No majority requirements	2/3 majority	Not specified
Romania	Not specified	2/3 majority	Not specified
Spain	Simple majority	Simple majority	Members present at the meeting
USA	Differs by co-ownership	Differs by co-ownership	Differs by co-ownership
China	Not specified	2/3 majority	Not specified

Note: Simple majority stands for 50% + 1 vote.
Source: (European Commission Joint Research Centre (JRC), 2018[27]), (de Feijter, van Vliet and Chen, 2019[26]), (Matschoss et al., 2013[28]).

The German government pursues an innovative approach to overcome the split incentive problem. In 2021, Germany introduced a carbon tax on heating in the buildings sector. In 2022, the government announced that the carbon tax liability would be split between landlords and tenants depending on the building's emission performance. Tenants in low-emission housing will bear most of the tax, while landlords will be liable for most of the additional tax for carbon-intensive rental dwellings. This measure reduces the carbon tax burden of tenants and encourages landlords to undertake investments to improve the emission performance of their homes while still providing incentives to tenants to reduce their carbon footprint. A key factor for the success of this measure is to ensure that landlords are not able to pass their higher tax burden onto their tenants (e.g., through higher rents) without making the associated investments (OECD, 2022[4]).

Pricing social costs explicitly using carbon taxes and emission trading schemes

25. In many countries, current residential building-related CO_2 emission trends diverge from the paths consistent with carbon neutrality by 2050. Abatement technologies either exist or are likely to be deployable soon, but market failures and imperfections and political economy obstacles prevent them from being implemented quickly. Theory suggests that the most efficient way to internalise the climate externality and spur innovation is to price carbon (Cournède and Gastaldo, 2002[29]). This can be done by taxing CO_2 emissions or trading emission permits.

26. Some sectors are highly responsive to price signals, while various market failures hold back action in others. Electricity generation tends to show a high elasticity of emission reductions to carbon pricing and households use electricity to heat, cool or power appliances. Direct household emissions from the use of coal, oil and gas for heating and cooling are more challenging to reduce (D'Arcangelo et al., 2022[30]). This is partly due to the long renovation cycles for some housing aspects. Roofs in Germany, for instance, are, on average, replaced every 50 years. Similarly, only two per cent of heating systems are being replaced per year (German Council of Economic Experts, 2019[31]).

27. Another reason for the low elasticity is that households tend to react less to price signals than businesses. This is due to the market failures, and imperfections discussed that characterise the housing sector. Even with a carbon tax providing the right incentives, the decline in emissions may thus be only gradual in the buildings sector, and additional measures are needed to speed up emission reductions. On the other hand, the long-run elasticity could be higher than empirically estimated because historical

reactions have been measured over relatively short periods of time, when relatively small price changes occurred, while new technological possibilities and substitution opportunities only become competitive because of higher prices.

28. Effective carbon rates (ECRs) measure how countries price carbon through fuel excise taxes, carbon taxes and emission trading systems for 71 countries and six sectors, including the residential and commercial buildings sector (OECD, 2022[3]). Effective carbon rates result mainly from the use of taxes on fossil fuels, some of which are labelled carbon taxes as the rate is explicitly linked to the carbon content of the fossil fuels.

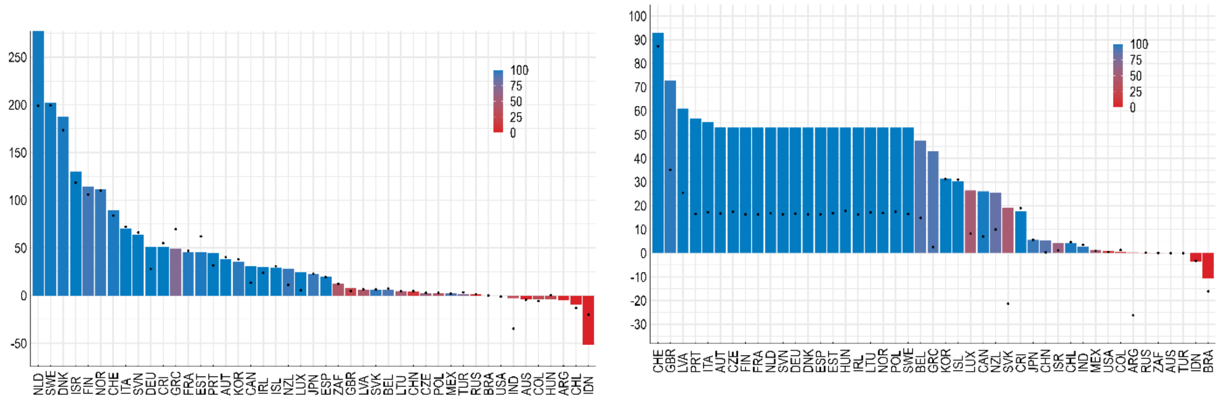
29. Explicit carbon pricing (carbon taxes and emission trading systems) exists in many countries. Currently, several countries levy a carbon tax and almost all use excise duties on fossil fuels. The only comprehensive emission trading scheme exists in Korea, though the free allocation of allowances is pervasive (OECD, 2021[32]). The EU-wide emission trading scheme covers mainly large plants in industry and electricity generation. However, Germany and Austria have decided to extend emission trading to the heating of buildings from 2026[2] and the EU is discussing including buildings in the EU emission trading scheme from 2026.

30. Net effective carbon rates on buildings are highest in Israel, the Netherlands and the Nordic countries (Figure 9). Only a few countries have so far achieved a net ECR above EUR 60, which is a mid-range estimate of current carbon costs (OECD, 2021[38]). In many countries, including Australia, the United States and many Eastern European countries, the effective carbon rates are still at or close to zero. On the other hand, carbon pricing is more extensively developed in the power generation sector, especially in Europe. This raises electricity prices and undercuts the electrification of buildings.

Figure 9. Carbon rates are low and cover a limited share of emissions in many countries

Net effective carbon rates (EUR/tCO_2)

Panel A. Buildings sector (direct emissions) | Panel B. Electricity sector (indirect emissions)



Note: The net effective carbon rate is composed of emission trading prices, carbon taxes, fuel excise taxes minus fossil fuel subsidies. The height of the bars refers to net effective carbon rates in 2021, while the black dots denote net effective carbon rates in 2018. The colour of the bars indicates the share of emissions covered in 2021. The electricity sector refers to electricity generation and the effective carbon rates do not incorporate electricity excise taxes.

2. Emission trading will take place among the fuel providers and not households. In Germany, a carbon tax that rises gradually is in place since 2021.

Source: OECD (2022), *Pricing Greenhouse Gas Emissions: Turning Targets into Climate Action*, OECD Publishing.

31. Cost-efficient emission abatement requires that carbon prices are applied uniformly across all sectors of the economy. However, uniform carbon pricing is far from being achieved, which is illustrated here by data from the buildings and electricity sectors (Figure 9). Progress in emission reductions will be uneven if the policy only covers a limited number of sectors or if carbon pricing is very low. In addition, if electricity taxes and prices are high, this will hamper electrification and will mean that cheaper fossil fuels will be used to heat and cool homes.

32. Apart from the low effective rates in many countries, excise taxes, rather than carbon taxes and emission trading prices, dominate the building sector (Figure 9). Excise taxes, which were historically mainly introduced for revenue-raising purposes, are misaligned with the carbon content of energy sources. The tax base of excise taxes should be refocused to reflect the carbon content of fuels, which would provide better abatement incentives for given tax receipts. On the other hand, before the energy crisis, fossil fuel subsidies existed only in a few OECD countries: they were sizable only in the Greek buildings sector. Since the onset of the energy crisis, they have spread, especially in Europe: an important policy challenge will be to roll them back as energy prices normalise.

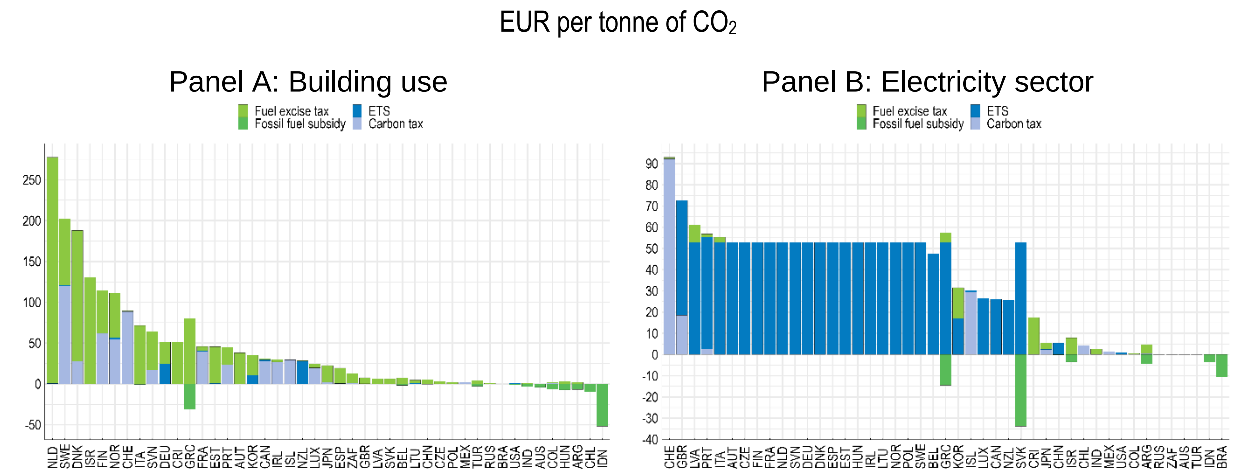
33. The effective carbon rates do not include electricity excise taxes paid by end-users. Such levies distort the pricing of energy products. First, as mentioned above, excise taxes are poorly targeted as they are not aligned with the carbon content of the energy product used to generate electricity. Second, electricity is already taxed at the production stage via emission trading systems, explicit carbon taxes and fuel excise taxes on the energy source used to generate electricity (Figure). The additional levy at the consumption stage makes electricity more expensive than natural gas for the end-user in some countries, notably Germany and the United Kingdom. This undercuts the installation of heat pumps, which need electricity (German Council of Economic Experts, 2019[31]) and (Höfling, 2019[33]). In the UK, taxes and charges on electricity equivalent to a price of GBP 70-80 per tonne of CO_2 are, in part, financing feed-in tariffs and other support policies for renewable energy products. In contrast, fossil fuels for heating are practically untaxed (OECD, 2022[34]) and (Adam et al., 2022[35]). Narrowing the gap between electricity and natural gas prices would accelerate the up-take of heat pumps in new buildings and foster deployment in existing buildings (IEA, 2021[36]).

34. Also, average carbon rates for steel and cement, which are important inputs for homebuilding and carbon-intensive to produce, are low. Cement production (including for other uses beyond housing) accounts for 8½ per cent of global greenhouse gas emissions (OECD, 2019[37]). Average carbon rates are low for steel and cement partly because the free allocation of permits in an emission trading system reduces the effective carbon emission base, for which the emitter needs to buy permits. Free allocation of permits drives a wedge between marginal and average carbon prices, much like tax allowances do for taxes (OECD, 2021[32]). Blanchard and Tirole (2021[17]) present estimates for different decarbonising options for these industries, which account for 18% of GHG emissions in Europe. The estimates suggest that costs are between EUR 40 and EUR 90 per tonne of CO_2.

35. Where countries cover industry with explicit carbon pricing, the energy-intensive inputs into the construction of houses, steel and cement are covered. However, the provision of free allocations implies that effective taxation can be low. In Europe, cement and steel producers will probably continue to receive 100% of their allocated allowances free-of-charge until 2030. This limits risks of carbon leakage (relocation of production to countries with less stringent environmental policies). Leakage would be environmentally particularly harmful for heavy products such as steel and cement, the transport of which requires considerable energy and typically entails high carbon dioxide emissions. Even with large free allocations, the inclusion of steel and cement in emission trading schemes encourages emission cuts by manufacturers, which can sell allowances. A considerable downside, however, is that such free

grandfathering of emission rights effectively amounts to an expensive lump-sum transfer from taxpayers to the manufacturers.

Figure 10. Effective carbon rates are a long way from being similar across sectors and countries



Source: OECD (2022), *Pricing Greenhouse Gas Emissions: Turning Targets into Climate Action*, OECD Publishing.

The role of environmental standards, regulations and certification

36. The ambitious decarbonisation goals require a rapid shift to the best available technologies. While labelling and certification provide essential tools for making well-informed choices, standards and regulations can also help overcome market imperfections, such as the split incentive problem and enforce the upgrading of new housing equipment and appliances. Standards and regulations can also overcome coordination failures. They can complement emission pricing and be very effective in certain cases. But they are usually not cost-minimising and can increase the cost of decarbonisation by blurring price signals and blunting economy-wide incentives (D'Arcangelo et al., 2022[1]). A regulatory approach can achieve a reduction target through intervention but rarely allows differences in the costs of avoidance between polluters to be taken into account. To achieve an efficient solution, the regulator would have to know the costs of each polluter and prescribe an individual code of behaviour (German Council of Economic Experts, 2019[31]).

Labelling and certification

37. Labelling and certification facilitate the comparison of the energy performance among properties and appliances and thus allow price formation to reward investment in the improvement and maintenance of the thermal characteristics of buildings as well as the purchase of energy-efficient appliances. The certification of buildings is similar to the ratings for the energy performance of domestic appliances. In the European Union, for buildings and appliances, a colour-letter rating on a scale from A to G applies, where A is very efficient, and G is very inefficient. The ENERGY-STAR labelling programme is the main certification scheme in the United States. In Japan, the Energy Label Program, which provides a five-star rating, is mandatory for many appliances. Similar systems exist in Australia and New Zealand.

38. Labelling and certification can have positive effects. For instance, (Andor, Gerster and Sommer, 2017[38]) show that energy labels for electrical appliances, revealing their energy efficiency, can significantly

influence purchasing decisions. Similar instruments known in behavioural economics as 'nudges' can also reduce individual energy consumption at a low cost (Andor and Fels, 2018[39]).

39. In the European Union, energy performance certification only applies to new buildings and those for rental or sale. It excludes most other buildings, which reduces the effectiveness of certification as an energy-saving tool for the existing housing stock. However, certification will become mandatory in France for multi-family properties, and the revision of the Energy Performance of Buildings Directive (Box 2) will extend the requirement for buildings undertaking large renovations in all EU countries. In the United States, energy performance certification is voluntary (Lartigue et al., 2022[40]). The empirical evidence on the price effect of energy performance certification (EPC) is largely inconclusive. Some studies find significant positive correlations with house prices, while others argue that adequately controlling for other house characteristics wipes out that effect, except for upper-tier quality buildings, which might be related to better awareness of their occupants (Marmolejo-Duarte and Chen, 2022[41]).

Standards

40. The coverage of mandatory minimum energy performance standards (MEPS) for appliances such as lighting, refrigerators and space cooling is nearly complete in the OECD (IEA, 2021[42]). Beyond coverage, the stringency of MEPS matters. In the European Union, for instance, new refrigerators now must be 75% more efficient than ten years ago, while comparative labels were rescaled in 2021 to help consumers identify the most efficient products. Progress remains limited in some areas. For example, lighting policies in many countries have not yet phased out halogen lamps, which are only about 5% more efficient than incandescent bulbs.

41. The energy efficiency standards of new buildings are of great importance because of the long life span of buildings. Standards embedded in building codes, because they are locked in for several decades, need to be aligned already now with long-term climate objectives (OECD, 2019[43]). In Europe, the revised Energy Performance of Buildings Directive (launched in December 2021) aims at building only near-zero emission homes from 2030 (Box 2). Mandatory building energy codes are in place in most OECD countries, though they are voluntary in some US states and Canadian provinces (IEA, Building energy codes by jurisdiction, 2019-2020). On the other hand, several US states have codes that are stricter than the national one. Codes in many countries have also become stricter over time.

42. Comparisons between standard and zero energy homes in the United States show that zero energy homes are more than 10% more expensive than standard homes but only 5% more expensive when taking into account federal and state financial incentives. They also lead to heating energy cost savings and a higher resale price (Zero Energy Project, 2022[44])). Building insulation standards bring far smaller savings on cooling energy costs, as, even in well-insulated homes, many households open their windows at times during hot days, negating the benefits of insulation (Davis, Martinez and Taboada, 2020[45]). Also, the strictness of the near-zero emission standard will affect the affordability of new homes. In the EU, for instance, countries set their near-zero requirements within a common framework. The primary energy requirements for single-family houses varied by a factor of six in 2021 (BPIE, 2022[46]).

Box 2. The EU Directive on the Energy Performance of Buildings

In December 2021, the European Union proposed a revision of the Energy Performance of Buildings Directive and the Energy Efficiency Directive. The objective of the amendment is to consolidate the three main objectives of the original directives: Increase energy efficiency, in particular for low-income households, lower energy consumption and foster job creation in the green building sector.

The directive sets a common framework for emission reduction targets of at least 60% by 2030 in the buildings sector in comparison to 2015 and the achievement of climate neutrality by 2050. In addition, the directive highlights several intermediate milestones and strategies to change energy sources and increase the pace of renovations.

For the transition to renewable energy, three targets are set. Renewables in the buildings sector should account for 49% of the stock by 2030. The increase in the use of renewable energy in heating and cooling should aim at a rate of 1.1 percentage point increase per year. The increase in district heating and cooling is planned to be 2.1 percentage points per year. As a complement, the phase-out of fossil fuels should be completed by 2040, at the latest. The phase-out will be underpinned by a sunset clause for financial incentives that use fossil fuels in buildings to ensure that no remaining incentives are given to install boilers powered by fossil fuels from 2027 onwards.

Regarding the renovation of energy inefficient buildings, the directive sets an objective of renovating at least 3% of the total floor area of all public buildings annually. The renovation plans for the private sector will focus on the most energy inefficient buildings with the objective that the worst performing 15% of the building stock will need to be upgraded from label G to at least F by 2030 (and at least E by 2033). The tracking of the worst performing houses will be ensured by the extension of mandatory energy performance certificates with increased reliability, quality and digitalisation for all public buildings, all buildings for rent or sale and all buildings undergoing a major renovation. To facilitate this transformation, a building renovation passport will be put in place in complement to the introduction of a legal requirement to put energy efficiency first in planning and investment decisions.

Incentivising decarbonisation using subsidies and tax breaks

43. Raising the relative price of carbon can be implemented through subsidies and tax incentives. Indeed, the right price signal of the climate constraint could be sent to all emitters by offering a subsidy per tonne of CO_2 saved. But funding such subsidy schemes would require raising additional tax revenues elsewhere in the economy either currently or, via borrowing, in the future. There are reasons for and against the use of debt to finance decarbonisation subsidies: on the one hand, emission reductions will benefit future generations that will have to repay the debt; on the other hand, the required fast pace at which emissions now need to be reduced stems from the lack of sufficient action by past and present generations. Another difficulty with decarbonisation subsidies is to determine the benchmark emission from which emission savings will be measured (Blanchard and Tirole, 2021[17]).

44. Despite these difficulties, a myriad of subsidy and tax incentive schemes exists, mainly to install new equipment, such as heat pumps or for deep renovations. Their widespread use reflects strong public support for mandatory and subsidised insulation of buildings (Dechezlepretre et al., 2022[47]).

45. Subsidy schemes can cover different technologies, building types and households and can also have very different characteristics. Subsidies and tax incentives can speed up the deployment of new technologies by overcoming the upfront cost barrier since they directly fill an immediate financial gap. On the other hand, they need to be accompanied by higher taxation in the medium run, their effectiveness in terms of emission reductions is difficult to assess ex-ante, they risk distorting market developments, and they can entail large deadweight losses. These caveats call for close monitoring of subsidy schemes from their introduction to their termination.

46. Bertoldi et al. (2021[48]) provide an overview of existing schemes in Europe.[3] Some subsidy schemes and their characteristics are summarised in Table 2. In Germany, for instance, federal subsidies are channelled through the Kreditanstalt für Wiederaufbau (KfW). Subsidies can only be obtained after prior advice from independent experts of the Deutsche Energie Agentur. In all the schemes shown in Table 2, subsidies partly fund the installation of new equipment up to a ceiling. The most generous scheme is probably the Italian Superbonus 110 scheme (110% tax credit on most of the energy efficiency work done). The main criticisms of this scheme are the lack of evidence on the actual energy efficiency gains, and the risk that overpricing by construction firms may be tolerated because homeowners do not bear the intervention costs (Brugnara and Ricciardi, 2021[49]). Tax incentives for retrofitting are generally capped as a percentage of costs, up to a fixed limit, and may take the form of a deduction or credit (OECD, 2021[32]).

Table 2. Characteristics of some subsidy schemes

	Germany	France	United Kingdom	Italy
Name	"Deutschland macht's effizient", KfW's "Energy-efficient construction and retrofitting"	"MaPrimeRénov", now a part of "FranceRénov"	"Green Deal"	"Superbonus"
What is subsidised?				
- Energy advice	Yes	Yes	No	No
- Energy efficiency improvements	Yes	Yes	Yes	Yes
- Renewable energy	Yes	Yes	Yes	No
- Other	N/A	N/A	N/A	Seismic improvements
Energy performance and control	Ex-ante and ex-post	Ex-ante and ex-post	Ex-ante	Ex-ante and ex-post
Subsidies provided	Loans, grants, tax breaks	Loans, bonuses, reduced tax rate	Grants	Tax deduction
Subsidy rate	Up to €25,000 for heating system improvement; Up to €120,000 for a complete renovation of a house	€1,000 for heating system improvement; Up to €8,000 for the installation of solar thermal; €20,000 as standard maximum amount (insulation, heating, general works; €30,000 for extended retrofit works	£5,000 as standard amount per household £10,000 for low-income households	110% on the tax base of the retrofitting costs
Does the subsidy rate depend on energy efficiency improvements?	Yes	Yes	No	Yes
Does the subsidy rate depend on income?	No	Yes	Yes	No
Possible rent increase after renovation	8%	N/A	N/A	N/A

Note: The UK has a £3,500 cap on landlord participation in the financing of energy retrofits in rented properties, which means that the rest of the costs are borne by the renters or the state. The vouchers for the UK's "Green Deal" cover up to 2/3 of any chosen improvement.
Source: (Federal Ministry for Economic Affairs and Climate Action of Germany, n.d.[50]), (Ministry of the Economy and Finance and the Recovery of France, n.d.[51]), (Government of the UK, n.d.[52]), (Brugnara and Ricciardi, 2021[49]).

3. Bertoldi et al. (2021[48]) also discuss other schemes that reduce energy bills and emissions. For instance, utility sponsored programmes can provide rebates or incentives to homeowners to invest in energy-efficiency improvements, initial investments by utilities can be paid back by the utility bill and energy efficiency obligations for energy companies and energy performance contracting with energy services companies can exist.

47. The effectiveness of subsidies in terms of reducing emissions is often assessed to be considerable by engineering assessments but rather weak by ex-post economic empirical work (Blaise and Glachant, 2019[53]) for France, (Allcott and Greenstone, 2012[24]) and (Gerarden, Newell and Stavins, 2017[19]), for the United States, where the Weatherisation Assistance Program provides means-tested federal aid to low-income households. This means that subsidies can have a high cost in terms of a tonne of CO_2 abated. Reasons include the rebound effect (better insulation leads to higher inside temperature, eating up some of the savings, or that some of the investments, such as the triple glazing of windows, has only little effect (Allcott and Greenstone, 2012[24]) (Gerarden, Newell and Stavins, 2017[19]) (Levinson, 2016[54]). Subsidies also risk funding renovation work that would have been undertaken anyway (Risch, 2020[55]): empirical estimates put the proportion of deadweight losses at 40 to 85% (Nauleau, 2014[56]).

48. To become more effective, subsidy schemes and tax incentives should focus on energy efficiency gains that can be achieved by a renovation, as in Germany (rules tightened for new houses from mid-2022 and gas boilers will not be subsidised anymore) and recently in France (MaPrimeRénov). Moreover, renovation packages should be assessed ex-ante by independent energy performance experts and also ex-post assessments performed (Sichel, 2021[57]), (Haut Conseil pour le Climat, 2020[58]). An independent assessment raises the awareness of the benefits of improved energy performance and trust in the accuracy of the advice. The French Haut Conseil pour le Climat (2020[58]) also suggested that the renovation of the worst-performing houses (F and G), where energy efficiency gains are largest, should become mandatory. The French Parliament recently decided that French apartments of the worst-performing category G can no longer be rented from 2023 and that energy performance requirements for landlords will be tightened further in the coming years.

49. Finally, several countries still provide subsidies or tax incentives to install fossil-fuel-fired equipment, such as gas boilers. In the European Union, for instance, gas boilers were still subsidised by 19 of the 27 EU countries in 2021 (Vikkelsø, 2021[59]). The supply disruptions due to the Ukraine/Russia war has triggered the phasing out of such incentives in several countries. Thus, in April 2022, the Czech Republic and Slovakia, countries where the share of gas for the residential sector represents around 30% of energy use (Figure 3) have decided to stop subsidising the installation of gas boilers. They will, instead, subsidise the installation of heat pumps and solar panels.

Address trade-offs and policy interactions

50. Deploying multiple policy instruments risks sending incoherent and conflicting signals. The large variety of policy instruments is a potential source of complexity and inefficiency. For example, subsidising the development of solar and wind electricity in Europe is costly for the public purse, but it will have no effect on EU emissions, at least in the short run, since the electricity sector is covered by the EU-ETS system. These subsidies simultaneously reduce the demand for allowances by the electricity sector and the emission price. This mechanically generates an equivalent increase in emissions by the other sectors covered by the ETS (waterbed effect). In short, the solar and wind subsidies are partly pocketed by the cement and steel industries (Blanchard and Tirole, 2021[17]; German Council of Economic Experts, 2019[31]).

51. Another example is the taxation of electricity. Many countries levy electricity taxes that partly fund the installation of solar energy and wind turbines. While that promotes the installation of solar panels, the high price undercuts the installation of heat pumps, which need electricity for their operation.

52. On the other hand, housing decarbonisation policy strategies can take advantage of complementarities across measures. For instance, energy-efficiency standards are more effective when combined with price signals. Without appropriate pricing, higher energy efficiency is likely to lead to greater energy-use, the so-called “rebound effect”. There have been examples where, in the absence of energy price changes, tighter insulation standards delivered much lower cuts in energy use than anticipated

(Levinson, 2016[54]). Finally, there are policy interactions across levels of government, which are reviewed in section 6.

4. Deploy complementary policies

Identify key technologies for the path to net zero emissions

53. Space and water heating account for the bulk of residential energy consumption. Stricter building codes and improved energy performance have allowed many countries to reduce energy use per m^2 just enough to offset the additional floor space worldwide. Currently, a considerable share of heating consumption relies on fossil fuels via oil and natural gas boilers, with the exceptions of New Zealand and especially Norway, which have made good progress in electrifying heating systems (Figure 3).

District heating

54. District heating systems have a high potential to decarbonise buildings as they allow for the integration of clean energy mixes (Box 3). The share of renewable sources and decarbonised electricity in global district heat production increases from 8% in 2020 to 35% by 2030 in the Net Zero by 2050 scenario, which alone reduces heat-related direct CO_2 emissions of buildings by one-third (IEA, 2021[60]). Electric heat pumps, assuming low-carbon electricity production, can contribute to reducing the carbon footprint of residential buildings. In 2020, only 7% of heating needs were satisfied by heat pumps. The Net Zero by 2050 scenario assumes that globally installed heat pumps will increase from 180 million in 2020 to 600 million by 2030 (IEA, 2021[36]).

Box 3. The revival of district heating

District heating and cooling systems can be important solutions for decarbonising buildings. Modern networks with low operating temperatures can integrate up to 100% of renewable sources to supply energy-efficient buildings. District heating and cooling is particularly important in high-density areas where decentralised solutions would not allow the direct integration of available clean energy sources or efficient operations, for example, due to space or infrastructure constraints (IEA, 2021[60]).

Many buildings and industrial sites rely on district heating and cooling, ranging from large urban networks in Beijing, Seoul, Milan and Stockholm to smaller networks, for instance, for university and medical campuses (IEA, 2021[60]). Central Stockholm has one of Europe's largest district heating and cooling systems, with the distribution system being 3 000km long. Close to 90% of the city's buildings are connected to the district heating network, which uses several innovative energy sources, such as excess heat and wastewater.

The district heating technology, which has been in operation since the late 1870s, has evolved over time, giving rise to improved energy efficiency, lower operating temperatures, better storage and facilitated integration of renewable energy sources such as geothermal heat or biomass (Lund et al., 2021[61]). The latter makes district heating a particularly appealing ingredient of decarbonisation strategies. Not only does it reduce the upfront investment costs when switching to a new, carbon-free energy source, it also helps to scale up the use of renewable energy production and thereby lowers CO_2 abatement costs.

A fifth generation where exchanges between the central system and the final users would occur with heat feedback loops is currently under development. At the core of its philosophy is the interaction with individual heat pumps, the latter being used as boosters to adapt to demand and take advantage of new energy sources to power these networks. For instance, since 2019, a nearby closed coal mine has been used in the Mijnwater Heerlend project in the Netherlands to store heat and cool before redistributing it to the network through an ultra-low temperature (10°C-30°C) network. This new way of thinking about district heating would allow profiting from local heat sources such as geothermal wells, dams, aquifers and even datacentres.

Rooftop photovoltaic panels

55. Solar photovoltaic (PV) generation is becoming the lowest-cost renewable energy source almost everywhere. However, installation of solar PV on rooftops often faces regulatory obstacles and political economy headwinds. Sustained efforts will be necessary to ensure the 7-fold-increase of solar PV capacities from 2020 to 2030 consistent with the net-zero by 2050 scenario. Currently, the roof-top market only represents less than half of the worldwide solar PV energy production capacity (IEA, 2022[62]).

56. Energy consumption for space cooling increases rapidly with rising living standards, particularly in areas with fast population growth. In 2020, around two billion air-conditioning units were deployed worldwide, accounting for almost 16% of the building sector's final electricity consumption (IEA, 2021[63]). The Net Zero by 2050 scenario assumes a 50% increase in the energy efficiency of air-conditioning appliances.

Building energy codes

57. Two-thirds of the countries still lacked mandatory building energy codes in 2020 (IEA, 2021[64]). The Net Zero by 2050 scenario requires worldwide coverage of such requirements by 2030 and also assumes an acceleration of retrofitting to increase the share of zero-carbon-ready buildings to around 20% by 2030 (Table 3).

Appliances

58. The share of appliances and electronic equipment in household final energy consumption has risen globally, with significant regional differences. While emerging countries witness an increase amid more widespread access to modern devices, more advanced countries experienced a relative decline in the share of appliances in total energy use thanks to the increased efficiency of refrigerators, washing machines or dishwashers (IEA, 2021[65]). The net-zero by 2050 scenario assumes global coverage of today's best technology so that the increase in energy efficiency offsets the projected increase in the use of appliances.

Light bulbs

59. In 2010, incandescent light bulbs were still the norm, although their energy efficiency was already only a fraction of the newly emerging LEDs. Since then, the energy efficiency of the latter has continued to increase, together with the widespread deployment of LEDs amid increasing affordability (IEA, 2021[66]). The success of LEDs is a prime example of how the scaling-up of energy-efficient technologies can reduce their price and pave the way for the replacement of carbon-intense technologies. As a result, the lighting energy intensity per dwelling has declined by more than 30% from 2010 to 2019 on average across the OECD.

Smart buildings

60. Smart buildings, seizing the opportunities delivered by digitalisation through the connectivity of appliances and automation of electricity demand, are the foundations for future "zero carbon-ready" residential structures. Retrofit rates for buildings to be "zero-carbon ready"[4] reach about 2.5% a year by 2030 in advanced economies and 2% a year by 2030 in emerging-market economies.

---

4. A zero-carbon-ready building is highly energy efficient and either uses renewable energy directly or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat.

Smart grids

61. A major driver of decarbonisation is electrification coupled with carbon-free energy production. Nevertheless, some of the less carbon-intensive energy sources are intermittent and non-dispatchable posing challenges to matching electricity supply and demand. Smart grid systems can help, but investment will have to triple during 2020-2030, accounting for around 40% of all necessary capital investments in the Net-Zero by 2050 scenario.

Table 3. Key milestones in the building sector on the road to net zero emissions

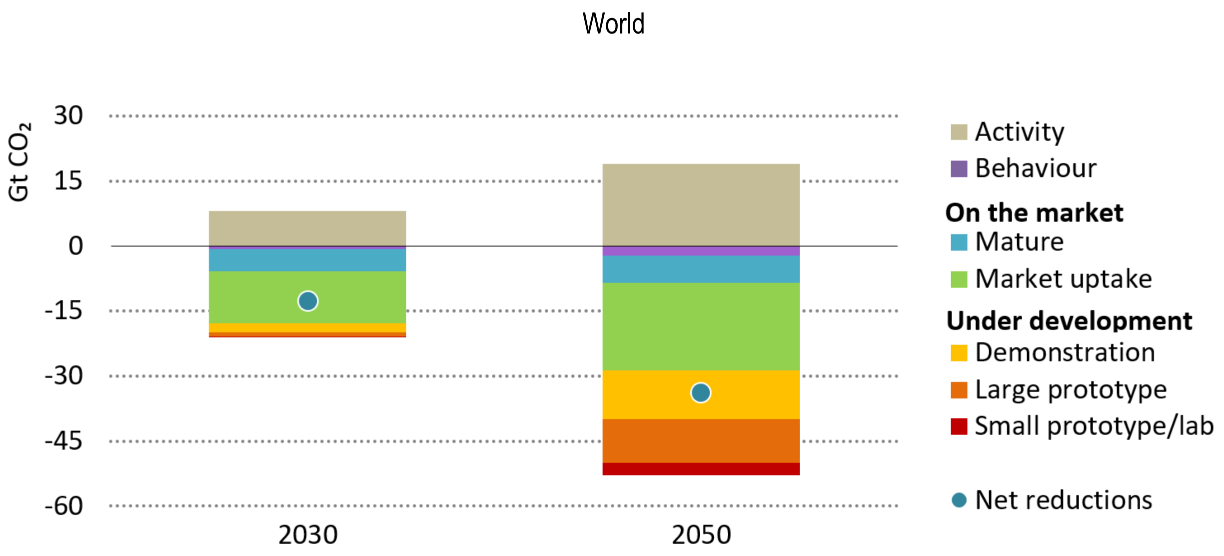
Category	2020	2030	2050
Buildings Share of existing buildings retrofitted to the zero-carbon-ready level	<1%	20%	>85%
Share of zero-carbon-ready new building construction	5%	100%	100%
Heating and cooling			
Stock of heat pumps (million units)	180	600	1,800
Million dwellings using solar thermal	250	400	1,200
Avoided residential energy demand from behaviour	n.a.	12%	14%
Appliances and lighting Appliances: unit energy consumption (index 2020=100)	100	75	60
Lighting: share of LED in sales	50%	100%	100%
Energy access			
Population with access to electricity (billion people)	7.0	8.5	9.7
Population with access to clean cooking (billion people)	5.1	8.5	9.7
Energy infrastructure in buildings			
Distributed solar PV generation (TWh)	320	2,200	7,500
EV private chargers (million units)	270	1,400	3,500

Source: "Net Zero by 2050 – A Roadmap for the Global Energy Sector", (IEA, 2020[18]).

Support innovation in clean technologies

62. While the emission reductions in 2030 mostly rely on available technologies, those under development today account for almost half of the emission reductions in 2050, according to the NZE scenario (Figure 11). Striving for decarbonisation coupled with the increasing demand for energy, particularly in buildings, inevitably calls for continued investments in innovative technologies to bring building-related CO_2 emissions on track to net-zero emissions. Yet, after a sharp rise in patenting of low-carbon energy innovations in end-use technologies of buildings from 2000 to 2013, patenting activity has declined more recently (IEA, 2021[67]). Abatement costs are still too high for many technologies, especially those still at the demonstration or prototype development stage.

Figure 11. Clean technology innovations are critical for decarbonising buildings

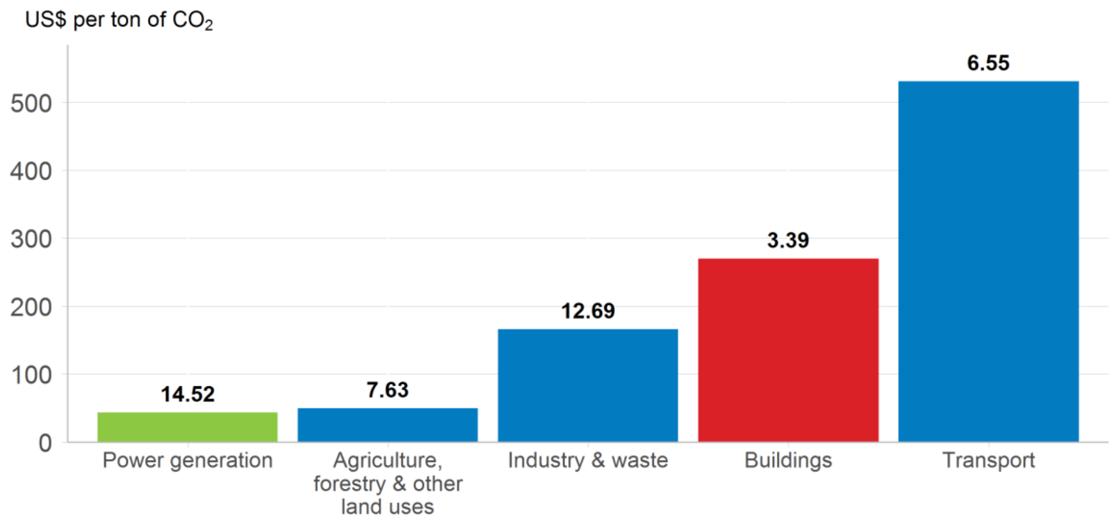


Source: Net-zero by 2050 – A roadmap for the global energy sector (IEA, 2020[18]).

63. R&D investments in carbon-free technologies for the building sector not only make these technologies available but also help to make them more cost-efficient. An important benchmark for calibrating and evaluating policies that aim at reducing GHG emissions is to create standardised measures of the monetary costs of reducing a ton of CO_2 for the deployment of alternative technologies (Blanchard and Tirole, 2021[17]). While there is considerable uncertainty around estimating such abatement costs, some indicate that direct emissions from the buildings sector are costly to abate (Figure 12).

64. The bulk of emissions from energy use in buildings is associated with high abatement costs (Figure 13). This includes the electrification of heating systems through the installation of heat pumps, the switch from gas to hydrogen for water boilers or the installation of “Building Automation Control Systems” (BACS) to reap the benefits of smart functions such as demand response, consumption prediction, energy storage or equipment maintenance. Indirect emissions from power generation, on the other hand, are less costly to abate under appropriate carbon pricing and available technologies.

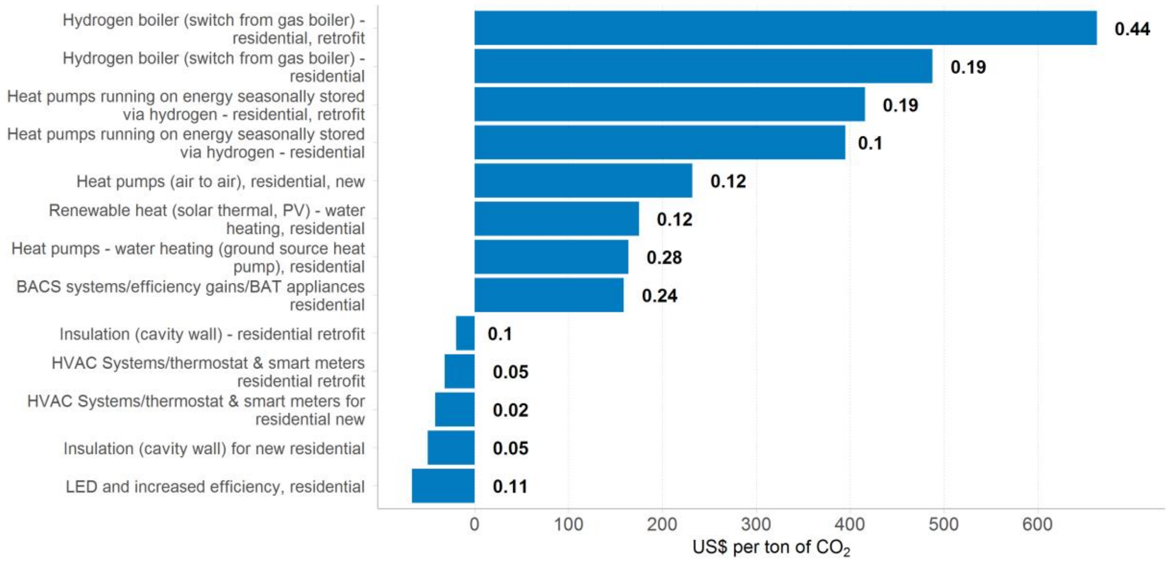
Figure 12. Abatement costs are high in the buildings sector



Note: The annotated numbers denote the abatement potential (in Giga tons of CO_2 equivalent) for each sector.
Source: "Innovation, Deflation and Affordable De-carbonization" (Goldman Sachs International, 2020[68]).

65. CO_2 abatement potential for direct emissions from buildings exists via the conversion of heating and cooking appliances away from the combustion of fossil fuels. But these technologies are expensive (Figure 13), and more innovation and up-scaling are needed to bring abatement costs down. Subsidies are useful to accelerate uptake and the required investments, especially if uncertainty lingers about the prospect that carbon pricing is here to stay and will intensify over time. Recent evidence shows the great potential of innovative solutions to reduce installation and maintenance costs. Goldman Sachs (2020[68]) estimated that from 2019 to 2020 alone, the flattening of the CO_2 abatement cost curves reduced the costs of abating 50% of global CO_2 emissions by 20% and the costs of decreasing 70% of global CO_2 emissions even by 30%. The challenge for direct emissions in the building sector is even more significant as abating the bulk of the emissions would require a carbon tax higher than 150 US$, although recent developments have lowered that number (Figure 13).

Figure 13. There is little low-hanging fruit to reduce direct emissions from buildings



Note: The annotated numbers denote the abatement potential (in Giga tons of CO_2 equivalent) for each sector. Abatement cost estimates are based on technology and price assumption from 2020.
Source: "Innovation, Deflation and Affordable De-carbonization" (Goldman Sachs International, 2020[68]).

66. High upfront costs remain an obstacle to the renovation of electricity and heating systems in residential buildings. Subsidies for research and installing heat pumps or hydrogen boilers would accelerate the switch to clean technologies, create economies of scale, and spur competition and innovation. The resulting reduction in installation costs for clean technologies would reduce the energy transition's social costs and flatten the required forward path of carbon taxes (Acemoglu et al., 2016[69]).

67. Support policies are also better socially supported and, therefore, politically sometimes more attractive than taxation (Dechezlepretre et al., 2022[47]). Such support should be limited in time and be phased out when carbon prices reach an appropriate level, offsetting the abatement costs that will have been reduced thanks to innovation and upscaling.

68. While not the most cost-efficient policy tool, feed-in tariffs and feed-in premia can help spur investments in low-carbon electricity generation technology and create positive externalities. Power generators receive a fixed price known in advance, reducing or eliminating uncertainty for investors. Reducing climate policy uncertainty can significantly increase firms' investment activity, in particular for capital-intensive firms that require long and stable planning trajectories for their investments (Berestycki et al., 2022[70]). In Germany, the generous feed-in tariff scheme for solar PV systems has propelled the country to the top ranks in terms of installed capacity per capita, with rooftops playing a large role. Solar PV is also a prime example of the cost-reduction effect of innovation and scalability: by 2020, solar PV displayed lower levelised costs of electricity than fossil fuels on average (Figure 14).

Figure 14. Innovation has cut installation costs for many renewables including rooftop photovoltaic

Note: The arrow signals change in levelised costs of electricity from 2010 to 2019.
Source: IEA (2020), Projected Costs of Generating Electricity.

69. Public support is also important for vocational education to ensure that enough workers are equipped with the skills necessary for housing decarbonisation. Deep retrofits and low-carbon construction, two labour-intensive activities, require specific skills.

Harness mortgage finance to support housing decarbonisation

70. Housing finance, one of the largest segments of global financial markets, can make a key contribution to cutting emissions from the residential sector. Mortgage lenders can support housing decarbonisation at different stages:

- For new construction, mortgage lenders can recognise that homes built in accordance with standards compatible with the net zero target will imply lower recurring energy costs and avoid the risk of expensive later retrofitting by their owners. These two characteristics respectively improve the cash flow and collateral value of borrowers, both enhancing the credit quality of the loan. Transparent, reliable energy certification would facilitate the take-up of building loans that can recognise the lower risk associated with a strong environmental quality of construction (Box 4).
- For existing homes, similarly, reliable certification would make it easier for banks to recognise the credit enhancement, also in terms of both collateral value and borrower cash flow, from greater energy efficiency. Plenty of evidence exists that favourable energy ratings are reflected in higher property prices (Taruttis and Weber, 2022[71]; Copiello and Donati, 2021[72]; Fuerst et al., 2015[73]; Hyland, Lyons and Lyons, 2013[74]; Fuerst and Warren-Myers, 2018[75]). (Taruttis and Weber, 2022[71]; Copiello and Donati, 2021[72]; Fuerst et al., 2015[73]; Hyland, Lyons and Lyons, 2013[74]; Fuerst and Warren-Myers, 2018[75]). While evidence of their effect on housing loans is narrower, analysis of Dutch residential mortgage data linked greater energy efficiency with a lower probability of default (Billio et al., 2021[76]).

- Retrofitting is currently missing a lending market. For an individual dwelling, the amount is much smaller than a mortgage, complicating the coverage of administrative and other issuance costs. The consumer credit market is also ill suited to the funding of retrofitting: the payback period of retrofits is typically longer than the maturity of consumer loans, and the higher risk associated with consumer credit results in elevated interest rates that can make retrofitting investment unprofitable.

Box 4. Real estate finance and climate transition: the role of green-labelled products

The large, required investments for housing decarbonisation mean that markets should be among the major players in this global effort. Green-labelled products, which mostly emerged over the past decade, however, remain small within the overall real estate finance markets. Green real estate bonds and mortgage-backed securities (MBS) represented about 1.5% of total mortgage bond and MBS issuance in 2021 in the United Kingdom, the United States, the European Union and China.

A recent OECD study identifies several factors that limit the capacity of green finance to support housing decarbonisation (OECD, 2022[5]):

- The “green” label is awarded through Green Building Rating Systems (GBRSs). Hundreds of GBRSs are currently in operation: even though four GBRSs are prevalent, the market is fragmented.
- The green label given by GBRSs covers a wide spectrum of environmental areas, including water usage and waste management, which contribute little to decarbonisation.
    - Nevertheless, energy performance has usually the greatest weight in the environmental performance assessment, with an average weight of 27% in the GBRS against 11% for each other dimension.
    - GBRSs typically give a much smaller weight to a building’s capacity to generate renewable electricity through solar panels.
- Green labelling criteria related to energy performance and renewable generation are not always aligned with the objective of net zero emissions by 2050, with some rating systems incorporating lower levels of ambition.

Financial market support for housing decarbonisation would strongly benefit from clarification and better international comparability of standards. Policy measures could encourage the development of common methodologies and rating criteria to strengthen certification processes and make it easier for investors to understand what the “green” label means. It is particularly important to have greater transparency about the weight that various green labels give to the decarbonisation target and whether it is in line with net zero emissions by 2050. More transparent and credible standards would foster greater liquidity in green real estate finance, creating more favourable conditions for an expansion to the large scale needed to attain decarbonisation objectives.

5. Design policies that limit adverse effects on low-income households

71. Decarbonising housing involves costs. Heating fuel taxation increases, new construction follows more demanding standards, and the existing housing stock has to undergo deep renovations much faster than without climate objectives. The rise in these costs can have adverse consequences for low-income households: a recent OECD analysis of the experience of 32 countries over 2007-2020 found that a 10% increase in the number of residential energy policies is associated with a 5% increase in a household’s

probability of falling into energy poverty (Brucal and McCoy, forthcoming[77]). This section reviews impacts and possible policy responses measure by measure.

Carbon taxes offer options to mitigate adverse distributional effects

72. Taxing carbon dioxide emissions from housing while delivering large economic efficiency and ease-of-administration benefits raises serious questions about impacts on low-income households. The taxation of heating fuels and residential electricity has a proportionally larger impact on low-income households, who spend a greater share of their income on these basic necessities than higher-income groups (Vona, 2021[78]). This regressive effect is limited in size for heating fuels but large for electricity (Flues and Thomas, 2015[79]). Furthermore, differences in the impact can be large within income groups (Flues and Thomas, 2015[79]): low-income households living in owner-occupied fossil fuel-heated detached houses will, for instance, face a much greater impact of residential carbon taxation than low-income residents of district-heated social housing.

73. Policy options are available to alleviate adverse distributional side-effects from the taxation of housing CO_2 emissions.

- First, the tax can focus on direct emissions, thus pricing the carbon content of heating fuels, and leave the pricing of CO_2 emission from electricity to taxes or permit schemes applied to power generators. A design of this nature will reduce the particularly regressive impact of electricity taxation. Compared with taxing electricity use, it will also create sharper incentives to reduce CO_2 emissions at the power generation stage.
- Second, a tax presents the advantage of generating revenues, some of which can be used to compensate for adverse regressive effects. An important feature of compensation mechanisms is that their design preserves the incentive created by the carbon tax so that they take the form of transfers to adversely affected households that are not positively connected with their use of carbon-intensive energy sources. This consideration, taken together with the observation that impacts differ along other dimensions than income, such as the type of housing, suggests allowing room for space-based differentiation in compensation strategies. In turn, introducing additional dimensions in the definition of compensation measures increases their complexity and administrative costs. For these reasons, compensation strategies will necessarily incorporate a certain degree of imperfection.

Tradeable permits have similar effects as taxes

74. If auctioned, tradeable emission permits for housing emissions would have very similar distributional effects as residential carbon taxation. As carbon taxes, auctioned permits would have regressive effects, before factoring in their large revenue potential, which offers ample scope to compensate adversely affected low-income households. One difference with taxes is that the price volatility inherent in emission trading systems entails a degree of cost uncertainty, which would be particularly harmful for low-income households whose economic conditions are particularly unstable (Cournède, Garda and Ziemann, 2015[80]).

Costs of energy efficiency standards weigh particularly on low-income households

75. Strict energy-efficiency standards on buildings and appliances have implications for costs, which are likely to weigh particularly on low-income households. There is substantial evidence (Fullerton and Muehlegger, 2017[81]), including from recent OECD work (Brucal and McCoy, forthcoming[77]), that regulatory approaches to climate policy are generally more regressive along the income distribution than

carbon taxes despite the associated reduction in energy bills. US data have shown more overcrowding among low-income households because of tighter energy-efficiency standards (Bruegge, Deryugina and Myers, 2019[82]).

76. Mandatory deep renovations of existing properties can impose large burdens on low-income owners, accompanied by liquidity difficulties, if introduced outside transactions. There is a case for providing bridging loans and subsidies, as the subsequent annual energy savings can be low compared with the cost of renovation. An *ex-post* study of a programme undertaken in France over 2000-13 showed annual energy-bill reductions of €8 per €1000 invested (Blaise and Glachant, 2019[53]). Mandatory deep renovations can work against social inclusion by contributing to so-called "gentrification" if they effectively push out low-income renters as rents increase in response to the improvement work to levels that they cannot afford (Anguelovski et al., 2019[83]).

Subsidies require appropriate targeting

77. Subsidies for emission reductions, even if beneficial to low-income owners living in high-emission-per-square meter dwellings, can bring large benefits to high-income owners. Energy-efficiency improvements have been shown to become capitalised in house prices (Reusens, Vastmans and Damen, 2022[84]). Countries could consider income-based eligibility criteria as well as the provision of refundable tax credits to overcome such concerns. Low-income owners may also struggle to finance up-front investments and may be sensitive to the time delay between the investment and reception of the tax benefit as well as the practical difficulties of living in a house under heavy renovation. The *MaPrimeRénov* in France, for instance, offers higher grants for retrofitting projects performed by lower-income households (up to EUR 10 000 per project) and an advance payment to undertake the renovations for the lowest-income households (OECD, 2022[4]). The French auditor general ("Cour des Comptes") has acknowledged the strong up-take of the scheme. It has accepted 297 000 demands for a total of EUR 862 million distributed between April 2020 and June 2021. 64% of the demand concerned lower-income households, a major improvement in terms of targeting compared to the previous scheme (Cour des Comptes, 2021[85]). The Italian 110% reimbursement under the Superbonus scheme was motivated in part by the objective of compensating the non-monetary costs associated with heavy renovation.

Information provision has little adverse effect

78. Information provision through mandates to certify the energy performance of dwellings implies small direct effects stemming from the certification cost. These costs may raise liquidity issues for low-income owners if they are required outside transactions or inheritance, an adverse effect that can be offset with targeted subsidies.

6. Mobilise all levels of government

Housing and environmental policies are highly decentralised

79. Well-functioning governance arrangements will be needed to align housing decarbonisation policies and implementation across all levels of government. Both environmental and housing policies are highly decentralised (Box 5). While emission goals are set by national governments in international (e.g., Paris Agreement) or supranational fora (e.g., European Green Deal), environmental policy is usually carried out on a shared basis between national, regional and local governments. This is also the case for housing policies, which have an even more prominent local component. Table 4 illustrates some examples of responsibility attribution for some policy areas. Without well-functioning governance capable of aligning policy agendas and implementation across all levels of government, countries will likely encounter serious difficulties in complying with environmental objectives (de Mello and Martinez-Vazquez, 2022[86]), including those in the housing sector.

Box 5. The importance of cities and regions for decarbonising buildings

The share of greenhouse gas emissions from buildings in total emissions is highest in large metropolitan regions and lowest in remote regions (OECD, 2022[2]). In addition, this share increases dramatically in large cities. CO_2 emissions from buildings in London and New York account for 78% and 70% of total emissions, respectively (London City Hall, 2022[87]) (NYC Mayor's office of Climate and Environmental Justice, 2022[88]).

The emissions from buildings within a country differ across regions. Climatic conditions affect the energy performance of buildings and also the property owner's motivation for energy efficiency improvements (OECD, 2022[2]). Also, the policy environment varies across cities and regions. Each local government has different capacities and policy priorities, including housing affordability, energy poverty, and local employment (OECD, 2022[2]). Also, the building stock and locally available heating sources differ across cities and regions. For instance, cities that are close to data centres or industry sites can profit from residual heat and invest in district heating infrastructure.

Energy efficiency improvements in buildings bring benefits, including local job creation, better health outcomes because of improved indoor quality, and reduced energy bills. The OECD – EU Committee of the Regions (CoR) city survey revealed that 89% of cities and regions valued "Reduced cost of paying the energy bill for low-income households" to be the most important benefit of energy efficiency improvements in buildings.

Collaboration across levels of government is fundamental in implementing effective measures. Policy tools such as the OECD checklist for Public Action to Decarbonise Buildings in Cities and Regions can help both national and sub-national policymakers to align both national and local actions towards building decarbonisation (OECD, 2022[2]).

Table 4. Responsibility allocation across government levels

	Spain	Canada	France	United States
Carbon pricing (tax, ETS)	Supranational and regional regulation and implementation	Provincial regulation and implementation, with federal backstop	Supranational and national regulation and implementation	State-level regulation and implementation
Housing planning and building standards	Supranational, national and regional regulation, regional and local implementation and funded by all the layers	Federal and provincial regulation, with local implementation	Supranational and national regulation, with regional and local implementation and funded by all the layers	Federal, and state (some also local) regulation and state (or local) implementation, funded by all the layers
Energy efficiency (e.g., isolation, heating systems)		Federal, provincial and local regulation, implementation and finance		
Energy performance information (labelling)	Supranational and national legislation, with regional implementation	Federal and provincial regulation, with local implementation	Supranational and national legislation, with national implementation	State and/or local regulation and implementation

Source: National, regional and local institutions' online resources regarding law, planning and information.

80. Competencies in relevant fields are often shared vertically, as observed even in unitary countries, such as France. While carbon pricing is usually centralised, with the exceptions of Canada, Spain and the United States, for housing planning and building standards (despite basic central regulation), legislation and implementation are usually in the hands of lower tiers of government. With respect to energy performance information, such as labelling, regulation is often the responsibility of central governments,

while sub-national entities usually carry out implementation. Finally, the largest contrast between federal (or heavily decentralised) and unitary countries is recorded in the governance of energy efficiency policies. While sub-national governments in decentralised countries can elaborate laws in this field, in unitary countries, lower tiers of government are limited to implementing centrally set legislation. A common practice is for sub-national governments to complement national policies with more ambitious targets or by adding additional funding.

Many policy instruments are under the purview of sub-central governments

81. Social housing is an important policy tool to address affordability and energy poverty challenges. Social housing comprises more than 28 million dwellings and about 6% of the total housing stock in OECD and non-OECD EU countries (OECD, 2020[89]). There are significant differences across countries in the definition, size, scope, target population and type of provider of social housing. For instance, social rental housing makes up less than 10% of the total dwelling stock in most OECD and EU countries but more than 20% of the total stock in Austria, Denmark and the Netherlands. Social housing dwellings are often owned by sub-national governments, and especially municipalities. As the social housing sector targets mainly low-income households, they cannot shoulder the cost of even small housing renovation projects. The funding of renovations is thus an important issue, also because the quality of the social housing stock requires attention in many countries. For example, in Belgium, Ireland, France and the United Kingdom, more than one out of five low-income households in the social housing sector struggled to keep their dwelling warm in 2017 (OECD, 2020[90]). Raising energy efficiency would thus also be a step towards reducing poverty.

82. Regulation is often generating new obligations for sub-national jurisdictions. This usually takes the form of minimum standard-setting by central legislation, aiming to avoid competition between jurisdictions that could end up in a race to the bottom. Carbon pricing in Canada is a clear example of the latter since the federal government established a minimum threshold (known as the federal backstop) that all provinces must reach (Snoddon and Tombe, 2019[91]). Provinces can still decide whether they use carbon taxes or emission trading systems to reach the yardstick and have room to determine the price of carbon emissions if it is higher than the federal backstop. Similar minimum standard-setting may be established (or strengthened in case it already exists) for buildings, electrification or energy savings. Importantly, the process to set them should consider sub-national governments' views to facilitate their engagement and minimise risks of politicisation of environmental policy.

83. In addition, financial incentives could induce sub-national governments to align with the housing decarbonisation process. The rationale behind it could mirror Ecological Fiscal Transfers (Busch et al., 2021[92]). These consist of fiscal transfers paid by the central government to sub-national entities with, for instance, a multi-variate index of environmental policies such as enhanced air quality and/or higher shares of land covered by natural protection areas. By doing so, the incentives to improve local government environmental performance can be boosted (Dougherty and Montes Nebrada, 2022[93]). For instance, making intergovernmental grants conditional on achievements in the housing decarbonisation strategy may help to reach objectives. Furthermore, ensuring that financial support to sub-national entities is provided in this area would help prevent the policies from turning into unfunded national mandates. The latter phenomenon arises when a central government creates new responsibilities for sub-national governments based on its own policy agenda without providing them with the financial support necessary to implement the policy (Posner, 1997[94]).

84. Finally, alternative non-regulatory mechanisms, such as soft-power tools, may be useful. Central governments could use their coordination capacity to support experimentation and pilot programmes of new innovative projects and may help sub-national governments learn from best practices used in other jurisdictions. Such policy laboratory and yardstick competition dynamics are characteristic of federations and one of the traditionally used arguments to support decentralisation (Oates, 1972[95]).

Targets and climate action plans at the sub-central government level

85. Many cities have introduced targets and climate action plans. Currently, 142 cities have introduced Climate Action Plans compatible with the Paris Agreement target, with 118 of these cities located in the OECD (C40, 2022[96]). Table 5 illustrates some of these city-level policies.

Table 5. Urban policies aimed at promoting energy efficiency in buildings

	Copenhagen	New York	Vienna	Paris	Tokyo
Taxes		Emission trading scheme for buildings planned			Emission trading scheme for buildings (industrial and commercial sectors only)
Subsidies and tax incentives	"One-stop-shop" energy-saving packages to commercial and service companies Tax deduction for retrofit program abandoned in 2022	Low- or no-interest loans to finance energy efficiency improvements (Green Housing and Preservation Program) Green Roof Tax Abatement program Property tax exemptions for green buildings (LEED-certified)	"Thewosan" support scheme: subsidies for new buildings achieving a low energy or passive-house-standard Additional subsidies for the installation of heat pumps, gas condensing boilers and access to district heating	Subsidies for retrofits provided by Anah (L'Agence nationale de l'habitat) Tax credit for retrofits No-interest Eco Loan (Éco-prêt à taux zéro) Reduced VAT of 5.5%	National and local subsidies for specific retrofits (e.g., Minato Ward, subsidy for window glazing)
Standards and regulations	Building regulations (revised in 2016) with mandatory energy efficiency requirements	Proposed mandatory energy use limits for existing buildings Performance-based stretch-energy codes for new construction	Low energy standards Passive-house-standards (voluntary)	Mandatory energy efficiency standards for all buildings	No strict standards; targets for zero emission house and zero emission buildings
Provision of information (labels)	Energy performance certificates	Building Energy Efficiency Rating Labels	Energy performance certificates	Energy performance certificates Effinergie (low energy) labels for new construction	Tenant Rating and Disclosure Program to reflect energy use (mandatory) Carbon Certification Program (voluntary)

Source: City climate action plans (City of Copenhagen, 2020[97]), (The City of New York, 2019[98]), (Magistrat der Stadt Wien, 2022[99]), (City of Paris, 2020[100]), (Tokyo Metropolitan Government, 2019[101]).

86. In a survey of OECD cities, 80% stated that they have energy efficiency goals, which are more ambitious than that of the central government (OECD, 2021[102]). For example, in 2012, the city of Copenhagen set the aim in the Climate Plan to achieve carbon neutrality by 2025, 25 years ahead of the Danish national commitment (City of Copenhagen, 2020[97]). Notably, the city aimed to foster energy efficiency of the existing building stock by encouraging the retrofitting of private homes and maintaining the renovation programme for social housing. For newly constructed dwellings, energy efficiency certificates should ensure the construction of energy-efficient new buildings and to provide quantitative indicators to track CO_2 emission progress.

87. Even if more ambitious, city-level targets, in addition to national commitments, can pose coordination challenges by sometimes contradicting national and local level commitments that reflect either different opinions on the objectives and/or different strategies of implementation. For instance, despite the United States having quit the Paris Agreement on Climate in 2019, New York City continued developing its own climate strategy by including city-specific energy efficiency standards for housing and providing low and no-interest loans to finance the retrofitting of the existing dwelling stock (The City of New York, 2019[98]).

88. While usually better adapted to local specificities, city-level climate action plans rely mostly on higher administrative levels for implementation and financing and often lack the resources to implement their usually more ambitious commitments. For instance, in a survey of 21 OECD cities and regions, 76% of the cities and regions mentioned that the lack of resources was the biggest constraint to implementing energy efficiency measures (OECD, 2021[102]). In the case of Copenhagen, the city recognised in 2021 that the 2025 target could not be reached. The main constraint is the lack of resources to support energy retrofitting since only 15% of Copenhagen's housing stock can be directly influenced by the city (5% are city-owned buildings, and 10% are social housing units). Another difficulty is the gap between the assumed and observed energy use of new buildings that frequently use more energy than required by the building code (City of Copenhagen, 2020[97]).

References

Acemoglu, D. et al. (2016), "Transition to clean technology", *Journal of Political Economy*, Vol. 124/1, pp. 52-104, https://doi.org/10.1086/684511. [69]

Adam, S. et al. (2022), "Tax policies to reduce carbon emissions", *Fiscal Studies*, https://doi.org/10.1111/1475-5890.12308. [35]

Allcott, H. and M. Greenstone (2012), *Is there an energy efficiency gap?*, https://doi.org/10.1257/jep.26.1.3. [24]

Andor, M. and K. Fels (2018), "Behavioral Economics and Energy Conservation – A Systematic Review of Non-price Interventions and Their Causal Effects", *Ecological Economics*, Vol. 148, pp. 178-210, https://doi.org/10.1016/J.ECOLECON.2018.01.018. [39]

Andor, M., A. Gerster and S. Sommer (2017), "Consumer inattention, heuristic thinking and the role of energy labels", *Ruhr Economic Papers*, Vol. No. 671, https://doi.org/10.4419/86788778. [38]

Ang, B. (2015), "LMDI decomposition approach: A guide for implementation", *Energy Policy*, Vol. 86, pp. 233-238, https://doi.org/10.1016/j.enpol.2015.07.007. [13]

Anguelovski, I. et al. (2019), "Why green "climate gentrification" threatens poor and vulnerable populations", *Proceedings of the National Academy of Sciences*, Vol. 116/52, pp. 26139-26143, https://doi.org/10.1073/pnas.1920490117. [83]

Berestycki, C. et al. (2022), "Measuring and Assessing the Effects of Climate Policy Uncertainty", *OECD Economics Department Working Papers No. 1724*. [70]

Bertoldi, P. et al. (2021), "How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU", *WIREs Energy and Environment*, Vol. 10/1, https://doi.org/10.1002/wene.384. [48]

Billio, M. et al. (2021), "Buildings' Energy Efficiency and the Probability of Mortgage Default: The Dutch Case", *The Journal of Real Estate Finance and Economics*, Vol. 65/3, pp. 419-450, https://doi.org/10.1007/s11146-021-09838-0. [76]

Blaise, G. and M. Glachant (2019), *Quel est l'impact des travaux de rénovation énergétique des logements sur la consommation d'énergie ? Une évaluation ex post sur données de panel*. [53]

Blanchard, O. and J. Tirole (2021), *Major Future Economic Challenges, International Commission chaired by Olivier Blanchard and Jean Tirole*. [17]

BMUB (2016), *Climate Action Plan 2050*, Federal Ministry for the Environment; Nature Conservation; Building and Nuclear Safety, http://www.bmub.bund.de/english. [16]

BPIE (2022), *Nearly Zero: A Review of EU Member State Implementation of New Build Requirements*, https://www.bpie.eu/wp-content/uploads/2021/06/Nearly-zero_EU-Member-State-Review-062021_Final.pdf.pdf (accessed on 31 August 2022). [46]

Brucal, A. and D. McCoy (forthcoming), "Social and distributional impacts of residential energy efficiency policies", *OECD Environment Working Papers*. [77]

Bruegge, C., T. Deryugina and E. Myers (2019), “The Distributional Effects of Building Energy Codes”, *Journal of the Association of Environmental and Resource Economists*, Vol. 6/S1, pp. S95-S127, https://doi.org/10.1086/701189. [82]

Brugnara, L. and G. Ricciardi (2021), *I risultati del Superbonus 110%*, Osservatorio sui Conti Pubblici Italiani, http://www.cnpi.eu/wp-content/uploads/2021/05/Superbonus-report-Enea-17-. [49]

Busch, J. et al. (2021), “A global review of ecological fiscal transfers”, *Nature Sustainability*, Vol. 4/9, pp. 756-765, https://doi.org/10.1038/s41893-021-00728-0. [92]

C40 (2022), *C40 Annual Report 2021*. [96]

City of Copenhagen (2020), *CPH 2025 Climate Plan Roadmap 2021-2025*. [97]

City of Paris (2020), *Paris Climate Action Plan*. [100]

Copiello, S. and E. Donati (2021), “Is investing in energy efficiency worth it? Evidence for substantial price premiums but limited profitability in the housing sector”, *Energy and Buildings*, Vol. 251, p. 111371, https://doi.org/10.1016/j.enbuild.2021.111371. [72]

Cour des Comptes (2021), *Premiers enseignements du déploiement du dispositif « MaPrimeRénov' »*. [85]

Cournède, B., P. Garda and V. Ziemann (2015), “Effects of Economic Policies on Microeconomic Stability”*, OECD Economics Department Working Papers*, No. 1201, OECD Publishing, Paris, https://dx.doi.org/10.1787/5js3f5cwj3jb-en. [80]

Cournède, B. and S. Gastaldo (2002), “Combinaison des instruments prix et quantités dans le cas de l’effet de serre”, *Économie & prévision*, Vol. no 156/5, pp. 51-62, https://doi.org/10.3917/ecop.156.0051. [29]

Cristián Yáñez O., A. (2019), *Informe final de usos de la energia de los hogares Chile 2018*. [12]

D’Arcangelo, F. et al. (2022), “Estimating the CO2 Emission and Revenue Effects of Carbon Pricing: New Evidence from a Large Cross-country Sample”. [30]

D’Arcangelo, F. et al. (2022), “A framework to decarbonise the economy”*, OECD Economic Policy Papers*, No. 31, OECD Publishing, Paris, https://doi.org/10.1787/4e4d973d-en. [1]

Davis, L., S. Martinez and B. Taboada (2020), “How effective is energy-efficient housing? Evidence from a field trial in Mexico”, *Journal of Development Economics*, Vol. 143, p. 102390, https://doi.org/10.1016/j.jdeveco.2019.102390. [45]

de Feijter, F., B. van Vliet and Y. Chen (2019), “Household inclusion in the governance of housing retrofitting: Analysing Chinese and Dutch systems of energy retrofit provision”, *Energy Research & Social Science*, Vol. 53, pp. 10-22, https://doi.org/10.1016/J.ERSS.2019.02.006. [26]

de Mello, L. (2023), “Real Estate in a Post-Pandemic World: How Can Policies Make Housing More Environmentally Sustainable and Affordable”, *Review of Public Economics*, forthcoming, https://services.bepress.com/hpe. [22]

de Mello, L. and J. Martinez-Vazquez (2022), “Climate Change Implications for the Public Finances and Fiscal Policy: An Agenda for Future Research and Filling the Gaps in Scholarly Work”, *Economics*, Vol. 16/1, pp. 194-198, https://doi.org/10.1515/econ-2022-0026. [86]

Dechezlepretre, A. et al. (2022), “Fighting Climate Change: International Attitudes Toward Climate Policies”, *OECD Economics Department Working Papers*, https://one.oecd.org/document/ECO/WKP(2022)15/en/pdf. [47]

Dougherty, S. and A. Montes Nebrada (2022), “Going global, locally? Decentralised environmental expenditure and air quality”, *Public Sector Economics*, Vol. 46/4, pp. 489-503, https://doi.org/10.3326/pse.46.4.3. [93]

European Commission Joint Research Centre (JRC) (2018), *Energy efficiency upgrades in multi-owner residential buildings*, https://doi.org/10.2760/966263. [27]

Federal Ministry for Economic Affairs and Climate Action of Germany (n.d.), *Deutschland Macht’s Effizient (program website)*. [50]

Flues, F. and A. Thomas (2015), “The distributional effects of energy taxes”, *OECD Taxation Working Papers*, No. 23, OECD Publishing, Paris, https://dx.doi.org/10.1787/5js1qwkqqrbv-en. [79]

Fowlie, M. et al. (2015), “Are the Non-monetary Costs of Energy Efficiency Investments Large? Understanding Low Take-Up of a Free Energy Efficiency Program”, *American Economic Review*, Vol. 105/5, pp. 201-04, https://doi.org/10.1257/AER.P20151011. [20]

Fuerst, F. et al. (2015), “Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England”, *Energy Economics*, Vol. 48, pp. 145-156, https://doi.org/10.1016/j.eneco.2014.12.012. [73]

Fuerst, F. and G. Warren-Myers (2018), “Does voluntary disclosure create a green lemon problem? Energy-efficiency ratings and house prices”, *Energy Economics*, Vol. 74, pp. 1-12, https://doi.org/10.1016/j.eneco.2018.04.041. [75]

Fullerton, D. and E. Muehlegger (2017), *Who Bears the Economic Costs of Environmental Regulations?*, National Bureau of Economic Research, Cambridge, MA, https://doi.org/10.3386/w23677. [81]

Gerarden, T., R. Newell and R. Stavins (2017), “Assessing the Energy-Efficiency Gap”, *Journal of Economic Literature*, Vol. 55/4, pp. 1486-1525, https://doi.org/10.1257/jel.20161360. [19]

German Council of Economic Experts (2019), *Setting out for a new Climate Policy: Special Report*, http://www.sachverstaendigenrat-wirtschaft.de. [31]

Goldman Sachs International (2020), *Carbonomics: Innovation, Deflation and Affordable De-carbonization*, http://www.gs.com/research/hedge.html. [68]

Government of the UK (n.d.), *Green Deal UK (program webpage)*. [52]

Haut Conseil pour le Climat (2020), “Rénover mieux : leçons d’Europe”. [58]

Höfling, H. (2019), *A successful energy transition requires a CO 2-oriented energy price reform*. [33]

Huo, T. et al. (2021), "Will the urbanization process influence the peak of carbon emissions in the building sector? A dynamic scenario simulation", *Energy and Buildings*, Vol. 232, p. 110590, https://doi.org/10.1016/J.ENBUILD.2020.110590. [10]

Hyland, M., R. Lyons and S. Lyons (2013), "The value of domestic building energy efficiency — evidence from Ireland", *Energy Economics*, Vol. 40, pp. 943-952, https://doi.org/10.1016/j.eneco.2013.07.020. [74]

IEA (2022), *Buildings*, https://www.iea.org/reports/buildings. [6]

IEA (2022), *Snapshot of Global PV Markets*, http://www.iea-pvps.org (accessed on 12 May 2022). [62]

IEA (2021), *World Energy Outlook (WEO) 2021 Extended Dataset (database)*. [9]

IEA (2021), *Appliances and Equipment*, IEA, Paris, https://www.iea.org/reports/appliances-and-equipment. [65]

IEA (2021), *Building Envelopes*, IEA, Paris, https://www.iea.org/reports/building-envelopes. [64]

IEA (2021), *Cooling*, IEA, https://www.iea.org/reports/cooling. [63]

IEA (2021), *District Heating*, IEA, Paris, https://www.iea.org/reports/district-heating. [60]

IEA (2021), *Emission Factors database*. [8]

IEA (2021), *Energy Efficiency Indicators (database)*. [7]

IEA (2021), *Heat Pumps*, IEA, Paris, https://www.iea.org/reports/heat-pumps. [36]

IEA (2021), *Lighting*, IEA, Paris, https://www.iea.org/reports/lighting. [66]

IEA (2021), *Patents and the Energy Transition*, https://www.iea.org/reports/patents-and-the-energy-transition (accessed on 12 May 2022). [67]

IEA (2021), *Tracking Buildings 2021*, https://www.iea.org/reports/tracking-buildings-2021 (accessed on 25 August 2022). [42]

IEA (2021), "World Energy Outlook 2021", http://www.iea.org/weo (accessed on 10 May 2022). [14]

IEA (2020), "Net Zero by 2050 - A Roadmap for the Global Energy Sector", https://www.iea.org/reports/net-zero-by-2050 (accessed on 10 May 2022). [18]

Kholodilin, K., A. Mense and C. Michelsen (2017), "The market value of energy efficiency in buildings and the mode of tenure", *Urban Studies*, Vol. 54/14, pp. 3218-3238, https://doi.org/10.1177/0042098016669464. [23]

Lartigue, B. et al. (2022), "Energy performance certificates in the USA and in France—a case study of multifamily housing", *Energy Efficiency*, Vol. 15/5, https://doi.org/10.1007/s12053-022-10036-x. [40]

Levinson, A. (2016), "How Much Energy Do Building Energy Codes Save? Evidence from California Houses", *American Economic Review*, Vol. 106/10, pp. 2867-2894, https://doi.org/10.1257/aer.20150102. [54]

London City Hall (2022), *Energy in Buildings*, https://www.london.gov.uk/what-we-do/environment/energy/energy-buildings. [87]

Lund, H. et al. (2021), "Perspectives on fourth and fifth generation district heating", *Energy*, Vol. 227, p. 120520, https://doi.org/10.1016/J.ENERGY.2021.120520. [61]

Magistrat der Stadt Wien (2022), *Wiener Klimafahrplan*, https://www.wien.gv.at/spezial/klimafahrplan/. [99]

Marmolejo-Duarte, C. and A. Chen (2022), "Uncovering the price effect of energy performance certificate ratings when controlling for residential quality", *Renewable and Sustainable Energy Reviews*, Vol. 166, p. 112662, https://doi.org/10.1016/J.RSER.2022.112662. [41]

Matschoss, K. et al. (2013), *Energy renovations of EU multifamily buildings: do current policies target the real problems?*, http://www.entranze.eu. [28]

Menu, T. (2021), *Denmark: A Case Study for a Climate-Neutral Europe*. [11]

Ministry of Economy, T. (2020), *Japan's 2050 Carbon Neutral Goal*. [15]

Ministry of the Economy and Finance and the Recovery of France (n.d.), *MaPrimeRénov' : la prime de transition énergétique*. [51]

Nauleau, M. (2014), "Free-riding on tax credits for home insulation in France: An econometric assessment using panel data", *Energy Economics*, Vol. 46, pp. 78-92, https://doi.org/10.1016/j.eneco.2014.08.011. [56]

NYC Mayor's office of Climate and Environmental Justice (2022), *Energy Benchmarking*, https://www1.nyc.gov/site/sustainability/codes/energy-benchmarking.page. [88]

Oates, W. (1972), *Fiscal Federalism*, New York, Harcourt Brace Jovanovich. [95]

OECD (2022), *Decarbonising Buildings in Cities and Regions*, OECD Urban Studies, OECD Publishing, Paris, https://dx.doi.org/10.1787/a48ce566-en. [2]

OECD (2022), *Draft Economic Survey of the United Kingdom*. [34]

OECD (2022), *Housing Taxation in OECD Countries*, OECD Tax Policy Studies, No. 29, OECD Publishing, Paris, https://dx.doi.org/10.1787/03dfe007-en. [4]

OECD (2022), *Pricing Greenhouse Gas Emissions: Turning Climate Targets into Climate Action*, OECD Publishing, https://doi.org/10.1787/e9778969-en. [3]

OECD (2022), "Real estate finance and climate transition: Market practices, challenges and policy considerations", *OECD Business and Finance Policy Papers*, No. 09, OECD Publishing, Paris, https://doi.org/10.1787/fa86b326-en. [5]

OECD (2021), *Effective Carbon Rates 2021: Pricing Carbon Emissions through Taxes and Emissions Trading*, OECD Publishing, Paris, https://dx.doi.org/10.1787/0e8e24f5-en. [32]

OECD (2021), *Working Party on Integrating Environmental and Economic Policies Updates on the OECD EPIC Household Survey Project*. [102]

OECD (2020), *Affordable Housing Database*, https://doi.org/www.oecd.org/social/affordable-housing-database.htm. [90]

OECD (2020), *Social Housing: A key part of past and future housing policy, Employment, Labout and Social Affairs Policy Briefs*. [89]

OECD (2019), *Accelerating Climate Action: Refocusing Policies through a Well-being Lens*, OECD Publishing, Paris, https://doi.org/10.1787/2f4c8c9a-en. [43]

OECD (2019), *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264307452-en. [37]

Posner, P. (1997), "Unfunded Mandates Reform Act: 1996 and Beyond", *Publius: The Journal of Federalism*, Vol. 27/2, pp. 53-71, https://doi.org/10.1093/oxfordjournals.pubjof.a029914. [94]

Reusens, P., F. Vastmans and S. Damen (2022), "The impact of changes in dwelling characteristics", *Working Paper Research*, https://www.nbb.be/doc/ts/publications/wp/wp406en.pdf. [84]

Risch, A. (2020), "Are environmental fiscal incentives effective in inducing energy-saving renovations? An econometric evaluation of the French energy tax credit", *Energy Economics*, Vol. 90, p. 104831, https://doi.org/10.1016/J.ENECO.2020.104831. [55]

Sallee, J. (2014), "Rational inattention and energy efficiency", *Journal of Law and Economics*, Vol. 57/3, pp. 781-820, https://doi.org/10.1086/676964/ASSET/IMAGES/LARGE/FG7.JPEG. [21]

Sichel, O. (2021), *Rapport pour une réhabilitation énergétique massive, simple et inclusive des logements privés*. [57]

Snoddon, T. and T. Tombe (2019), "Analysis of Carbon Tax Treatment in Canada's Equalization Program", *Canadian Public Policy*, Vol. 45/3, pp. 377-392, https://doi.org/10.3138/cpp.2019-036. [91]

Taruttis, L. and C. Weber (2022), "Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter?", *Energy Economics*, Vol. 105, p. 105750, https://doi.org/10.1016/j.eneco.2021.105750. [71]

The City of New York (2019), *OneNYC 2050*. [98]

Tokyo Metropolitan Government (2019), *Zero Emission Tokyo Strategy*. [101]

Van Oorschot, J., E. Hofman and J. Halman (2016), "Upscaling Large Scale Deep Renovation in the Dutch Residential Sector: A Case Study", *Energy Procedia*, Vol. 96, pp. 386-403, https://doi.org/10.1016/J.EGYPRO.2016.09.165. [25]

Vikkelsø, B. (2021), *Analysis of the existing incentives in Europe for heating powered by fossil fuels and renewable sources*. [59]

Vona, F. (2021), "Managing the distributional effects of environmental and climate policies: The narrow path for a triple dividend", *OECD Environment Working Papers*, No. 188, OECD Publishing, Paris, https://dx.doi.org/10.1787/361126bd-en. [78]

Zero Energy Project (2022), *Zero Energy Homes: Comparable in Cost*, https://zeroenergyproject.org/sell/zero-homes-comparable-cost-standard-homes/ (accessed on 30 August 2022). [44]

APPENDIX A. DEFINITIONS

CO_2 emissions of the residential sector include:

- **direct emissions** (from household combustion of fossil fuels) and
- **indirect emissions** (from the production of the electricity used by households and district heating).

Total emissions also include the emissions occurring during the construction, maintenance and demolition phase of buildings. In the residential sector, direct and indirect emissions emanate from space and water heating, cooling, ventilation, lighting, and the use of appliances and other electrical plug loads.

Embodied carbon refers to carbon emissions associated with materials and construction processes throughout the whole life-cycle of a building. Embodied carbon therefore includes upfront, operational, end use, and use stage embodied carbon.

Carbon sink is any reservoir that accumulates and stores carbon-containing chemical compounds for an indefinite period and thereby lowers the concentration of carbon dioxide (CO_2) in the atmosphere.

Net-zero carbon dioxide (CO_2) emissions means that anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

A zero-carbon-ready building is a building that is highly energy efficient and either uses renewable energy directly, or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heating.

- A zero-carbon-ready building will become a zero-carbon building by 2050, without any further changes to the building or its equipment.
- Whenever possible, new and existing zero-carbon-ready buildings should integrate locally available renewable resources, e.g., solar thermal, solar PV, PV thermal and geothermal, to reduce the need for utility-scale energy supply.
- Zero-carbon-ready building energy codes should also target net-zero emissions from material use in buildings.

Nationally determined contribution (NDC) is a climate action plan to cut emissions and adapt to climate impacts. Each Party to the Paris Agreement is required to establish an NDC and update it every five years.

Low carbon electricity includes renewable energy technologies, hydrogen-based generation, nuclear power and fossil fuel power plants equipped with carbon capture, utilisation and storage.

Clean energy includes renewables, low-carbon fuels, nuclear power, battery storage and carbon capture, utilisation and storage.

Renewable energy includes bioenergy, geothermal, hydropower, solar photovoltaics (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation.

Bioenergy is energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. It includes solid biomass, liquid biofuels and biogases.

APPENDIX B. SUPPLEMENTARY TABLES

NZE commitments and housing targets

Countries with housing specific plans and targets

Country	Year to reach Net Zero	Original source for national plans
Australia	2050	https://www.industry.gov.au/sites/default/files/October%202021/document/australias-long-term-emissions-reduction-plan.pdf
Austria	2040	National energy and climate plans | European Commission (europa.eu)
France	2050	National energy and climate plans | European Commission (europa.eu)
Germany	2045	National energy and climate plans | European Commission (europa.eu)
Hungary	2050	National energy and climate plans | European Commission (europa.eu)
Ireland	2050	National energy and climate plans | European Commission (europa.eu)
Italy	2050	National energy and climate plans | European Commission (europa.eu)
Japan	2050	
South Korea	2050	https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf
New Zealand	2050	https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/),
Portugal	2050	National energy and climate plans | European Commission (europa.eu)
Slovenia	2050	National energy and climate plans | European Commission (europa.eu)
South Africa	2050	https://www.dffe.gov.za/sites/default/files/docs/2020lowemission_developmentstrategy.pdf
Spain	2050	National energy and climate plans | European Commission (europa.eu)
United Kingdom	2050	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf
United States	2050	https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf