Climate Action Tracker

# Decarbonising buildings

## Achieving zero carbon heating and cooling

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CLIMATE ANALYTICS

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# Executive Summary

## Why is the buildings sector important?

The urgency of addressing emissions from buildings is clear; greenhouse gas (GHG) emissions from this sector make up roughly a fifth of total global emissions. Despite the rapidly diminishing global carbon budget and need for all sectors to decarbonise, buildings sector emissions have remained stubbornly consistent. While there is positive movement in some sectors – renewable energy, light-duty vehicles – decarbonising the buildings sector has been slow-moving. Why is there so little progress, and what would it take to initiate the kind of transformative change required?

A key reason behind the sector's persistently high emissions is its diversity and complexity. Buildings come in all shapes and sizes, are used as residences or for commercial operations, and vary across a wide range of climate zones. The decarbonisation measures required for existing buildings also differ dramatically for those appropriate for ensuring new buildings are zero carbon.

Nonetheless, the range of technologies needed to achieve building sector decarbonisation are mature and widely available, it is their widespread adoption that is proving elusive. This stands in contrast to other sectors where low carbon alternatives, for example for cement production or long-distance travel, are not always available at commercial scale and/or remain prohibitively expensive.

## What needs to happen?

Meeting the 1.5°C temperature limit of the Paris Agreement requires global greenhouse emissions to halve during the decade to 2030 and carbon dioxide ($CO_2$) emissions to reach net zero by 2050. The Climate Action Tracker and other analysts have developed sector specific benchmarks to outline what these global targets mean for the buildings sector.

- Reduce the emissions intensity of building use ($kgCO_2/m^2$) compared to 2015 levels by 90-95% by 2040 and 95-100% by 2050 (Climate Action Tracker, 2020).
- The energy intensity of operations in key countries and regions should decrease by 20–30% in residential buildings and by 10–30% in commercial buildings, relative to 2015 by 2030 (Climate Action Tracker, 2020; Lebling *et al.*, 2020).
- All new buildings should be zero carbon buildings as of now (Climate Action Tracker, 2016, 2020; Kuramochi *et al.*, 2018), which also means no expansion of fossil-fuel infrastructure like gas networks.
- Many buildings that exist today will still stand in 2050 or beyond and need to be retrofitted to zero emissions by then at the latest. To reach the emissions and energy intensity goals, 2.5-3.5% of buildings need to be retrofitted every year (Climate Action Tracker, 2020).

### Get out of gas

One large obstacle to decarbonising buildings is the use of gas, which is currently the largest single energy source for buildings globally (IEA, 2021j). Gas is wrongly promoted as a "bridging fuel" and mischaracterised as a "green" fuel. It is still a fossil fuel, and converting buildings away from gas must be a priority.

To meet the 1.5°C temperature goal, gas use "should already have peaked and be declining globally, and … needs to drop by more than 30% below 2020 levels by 2030, and 65% below 2020 levels by 2040." (Hare et al., 2021). Any new gas infrastructure critically undermines the Paris Agreement.

Ceasing the expansion of gas networks now also makes sense for those paying energy bills. New gas connections now will mean expensive upgrades to all-electric systems in the future (McKenna, Shah and Louis-Prescott, 2020). Gas price volatility can lead to high energy costs, particularly impacting low-income households, especially in poorly insulated homes, exacerbating energy poverty. Reducing reliance on gas can reduce household vulnerability as well as energy security concerns.

The European energy crisis in 2021/22, that saw skyrocketing gas prices, is an example of the price volatility inherent to fossil fuel markets that can be partially or fully avoided by electrifying buildings' heating systems.

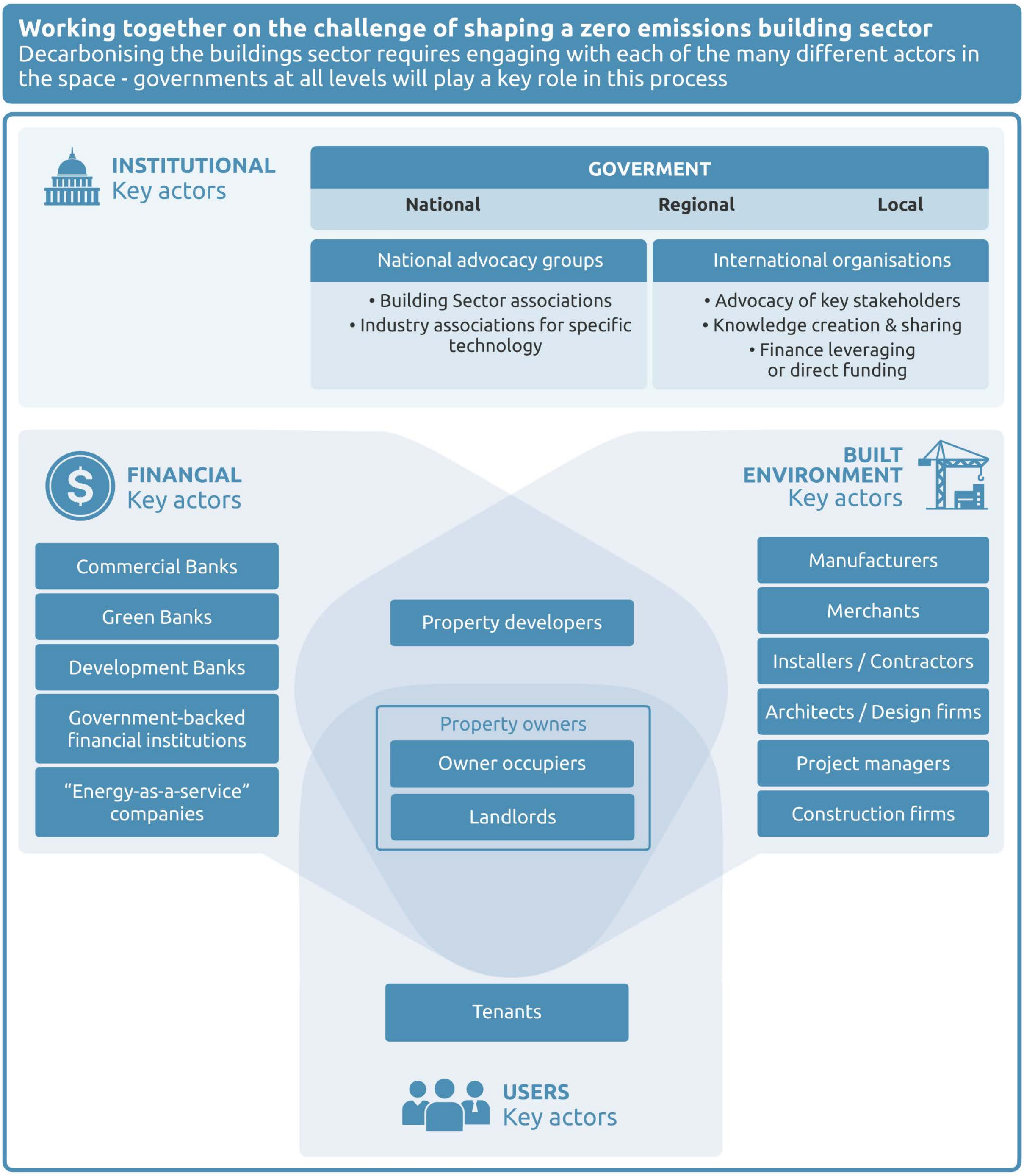


Figure 1: Key actors in the buildings sector that need to work together toward decarbonisation

## How can we achieve these targets?

A by-product of buildings sector complexity and diversity is the existence of a wide variety of actors, actors that need to be engaged, incentivised, or compelled through legislation, to achieve these benchmarks and decarbonisation of the sector. Deriving strategies to accomplish such wide-reaching engagement and spur fast action needs to be high on government agendas.

This report outlines the broad set of actions that governments can include in their buildings sector decarbonisation strategies. The recommendations are based on analysis of four vital elements:

1. the technologies needed to replace the current carbon-intensive technologies;
2. minimum energy performance standards (MEPS) and building energy codes;
3. providing access to affordable financing options and designing financial incentives and disincentives to catalyse and redirect investments, and
4. finding novel means with which to engage the multitude of actors in the buildings sector to effect change.

### Element 1
### The technologies to transform the buildings sector are already here

Technological solutions are not the main challenge for transforming the buildings sector. Various technologically mature options to decarbonise heating and cooling are already available, including energy efficient building envelopes, heat pumps, and on-site renewables. The most appropriate technological strategy depends on the climatic conditions, building purpose, and existing infrastructure. This calls for tailor-made solutions for national and local circumstances.

In many cases, heat pumps are the best option for thermal energy supply, while district heating or cooling is a proven approach in densely populated areas. Renewable hydrogen is unlikely to play a significant role as a transition fuel or to replace gas given its high costs and a high expected level of competition for supply from hard-to-decarbonise sectors. Smart controls can help to ensure electricity use is efficient and to integrate new demand into the grid.

Production markets for key technologies are well established. Some improvements in the efficiency of equipment are still possible but the bigger challenge is the actual uptake of zero carbon technology and implementation of energy efficiency measures. Accelerating uptake is dependent on many other factors, including regulation, finance and actors.

### Case studies

**Case Study 1: Sweden - mainstreaming heat pumps**
Sweden has shown a sustained commitment over numerous decades to supporting a domestic heat pump manufacturing industry. A technology procurement programme was launched in 1993 and was combined with investment subsidies, information campaigns, and evaluations of heat pump installations – see page 17.

**Case Study 2: The United Kingdom - A decade of poor scheme design**
Throughout much of the 2000s and into the 2010s, the UK government placed a heavy focus on incentivising the uptake of efficient condensing gas boilers. When policy shifted to incentivise the uptake of heat pumps and insulation, it was poorly designed and executed, resulting in lower than anticipated participation, despite several policy iterations – see page 19.

## Element 2
## Regulation through Minimum Energy Performance Standards (MEPS) is a necessary instrument

Minimum energy performance standards (MEPS) have been recognised by many as fundamental to transforming the sector (Element 2 - MEPS; Economidou *et al.*, 2020; Nadel and Hinge, 2020). One third of nations have some type of energy efficiency requirement in building codes, but many do not have regulations in place for existing buildings and very few are stringent enough to ensure Paris Agreement compliance. Enforcement of those existing codes and standards is often weak and limits their effectiveness.

Improving the stringency, extent, and enforcement of building codes and standards is a necessary component of a building decarbonisation strategy. Building codes have been particularly effective where a long-term plan was developed with the involvement of key stakeholders and clearly communicated to those affected.

Utilising MEPS for increasing the retrofitting rate of existing buildings is particularly important in regions - such as the EU, the US and, increasingly, China – with substantial building stock that will stand for many decades. Trigger points for retrofits, such as a change in occupancy or specific years, need to be incorporated into regulations to speed up the rate of retrofitting and ensure all buildings are brought up to a zero-carbon standard by 2050 at the latest.

## Case studies

**Case Study 3: China - A coordinated top-down policy package and a comprehensive enforcement strategy**

China has a comprehensive policy package to increase energy efficiency of new and existing buildings. The policy package consists of energy conservation targets set in a top-down approach, minimum energy performance regulations, voluntary building energy standards for "green" buildings, mandates for the installation of renewable energy systems in buildings, a governance mechanism to monitor and evaluate energy performance of buildings, and policy targets and incentives to increase the rate of energy retrofits of existing buildings – see page 39.

**Case Study 4: US - A voluntary framework for local mandatory codes**

Different jurisdictions in the US adopt and develop their own codes and regulations. Most jurisdictions use the International Energy Conservation Code (IECC) developed at the national level. The IECC and technology specific MEPS are more stringent in the US than in China but final energy consumption by square metre is higher by close to 50 kWh/m2 on average in 2017 – see page 43.

**Case Study 5: New York - Building energy code for existing buildings**

Enforcement of building energy code occurs at the State and city-level in the US. NYC enforced the 2018 IECC and complemented it with local laws to create a long-term decarbonisation strategy, establish a dedicated department for planning monitoring and enforcement rules – see page 47.

## Element 3
### Access to affordable finance and financial (dis-)incentives are key to decarbonising buildings

In some cases, new or retrofitted zero carbon buildings are cheaper than more carbon-intensive alternatives, at least when considered over the lifetime of the building. In these cases, easy access to finance can reduce the perceived risk of high up-front costs and overcome financial barriers. However, where gas and heating oil remain cheap relative to the cost of electricity (when onsite renewables are not an option), and for more expensive upgrades, payback periods may be beyond an investor's time horizon.

Alternative financial support arrangements are required to change the market through improving the cost-competitiveness of low carbon investments, addressing high upfront costs, and reducing financial risks (Element Three – Financing). Multiple policy instruments are available (see Table 5) and the most appropriate depends on the regulatory framework and financial situation of the country or region.

Carbon pricing has proven effective in encouraging electrification but ensuring that any money collected through a pricing instrument is redistributed, such that it does not exacerbate social inequalities, is crucial for a policy's long-term viability.

## Case studies

**Case Study 6: Germany's KfW's financial support scheme linked to voluntary building energy codes**

Germany's development bank, the KfW, provides a mix of public financial instruments to incentivise the construction of and retrofitting to zero carbon buildings. The mix of finance instruments composed of grants, subsidised loans, loan guarantees and performance-based debt-relief results in a financial support package that is offered and disbursed by commercial banks. These financial support packages are linked to the mandatory building energy code as well as to building standards that go beyond minimum energy standards and thereby can support ambitious building energy codes – see page 75.

**Case Study 7: Netherlands - Energiesprong's standardised EPCs for affordable, quick, and deep energy retrofits**

Energiesprong is an energy service company providing Energy Performance Contracts (EPCs) to households to perform deep energy retrofits. The economies of scale allow for affordable and quick interventions in up to ten days. The energy retrofits consist of new prefabricated façades, the installation of smart heating and cooling systems, such as heat pumps, and the insulation of rooftops with integrated solar photovoltaic panels. The intervention is financed through energy savings so that monthly costs remain the same for 30 years, after which customers only pay for significantly reduced energy bills – see page 77.

## Element 4
### Dealing with the multitude of actors

The buildings sector is complex. Each building requires a unique, multi-faceted approach to decarbonisation and has a different set of independent actors making decisions and providing relevant knowledge. For all buildings to be zero carbon, it is important to ensure that all relevant actors are sufficiently well informed, motivated - and even incentivised - to take the zero-carbon options, and that the necessary skills are locally available to execute them.

The landlord-tenant dilemma – whereby the landlord is responsible for energy retrofits but the tenant benefits from reduced energy bills – can be a major obstacle in scaling up retrofitting rates. Incentives need to be put in place for landlords to act. Tested approaches include enforcement of building standards and rental agreements that allocate excessive energy costs to the landlord.

"One stop shops" are a promising approach to solving some of the complexity challenges. Here a property owner can get access to all the information they need regarding technical recommendations, financing options, and contact to verified contractors. Making retrofitting an easier process through the availability of clear, helpful, and trustworthy advice could help to increase the rate and depth of retrofitting.

## Case studies

**Case Study 8: Australia's Clean Energy Finance Corporation**
Australia's government-sponsored Clean Energy Finance Corporation (CEFC) operates a USD 7bn fund with the purpose of accelerating Australia's transition to net zero emissions. The CEFC's varied avenues for channelling investments into buildings decarbonisation have successfully incentivised a multitude of financial and built environment actors. These include investing in energy efficiency upgrades, improving the design of proposed developments, and creating a 'green home loan' to spur construction of energy efficient new housing – see page 98.

**Case Study 9: EU - Private Finance for Energy Efficiency Instrument**
The Private Finance for Energy Efficiency instrument is a joint initiative between the European Investment Bank and the European Commission that seeks to overcome barriers to greater participation from commercial banks in financing energy efficiency upgrades. Directly engaging commercial banks through the provision of finance and offering consultancy services to both banks and business owners creates a vital link connecting private finance with decision makers who ultimately progress energy efficiency upgrades and construction of zero carbon buildings – page 100.

**Case Study 10: The US - Ithaca's multi-level governance approach**
The ambitious multi-level governance program was conceived as the first plan of the Green New Deal adopted by the City of Ithaca in 2019 and targets a full decarbonisation of the entire city's building stock, projected to lead to extensive job creation. It aims to use a USD 10m state government-backed loan loss reserve to guarantee loans obtained from private equity and has attracted USD 100m in commitments to the program so far. This project demonstrates that cooperation leveraging the unique capacities of different levels of government and private finance can lead to novel, wide-reaching program design – see page 102.

**Case Study 11: EU/Spain - BUILD UP Skills Initiative/Contruye 2020**
The BUILD UP Skills Initiative is an EU funded project that aims to "increase the number of qualified workers across Europe to deliver renovations offering a high energy performance as well as new, nearly zero-energy buildings" (BUILD UP Skills, 2016) – see page 104.

**Case Study 12: Sweden - Fossil Free Sweden's stakeholder engagement process**
Fossil Free Sweden, an initiative of the Swedish government established in 2015, provides an example of comprehensive stakeholder engagement in the buildings sector. Fossil Free Sweden requires each sector in the Swedish economy to set out a roadmap for removing fossil fuels from its energy supply. The heating sector has its own roadmap and represents a particularly important industry for decarbonisation in Sweden, as the heating sector makes up a large part of the Swedish energy market at 100 TWh per year – see page 106.

## The key role of governments in decarbonising the buildings sector

As a complex challenge, reducing emissions in the buildings sector requires a comprehensive strategy to address the multiple facets. The buildings sector is unlikely to 'tip' with just a few initiatives from the private sector. Instead, it will require a wide range of actors to work together towards a Paris Agreement compatible sector.

Governments are in a unique position to effect change, as they can influence many of the wide range of actors and set the overall direction of the economy towards decarbonisation. In the final chapter - The key role of governments in decarbonising the buildings sector - we outline in detail what governments need to do.

Three major steps are required from national, regional, and local governments (Figure 2):

1. Set out a clear vision and climate targets for the buildings sector.
2. Develop a detailed strategy for decarbonisation at the national, regional, or local level.
3. Operationalise the plan with a broad set of policies that regulate, facilitate, and incentivise the transition.

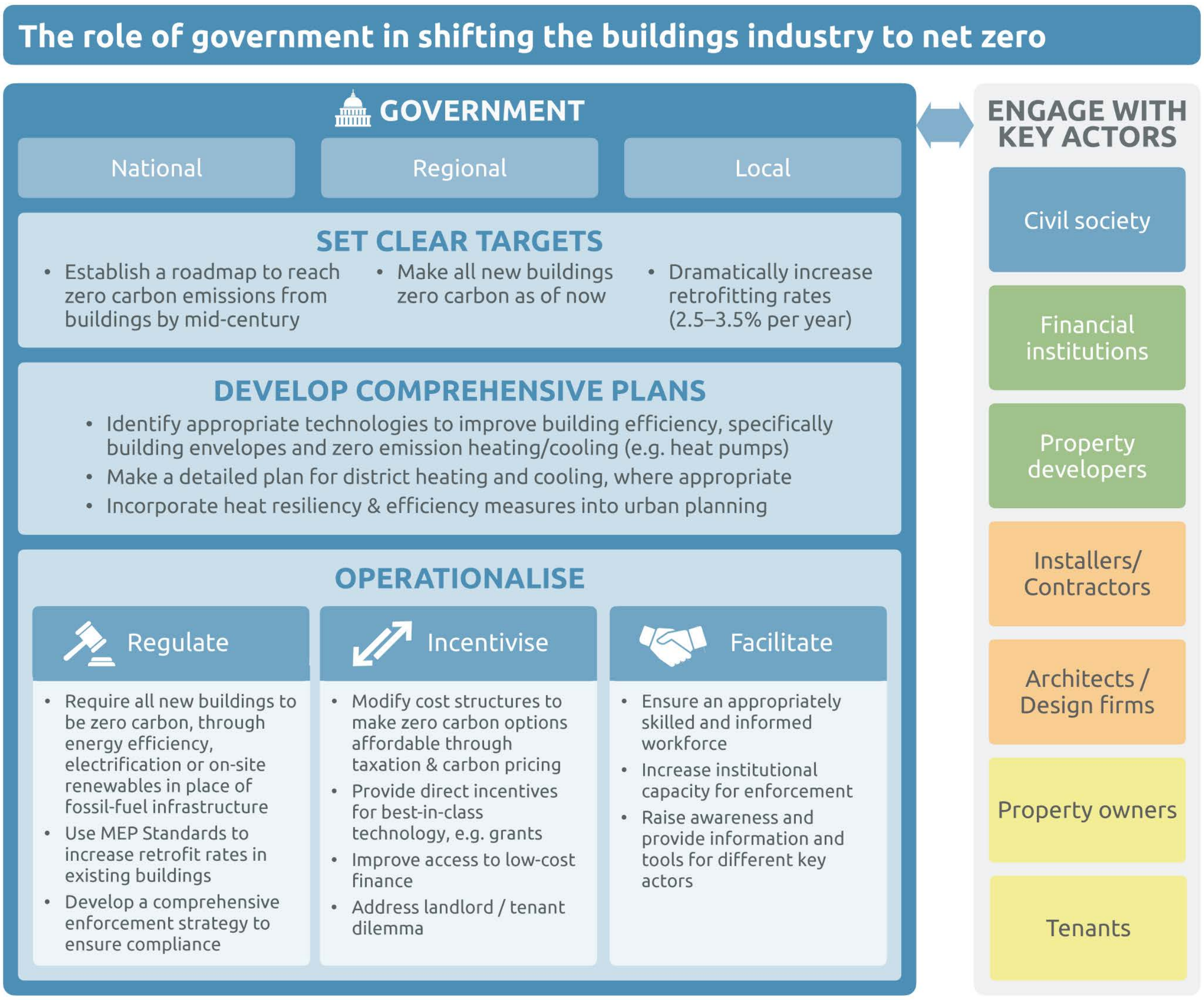


Figure 2: Role of governments in providing incentives for other actors to take appropriate actions to decarbonise the buildings sector.

## Set clear targets

All governments are expected to set national emissions reduction targets in line with the Paris Agreement and elaborate them in long-term decarbonisation strategies. The buildings sector should be explicitly included in those strategies with a timeframe for reaching zero operational emissions.

Clear targets send a signal to all regarding the direction of travel and are a necessary first step.

## Make a plan

Plans should be developed in collaboration with key stakeholders, both to ensure feasibility and to develop engagement and buy-in from those who will enact the plans. This collaboration should not only cover the technical details but also the policies that will be implemented to operationalise the plans.

The focus of this paper is on operational emissions from heating and cooling, but a buildings sector plan should incorporate all emissions and provide a co-ordinated strategy with other sectors. Embodied emissions in buildings are a major contributor to global emissions and national plans for retrofitting and new builds should take these into account. Where possible, retrofitting should be prioritised over demolishing and rebuilding (Power, 2008).

## Operationalise the plan - regulate, incentivise, facilitate

Governments also play a fundamental role in the details of implementing decarbonisation plans. National and sub-national governments have multiple possible intervention points to instigate change. Our analysis indicates that many of these intervention points need to be utilised in a co-ordinated manner and that no single action will suffice alone.

Government interventions can be considered along three dimensions – regulate, incentivise, and facilitate. Each dimension has its own role, and all are necessary; the measures catalyse each other. In all case studies considered in this report, those with most success took a multi-pronged approach whereas those that were not backed up with sufficient supporting policies did not fare well.

If effective, building codes and accompanying incentives should lead to a scale-up of the market and help to reduce the costs of zero carbon options. The stringency of building codes should increase over time, ideally according to a pre-announced roadmap, and incentives can be shifted to support only those options that are not cost-competitive.

The table below outlines the main interventions that a government can support, and highlights some of the more successful examples to date that are elaborated on in subsequent chapters. Governments and policy makers can use this table as an overview to check that their plans and policies are sufficiently comprehensive in that they address all the potential challenges and provide a combination of both regulatory and supportive approaches.

Finally, governments can also ensure that implemented policies are supportive of other priorities, including ensuring protection for the most vulnerable. Any new policies that aim to reduce emissions need to ensure protection of low-income households so that they are neither faced with higher costs nor trapped in low-standard housing.

## Operationalise the vision

A zero carbon buildings vision should inform the creation of a comprehensive policy package consisting of policies to regulate, incentivise and facilitate the transformation towards decarbonised space heating and cooling. This table provides an overview of available interventions governments can choose from. Governments need to ensure a broad selection of different intervention types and the more options taken, the higher the likelihood that the transition will be fast enough to meet the Paris Agreement goals.


Figure 3: Key policy interventions. For more details, including links to examples and case studies, view Table 7 in last chapter.

## Why should governments act?

Reducing emissions from buildings can have multiple other benefits when done well. Securing energy supply is a fundamental role of government and energy efficiency should be a major strategy for doing so. Pursuing electrification and decarbonising the power grid also reduces reliance on fossil fuel imports and increases energy independence, eliminating a source of energy price volatility. Further benefits of ambitious mitigation policies include cost-savings, and boosts to employment, health, productivity, and comfort for occupants (UNEP, 2019).

While governments are key to transforming the buildings sector, other actors also have tools at their disposal to accelerate and push this transformation. One critical role is holding governments accountable for their promises and highlighting gaps in action. This is particularly relevant for developed countries' governments, that have the capacity and responsibility to implement action in line with the Paris Agreement.

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## Boxes on key issues



## Case studies

## Terms used in this report

| | |
|---|---|
| **Building envelope** | The building envelope is the physical separation between the conditioned indoor and unconditioned outdoor environment of a building and consists of the floor, walls, including doors and windows, and the roof. |
| **Commercial bank** | A financial institution with a banking license that accepts deposits, offers account services and disburses loans. |
| **Commercial debt** | Debt provided to individuals and companies by commercial banks and financial institutions at market conditions. |
| **Concessional debt** | Debt provided to individuals and companies by public institutions at below-market conditions. |
| **Deep energy retrofit** | A bundle of emission mitigation measures that retrofit an existing building to a zero-carbon building. These include better insulation, the installation of energy efficient heating and cooling appliances, and the installation of on-site renewable energy systems. |
| **Financial institution** | Financial institutions that offer financing products, such as loans, but do not possess a banking license. |
| **Zero emission buildings** | Zero emission buildings have low energy requirements and source any remaining energy needs from zero emissions energy, either on-site or from the grid. |
| **Zero carbon ready buildings** | A zero carbon ready building is defined by the IEA as "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. This means that a zero-carbon-ready building will become a zero-carbon building by 2050, without any further changes to the building or its equipment." (IEA, 2021h) |
| **On-site renewable energy systems** | On-site renewable energy systems installed on a property, such as solar thermal heaters, solar photovoltaic panels, or geothermal systems. |
| **Real estate / property** | We define both real estate and property as a plot of land, including the buildings on the land. |
| **Social Housing** | Government-owned residential buildings offered to low-income individuals and families that are otherwise priced out of the housing market. |

## Acronyms

| | |
|---|---|
| **AC** | Air conditioning/er |
| **ASHP** | Air source heat pump |
| **BgEEF** | Bulgarian energy efficiency fund |
| **Btu** | British Thermal Unit |
| **CaaS** | Cooling as a Service |
| **CARB** | California Air Resources Board |
| **CEFC** | Clean Energy Finance Corporation |
| **CFCs** | Chlorofluorocarbons |
| **$CO_2$** | Carbon dioxide |
| **COP** | Coefficient of Power |
| **EER** | Energy Efficiency Ratios |
| **EHPA** | European Heat Pump Association |
| **EPBD** | Energy Performance of Buildings Directive |
| **PC** | Energy Performance Contract |
| **ESA** | Energy Service Agreement |
| **ESCO** | Energy Service Company |
| **ESI** | Energy savings insurance |
| **EU** | European Union |
| **FYP** | Five year plan |
| **GBP** | Pound Sterling |
| **GHG** | Greenhouse gas |
| **GSHP** | Ground source heat pump |
| **GWP** | Global warming potential |
| **HCFCs** | Hydrochlorofluorocarbons |
| **HFCs** | Hydrofluorocarbons |
| **HP** | Heat pump |
| **IEA** | International Energy Agency |
| **IECC** | International Energy Conservation Code |
| **IFC** | International Finance Corporation |
| **KfW** | Kreditanstalt für Wiederaufbau - German Credit Institute for Reconstruction |
| **LCBP** | Low carbon building programme |
| **LPG** | Liquid petroleum gas |
| **LULUCF** | Land use, land use change and forestry |
| **MEPS** | Minimum energy performance standards |
| **MoHURD** | Ministry of Housing and Urban-Rural Development |
| **NGO** | Non-governmental organisation |
| **NYC** | New York City |
| **PACE** | Property Assessed clean energy |
| **PF4EE** | Private finance for energy efficiency |
| **PV** | Photovoltaic |
| **R&D** | Research and development |
| **REEEP** | Renewable Energy and Energy Efficiency Partnership |
| **RHI** | Renewable Heat Incentive |
| **SNAP** | Significant New Alternative Policy |
| **TWh** | Terawatt-hour |
| **UK** | United Kingdom |
| **UNEP** | United nations environment program |
| **US** | United States |
| **US EPA** | United States Environmental Protection Agency |
| **USD** | United states dollar |
| **VAT** | Value added tax |
| **VT** | Visible light transmittance |
| **WWR** | Window-wall ratio |

# Introduction

## Why is heating and cooling so important?

Improving buildings to reduce energy requirements and decarbonise energy use is a fundamental component of reaching the Paris Agreement's 1.5°C temperature limit. Solutions exist to make improvements – so why haven't we already done so?

Without intervention, energy demand and emissions from space heating and cooling are anticipated to increase substantially in the coming decades. The buildings sector is currently responsible for 29% of global energy consumption and 18% of global emissions (excl. LULUCF, Gütschow *et al.*, 2021; IEA, 2021j, 2021f). When embodied emissions from the construction of buildings are also taken into account, those shares grow to 35% and 38% respectively (UNEP, 2020). Urbanisation, a warming world, and increasing income levels are all expected to rapidly increase demand for space cooling. At the same time, substantial growth in floor area is anticipated, particularly in the developing world.

For many, homes have become increasingly important spaces since the COVID-19 pandemic struck in early 2020. Those who can, have been working from home and many countries have experienced lockdowns with requirements to spend time at home. These homes should be safe, comfortable, and affordable, but that is not always the case. Workspaces should also be comfortable, with too hot or too cold conditions having substantial impacts on productivity and, in extreme cases, health and safety. Improving buildings allows us to address health, safety, comfort, and climate change concerns.

## What needs to happen to reduce buildings sector emissions in line with the Paris Agreement?

Meeting the 1.5°C long-term temperature goal of the Paris Agreement requires global greenhouse emissions to halve during the decade to 2030 and carbon dioxide emissions to reach net zero by 2050. The Climate Action tracker and other analysts have developed sector specific benchmarks to outline what these global targets mean for the buildings sector.

1. Reduce the emissions intensity of building use ($kgCO_2/m^2$) compared to 2015 levels by 90-95% by 2040 and 95-100% by 2050 (Climate Action Tracker, 2020).
2. The energy intensity of operations in key countries and regions should decrease by 20–30% in residential buildings and by 10–30% in commercial buildings, relative to 2015 by 2030 (Climate Action Tracker, 2020; Lebling et al., 2020).
3. **All new buildings should be zero carbon buildings as of now** (Climate Action Tracker, 2016, 2020; Kuramochi *et al.*, 2018)
4. Many buildings that exist today will still stand in 2050 and beyond and will need to be retrofitted to net zero emissions by then at the latest. To reach the emissions and energy intensity goals, **2.5-3.5% of buildings need to be retrofitted every year** (Climate Action Tracker, 2020).

## Box 1: What is a zero carbon building?

- **Net zero energy** buildings are buildings with low energy consumption and all energy used is generated through on-site renewables on a net basis.
- Zero emissions buildings or Zero carbon buildings are buildings that are energy efficient and do not produce any GHG or carbon dioxide emissions during operation, either on or off-site.

Net zero energy buildings are an important component of the drive toward decarbonising the buildings sector because reducing overall energy demand makes it easier to decarbonise. Challenges to retrofitting existing buildings may mean that it's not always possible to generate enough renewable energy on site and meet net zero energy standards. However, it is still possible to make these zero emissions buildings through electrification of remaining energy use and accompanied decarbonisation of the electric grid (Box 2: Refrigerants with low global warming potential).

Our focus in this paper is on zero emissions buildings because reducing carbon emissions to net zero by mid-century is what matters for meeting the 1.5°C Paris Agreement temperature limit. To save confusion, and because $CO_2$ emissions dominate in the buildings sector, we refer to zero carbon buildings throughout the text.

It's worth noting that not only $CO_2$ but all greenhouse gases should be addressed through buildings sector policies. Some, such as methane from upstream gas production, could be reduced by energy efficiency improvements and reduced gas use. Others, such as the HFCs used as coolants in heat pumps, will also require more direct regulation (Box 2: Refrigerants with low global warming potential).

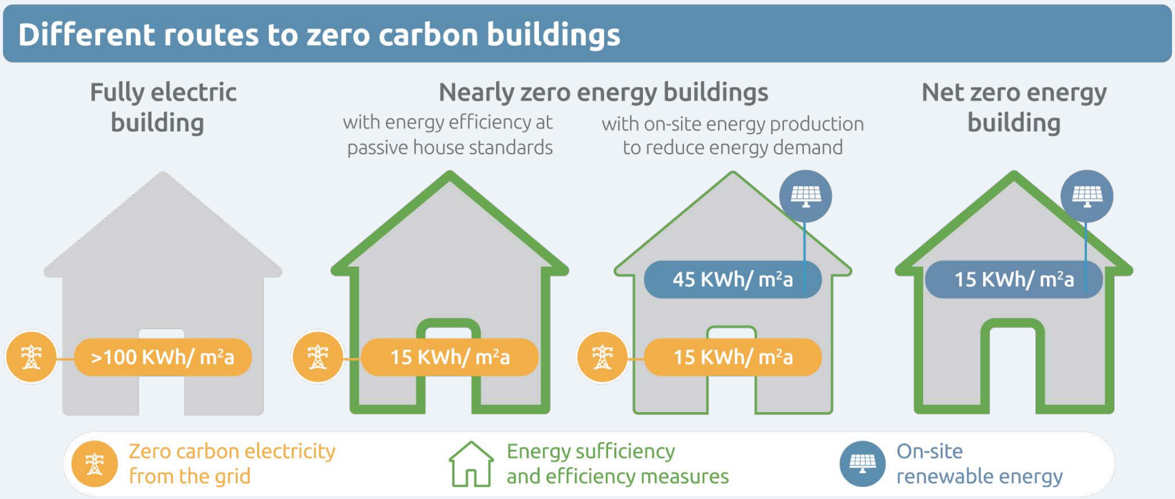


Figure 4: Different options for decarbonising buildings include electrification of equipment, improvements to the building envelope to reduce energy demand, and the installation of on-site renewable energy. Each of the buildings shown here combine these elements in different ways but all are zero carbon when the grid is zero carbon.

The technological solutions for meetings these goals are available and quite mature. Decarbonising building operations, specifically heating and cooling, requires three components:

- Improve the efficiency of the building envelope to reduce energy requirements.
- Switch to high efficiency heating and cooling appliances that are powered by electricity or direct renewables.
- Provide zero carbon electricity supply through a decarbonised grid or on-site renewables.

Improving the energy efficiency of a building involves many components and the exact solution is often building specific. Regarding insulation, key components of the building envelope include roofs, walls, doors, and windows. Each can be technically optimised to ensure functionality and provide the maximum insulation.

The design of the building itself can also be used to ensure energy efficiency through passive building techniques. For example, the use of shading to reduce the warming effects of sunlight, through the orientation of the building to catch sunlight during different times of the day, or construction to optimise air flow through the building. The optimal design depends on the heating and cooling needs dictated by the local climate, and the local environmental conditions. The Passivhaus standards provide guidance on passive design strategies that have been shown capable of reducing building thermal energy needs to around 15 kWh/$m^2$ in most climates.

When improving building insulation, it's also essential to ensure that appropriate ventilation is incorporated into the building to prevent condensation, mould, and consequent health problems.

To achieve full decarbonisation, any remaining energy used needs to be carbon free. This is particularly challenging for space and water heating given that most heating is currently powered by gas, oil, or coal burned on-site. The major route for decarbonising heating is through electrification using heat pumps. However, some Paris Agreement compatible scenarios also see a role for biomass and district heating. We explore some of these options in Element One — Technologies.

Cooling buildings is in some ways easier to decarbonise as most air conditioners (ACs), a form of heat pump, are electric. With a zero-carbon grid or on-site renewables a lot of space cooling could be zero carbon. However, current ACs are not as efficient as they could be and many also currently use hydrofluorocarbons (HFCs) with a high global warming potential (GWP) as a coolant. With demand for cooling expected to grow substantially in the coming decades, ensuring that new equipment is highly efficient and utilises coolants with low GWP needs to be a high priority (IEA, 2021a).

The third step in decarbonising heating and cooling is the decarbonisation of the power source. Once dominantly electrified, it's important that the electricity supply is zero carbon. On-site renewables are carbon free and can reduce stress on the power grid from additional demand. Wherever possible, new builds should incorporate on-site renewables. Smart meters can also play a role in helping to integrate additional demand into a renewable energy-dominated grid.

In this report we focus on the operational emissions of buildings, but it is also essential to decarbonise construction and construction materials. Accounting for embodied emissions means that it usually makes more sense to retrofit a building rather than demolish and rebuild it. It also means that emissions from building materials need to be reduced, either by decarbonising the production of steel and cement, or by using alternate building materials, including sustainably-sourced wood.

## What has happened to date, and what has not?

The energy intensity of building use varies substantially between countries (Figure 5). Much of this variation results from different climates and consequent differences in energy needs, but some of the variation also reflects the building standards and construction techniques. In all countries, energy performance lies well above the Passive House standard of 15 kWh/$m^2$, with the EU average at 180 kWh/$m^2$ for residential buildings and estimates for Italy's commercial buildings, for example, reaching to over 600 kWh/$m^2$.

Energy efficiency has been improving on a per $m^2$ basis (Figure 6) but not as quickly as the growth in floor area, meaning that overall emissions continue to rise (IEA, 2019b). Globally, from 2000 to 2017, average energy use per $m^2$ improved by nearly 25%. However, at the same time, total floor area increased by around 65%.

Constructed floor area is expected to continue to increase in the coming decades, particularly in developing countries. To reach the sectoral benchmarks outlined above and counteract this driver of emissions growth, the rate of energy efficiency improvements needs to significantly increase (Boehm *et al.*, 2021).

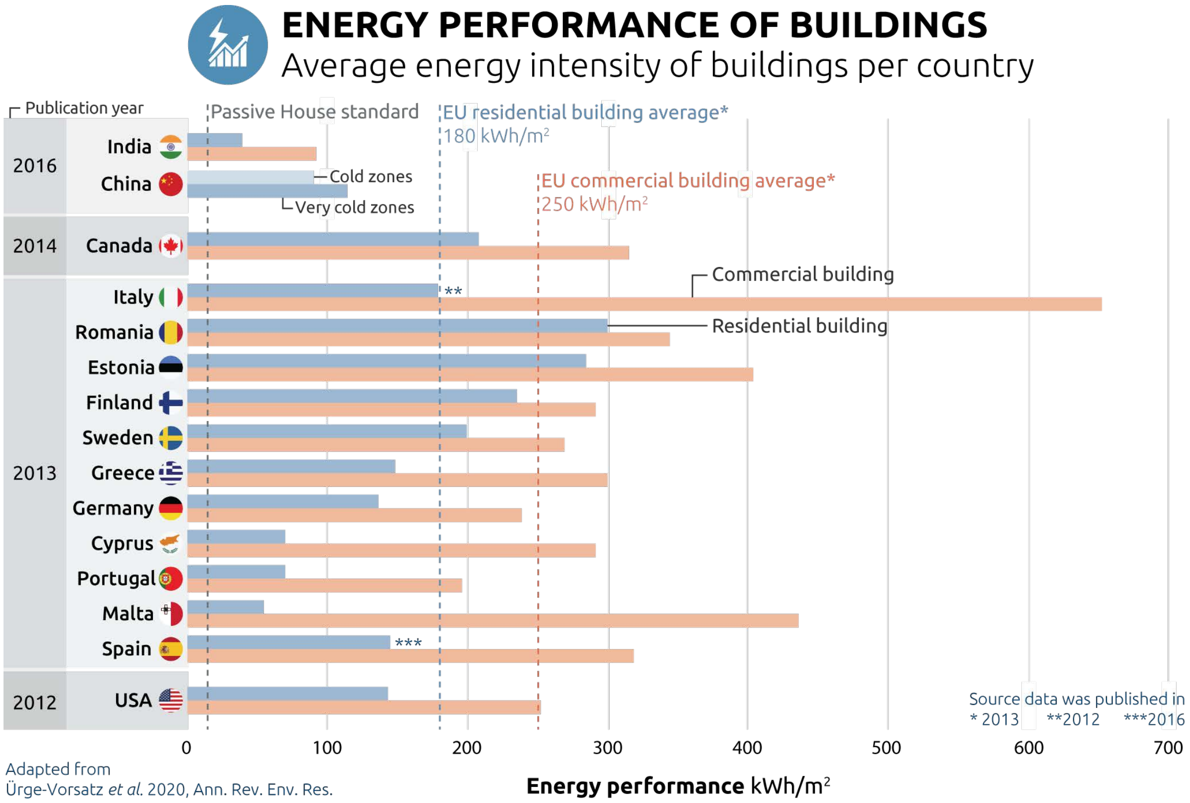


Figure 5: The average energy performance of buildings varies significantly between countries. Some of the variance can be explained by local climates and the consequent difference in heating and cooling needs but local building standards and techniques also play a role. Average buildings in nearly all countries have energy use far above the Passive House standard of 15 KWh/m² that is theoretically achievable in all climates.

*Source: Urge-Vorsatz et al., 2020*

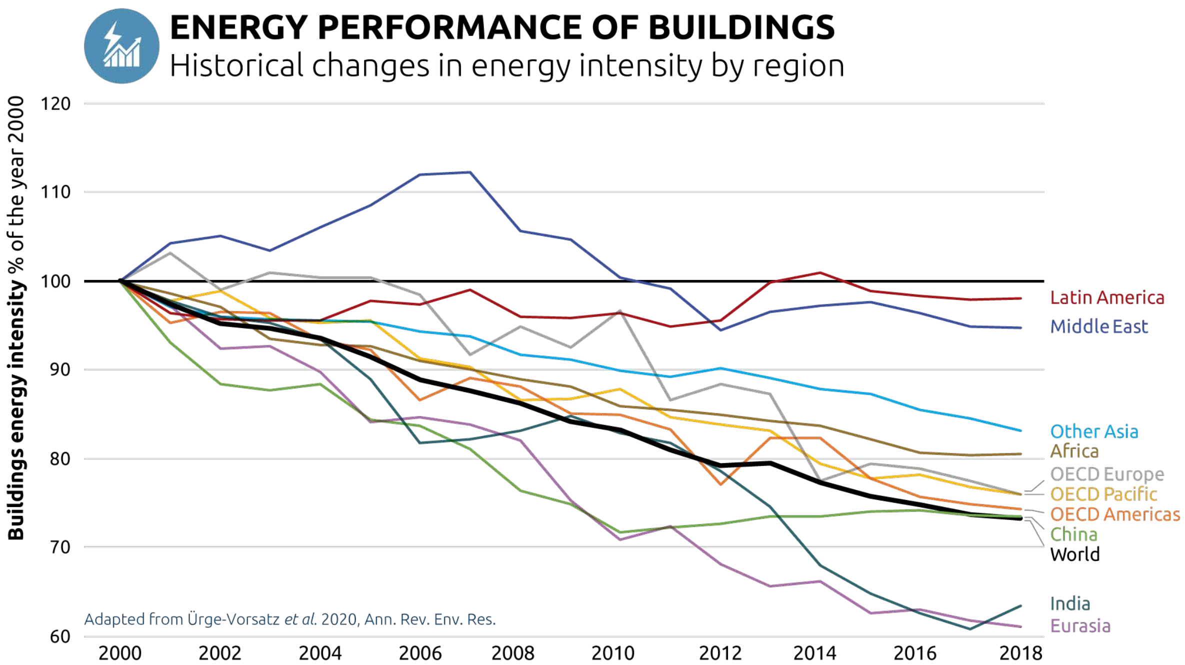


Figure 6: Improvements in energy intensity since 2000 for a selection of countries and regions.

*Source: Urge-Vorsatz et al., 2020*

## How does the buildings sector compare to other sectors?

Across multiple sectors, the State of Climate Action report did not find any indicators of change to be in line with limiting warming to 1.5°C (Boehm *et al.*, 2021). However, some indicators were shown to be heading in the right direction at a more promising pace than others, such as the increase in the share of renewables or recent increases in the sale of light-duty electric vehicles (Boehm *et al.*, 2021).

Few positive signs of rapid change can be found for the buildings sector. As noted above, energy intensity per floor area is improving at a global level but not at a sufficient pace (IEA, 2019b). There is insufficient data to track other indicators, although available information suggests that retrofit rates remain low, and the emissions intensity of buildings remains high (Boehm *et al.*, 2021).

In countries where emissions have decreased in the last decade, those reductions have tended to come from the power sector or industry (Lamb *et al.*, 2021). Despite promising signs from EV sales, emissions from the transport sector have minimally decreased, or even increased, in those same countries. The buildings sector has fared better than transport overall, with decreasing emissions positively contributing to the overall decrease in all countries, but to a limited extent in most. Exceptions include Sweden, Belgium, France, and the Slovak republic where significant emissions reductions in the buildings sector have occurred since national emissions peaked (Lamb *et al.*, 2021).

## What do we aim to establish in this analysis?

Despite reasonably well understood options for decarbonisation, emissions from the buildings sector are not decreasing in most countries. This report sets out to understand why emissions are remaining high, or even increasing, and to identify what opportunities there might be to initiate transformative change. More specifically, we set out to identify what type of interventions could be targeted by governments to accelerate retrofitting rates and ensure that all new buildings are zero carbon.

The analysis is intended for national and sub-national policymakers to understand the sector and the policy options available to them for aligning buildings with the Paris Agreement. It should also serve as a guide to those seeking to support, critique, or influence policymakers to make for a more robust set of policies.

## How we go about the analysis

We organise our analysis along four key elements within the buildings sector – technologies, minimum energy performance standards (MEPS), finance, and actors. Three of these elements include components - technology availability, availability of skills, and high investments – that have been identified as key challenges and barriers to the transition to a zero carbon buildings sector (Toleikyte *et al.*, 2016). The fourth – MEPS – are broadly recognised as a cornerstone policy for the sector.

**Technologies** – Diffusion of low carbon technologies will be at the centre of the buildings sector transition needed. The technology portfolio needed to reduce the heating and cooling related emissions of the buildings sector is well known and studied, and technologies are commercially available in most markets. We examine some of the remaining technology-related questions for the sector, such as the potential roles of hydrogen and district heating and cooling, and use case studies to explore what it would take to scale-up the use of heat-pumps.

MEP STANDARDS

**Minimum Energy Performance Standards** – MEPS and building codes are at the core of every policy intervention for promoting low carbon buildings and are increasingly being taken up but are still limited in coverage and stringency. Countries face various challenges with regards to implementation of building codes. While some countries, such as selected European ones, already have building codes/MEPS in place that strongly promote low carbon buildings and which are largely adhered to by developers, other countries with building codes still struggle with non-compliance. We identify the key features of a good building code and explore strategies to improve their effectiveness as a policy instrument.

**Financing** – Zero carbon buildings have generally been identified as a mitigation option with negative mitigation costs, but this is not reflected in their global uptake. Major barriers are the high up-front costs and the long lifetime of buildings, requiring homeowners to increase their often already significant debt levels even further. Well-designed financing schemes such as low-cost loans or grants can increase their willingness to do so. In addition to debt instruments, other financial policies including tax structures or carbon pricing, could incentivise the uptake of zero carbon technologies and buildings by making zero carbon options cost-competitive. Strong financial incentives can support the uptake of best-available technologies making it more likely that MEPS are met. We outline the range of financial instruments that governments have available to them and use case studies to outline some of the more innovative and effective models.

**Shifting actors** – Architects, builders, property managers, homeowners, contractors, landlords, and tenants and all have an important role in shaping building design and development. Existing practices, customs, and interests need to be shifted towards enabling these actors to plan, develop and build zero carbon buildings. We look at the range of actors involved in the buildings sector, the various challenges faced in making decisions, and how these actors can be supported and incentivised to work with and for zero carbon options.

For each of these elements (technology, MEPS, financing, and actors) we start by outlining the state-of-play. That understanding is used as the basis for identifying key opportunities for accelerating action for that element. Our analysis follows a similar approach for each element, specifically:

- **State of play** – We outline the important characteristics of the element (such as design elements for policies, existing financial incentives, or key actor interactions) and describe current progress at the global level. We also highlight key challenges and open questions for that element, such as "what's the potential role of hydrogen as a decarbonisation option?" (Box 4).
- **Case studies** – Examples of more ambitious or innovative approaches to dealing with challenges associated with this element. For each case study, we describe the initiative or policy, assess its mitigation potential or impact, and reflect on the replicability of the approach. Not all the case studies can be described as good practice but were selected because they highlight possible strategies and reasons why those strategies may succeed or fail.
- **Lessons learned** - What are the key take-away messages from observations regarding the current state of play and the case studies identified? (How) can successful studies be replicated and what interventions could enable progress on this element?

## Equity and fairness

Underlying our analysis is an assessment of how policies, finance, and technology uptake can be incentivised and upscaled in a manner that takes social justice into account. We apply the basic principle that our recommendations should not exacerbate existing inequalities and aim toward recommendations that help to increase access to healthy, resilient, comfortable, affordable housing.

The case studies presented in this report have a bias to the global north. The bias results partly from the maturity of policies and examples, and partly from access to more detailed information that is only available in local languages. Many of the recommendations and some of the case studies are relevant in all jurisdictions but some developing countries will face different challenges, or priorities, than those addressed by the case studies. Under our finance element (Element Three – Financing) we highlight some of the challenges faced by those in developing countries in accessing low-cost finance for investment in buildings, including high interest rates, creditworthiness, irregular income, or the lack of stable and liquid financial markets.

Considering equity and fairness between countries is fundamental to global climate mitigation and that plays out at the sectoral level too. We've shown how reducing operational building emissions requires financial investments and access to the right materials, skills, and knowledge. Knowledge sharing, financial support between countries, and increasing access to finance could support a more successful and equitable sustainable development of buildings in developing countries.

## Case Studies in this report

| Element One — Technologies | |
|---|---|
| **Case Study 1: Sweden - mainstreaming heat pumps** | **Summary:** Sweden has shown a sustained commitment over numerous decades to supporting a domestic heat pump manufacturing industry and the widespread local adoption of the technology. A technology procurement programme was launched in 1993 and was combined with investment subsidies, information campaigns, and evaluations of heat pump installations.<br><br>**Key lessons:** Consistent funding to subsidise heat pump uptake sent a clear signal to industry participants that investing in the development of the sector was less risky than it would have been otherwise. Countries with low electricity prices are likely to have a lower barrier to achieving increased uptake. |
| **Case Study 2: The United Kingdom - A decade of poor scheme design** | **Summary:** Throughout much of the 2000s and into the 2010s, the UK government placed a heavy focus on incentivising the uptake of efficient condensing gas boilers. Renewable heating tariffs would have needed to be higher to drive technology deployment, while underfunding and discontinuity of subsequent schemes has stunted their stated goals.<br><br>**Key lessons:** Short-term nature of schemes fails to provide the certainty that encourages industry participants to invest in widescale heat pump installation. The Renewable Heat Incentive failed to address the high upfront cost of heat pump technology. |

| Element Two — Minimum Energy Performance Standards - MEPS | |
|---|---|
| **Case Study 3: China - A coordinated top-down policy package and a comprehensive enforcement strategy** | **Summary:** China has a comprehensive policy package to increase energy efficiency of new and existing buildings. The policy package consists of energy conservation targets set in a top-down approach, minimum energy performance regulations, voluntary building energy standards for "green" buildings, mandates for the installation of renewable energy systems in buildings, a governance mechanism to monitor and evaluate energy performance of buildings, and policy targets and incentives to increase the rate of energy retrofits of existing buildings.<br><br>**Key lessons:** The Chinese central government's growing emphasis on code enforcement and compliance has driven energy efficiency improvements. Mandatory building energy codes could be more ambitious but voluntary standards beyond mandatory MEPS have driven the construction of green buildings in relation to meeting Corporate Social Responsibility (CSR) standards and accessing green bond financing. Retrofitting targets and rates are too slow and there is no one national building code. |
| **Case Study 4: US - A voluntary framework for local mandatory codes** | **Summary:** Different jurisdictions in the US adopt and develop their own codes and regulations. Most jurisdictions use the International Energy Conservation Code (IECC) developed at the national level. The IECC 2021 update represents a stringent energy code that can be adapted based on a jurisdiction's climate conditions. It is also the basis of the international Zero Code.<br><br>**Key lessons:** The 2021 IECC is ambitious, includes existing buildings, is revised every three years, and is also the basis of the international net zero building standard ASHRAE. The building energy code developed at the federal level can be adapted and applied to many jurisdictions. However, the IECC remains voluntary and is not applied in all States. As a non-governmental entity, the IECC has been influenced by lobbies from the construction sector. The 2021 IECC for commercial buildings calculates a building's energy performance based on a building's energy cost rather than energy consumption; unpredictable energy costs and cheap subsidised fossil fuels can negatively affect the ambition level of the code. |

| | |
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| **Case Study 5: New York - Building energy code for existing buildings** | **Summary:** Enforcement of building energy code occurs at the State level in the US. NYC enforced the 2018 IECC and complemented it with local laws to create a long-term decarbonisation strategy with clear phased targets and established a dedicated department for planning monitoring and enforcement rules.<br><br>**Key lessons:** The strategy to decarbonise the buildings sector coupled with long-term goals provide a clear mitigation pathway. NYC put in place a committee specifically to plan for, monitor, evaluate and enforce the emissions reduction pathway towards zero emissions in the buildings sector and the building energy code. Still, NYC currently enforces the 2018 IECC and not yet the latest 2021 IECC. A change of occupancy does not yet oblige existing buildings to comply with the 2020 NYC Energy Conservation Code. |

| **Element Three – Financing** | |
|---|---|
| **Case Study 6: Germany's KfW's financial support scheme linked to voluntary building energy codes** | **Summary:** Germany's development bank, the KfW, provides a mix of public financial instruments to incentivise the construction of and retrofitting to zero carbon buildings. The mix of finance instruments composed of grants, subsidised loans, loan guarantees and performance-based debt-relief results in a financial support package that is offered and disbursed by commercial banks so that clients can easily access information and public financial support from those banks taking part in the scheme.<br><br>**Key lessons:** The ease of access to public finance and the financial support packages disbursed by commercial banks facilitates the uptake of debt to cover the additional upfront costs of zero carbon buildings and (deep) energy retrofits. Moreover, the government backs loans for the construction of, and retrofitting to, zero carbon buildings and therefore reduces funders' perception that such investments are risky. Such generous financial schemes can drive the market towards higher energy efficiency levels but should be dynamic and anchored in a long-term vision to ensure they do not overlap with minimum performance standards. |
| **Case Study 7: Netherlands - Energiesprong's standardised EPCs for affordable, quick, and deep energy retrofits** | **Summary:** Energiesprong is an energy service company providing energy performance contracts to households by performing deep energy retrofits. The economies of scale allow for affordable and quick interventions in up to ten days. The energy retrofits consist of new prefabricated façades, the installation of smart, efficient and electrified heating and cooling systems, such as heat pumps, and the insulation of rooftops with integrated solar photovoltaic panels. The intervention is financed through energy savings so that monthly costs remain the same for 30 years, after which no more costs occur to the customers.<br><br>**Key lessons:** The Energiesprong model has quickly expanded in several countries and regions and governments have played a key role in providing the enabling conditions for the kick-off and upscaling of the Energiesprong initiative in each single case. Governments play a key role in supporting the uptake of such financial schemes for example by backing ESCO to enhance trust and reduce risk and/or by adapting legislation to accommodate the conversion of monthly energy bills into a monthly energy service fee. Governments can also act as front-runners by making use of the Energiesprong model for social housing operated by public entities and government buildings, as done in the UK. |

| Element Four — A multitude of actors | |
|---|---|
| **Case Study 8: Australia's Clean Energy Finance Corporation** | **Summary:** Australia's government-sponsored Clean Energy Finance Corporation (CEFC) operates a USD 7 billion fund with the purpose of accelerating Australia's transition to net zero emissions. The CEFC's varied avenues for channelling investments into buildings decarbonisation have successfully incentivised a multitude of financial and built environment actors. These include investing in energy efficiency upgrades, improving the design of proposed developments, and creating a 'green home loan' to spur construction of energy efficient new housing.<br><br>**Key lessons:** The CEFC's broad mandate to help Australia achieve net zero emissions encouraged the design of a range of interventions in the buildings sector. In general, green banks' unique ability to engage across various stakeholder types, combined with their considerable fiscal capacity make them an invaluable tool to tackle building sector emissions. |
| **Case Study 9: EU - Private Finance for Energy Efficiency Instrument** | **Summary:** The Private Finance for Energy Efficiency instrument is a joint initiative between the European Investment Bank and the European Commission that seeks to overcome barriers to greater participation from commercial banks in financing energy efficiency upgrades. Directly engaging commercial banks through the provision of finance and offering consultancy services to both banks and business owners creates a vital link connecting private finance with decision makers who ultimately progress energy efficiency upgrades and construction of zero carbon buildings.<br><br>**Key lessons:** Leveraging the financial resources of a development bank like the EIB together with building sector knowledge and practitioners to create a platform where individuals and businesses can access resources and be connected with each other in one place lowers several barriers to buildings decarbonisation. These include: the knowledge deficits of prospective renovators and commercial lenders and the ability of renovators to find accredited contractors. |
| **Case Study 10: The US - Ithaca's multi-level governance approach** | **Summary:** The ambitious multi-level governance program was conceived as the first plan of the Green New Deal adopted by the City of Ithaca in 2019 and targets a full decarbonisation of the entire city's building stock, projected to lead to extensive job creation. It aims to use a USD 10 million state government-backed loan loss reserve to guarantee loans obtained from private equity and has attracted USD 100 million in commitments to the program so far. This project demonstrates that cooperation leveraging the unique capacities of different levels of government and private finance can lead to novel, wide-reaching program design.<br><br>**Key lessons:** A locally managed programme leveraging loan guarantees from a higher level of government with greater fiscal capacity to attract private finance is a novel approach with many potential benefits. The comprehensive scale of this program, its temporal ambition, and the relative ease with which it secured significant levels of private finance make this approach a potentially viable candidate for broader adoption. |
| **Case Study 11: EU/Spain - BUILD UP Skills Initiative/Contruye 2020** | **Summary:** The BUILD UP Skills Initiative is an EU funded project that aims to "increase the number of qualified workers across Europe to deliver renovations offering a high energy performance as well as new, nearly zero-energy buildings" (BUILD UP Skills, 2016).<br><br>**Key lessons:** The status quo analyses and national roadmaps approach designed and implemented by the EU has shown to be an effective way to kickstart the creation and development of educational institutions tasked with increasing the number of skilled workers needed to facilitate the zero carbon transformation of the buildings sector. |

| | |
|---|---|
| **Case Study 12: Sweden - Fossil Free Sweden's stakeholder engagement process** | **Summary:** Fossil Free Sweden, an initiative of the Swedish government established in 2015, provides an example of comprehensive stakeholder engagement in the buildings sector. Fossil Free Sweden requires each sector in the Swedish economy to set out a roadmap for removing fossil fuels from its energy supply. The heating sector has its own roadmap and represents a particularly important industry for decarbonization in Sweden, as the heating sector makes up a large part of the Swedish energy market at 100 TWh per year.<br><br>**Key lessons:** The comprehensive, sector by sector approach taken by the Swedish government to formulate plans for economy-wide decarbonisation provides a template for other countries to follow. The heating roadmap has broad participation from various buildings sector actors, that, together agreed on a set of targets and measures to achieve sectoral decarbonisation. This process establishes new and strengthens existing lines of communication and modes of cooperation between government, the private sector, and civil society. |

| National Case Study | |
|---|---|
| **Case Study 13: How Sweden has cut carbon intensity by two thirds** | **Summary:** Sweden has seen a drastic decrease in buildings sector emissions over the last three decades. While maintaining fairly steady energy use, Sweden's $CO_2$ emissions for the buildings sector have decreased, particularly direct emissions. Sweden is not alone but is one of very few that has achieved this. The strong supply-side focus to buildings sector decarbonisation taken by Sweden means that there is still great potential to realise energy efficiency gains in its building stock.<br><br>**Key lessons:** The actions have been diverse and tackling different areas that together enable the decarbonisation of buildings. The actions have in common that they target the goal of minimising the use of fossil fuels in buildings. Such a common goal and sense of direction is essential, particularly in a heterogeneous environment as the buildings sector. Building on performance-based energy standards is key, however their verification is more difficult and requires greater resources. The changes in carbon intensity in Sweden happened mainly over two decades, with a foundation in energy efficiency measures already existing for decades before. |

# Element One — Technologies

Decarbonising the buildings sector will require a multi-pronged approach, but a central component to any strategy will be ensuring the use of efficient and efficiency-maximising technologies. The technology analysis will focus on two technologies, one representing the local market (Windows) and one the global market (Heat Pumps).

For each of these technologies, we will identify the current state of play, how these key technological options fit into the overall need for minimising the need for heating and cooling as well as any variation in requirements for these technologies depending on climate and local resources. We will also provide an overview of the market dynamics for these key technologies, and some of the barriers to technology diffusion.

## Heat Pumps

A heat pump, very basically, is an electrically driven device that extracts heat from a low temperature place and delivers it to a higher temperature place, using a compressor, and a refrigerant as the medium. Heat pumps are mostly used in air conditioners but are also increasingly used in split systems that provide both cooling and heating, as well as for heating water. In some colder climates they are used mostly for heating.

This report will focus primarily on air-source heat pumps (ASHP) that are used for space heating and cooling, but particularly on heat pumps for heating, as this is where the largest potential for emissions reductions lies. This is due to the aforementioned nascency of heat pumps as a means for space heating, and the fact that a large portion of buildings are currently heated via the combustion of either fossil fuels (primarily natural gas and oil, but to a lesser extent coal), or biomass.

Compared to currently common methods of building heating like gas or oil boilers, or direct electric heating, heat pumps are far more energy efficient, a large part of why they produce lower GHG emissions. For each kW of electricity consumed by a heat pump, about 4kW of thermal energy is produced, which corresponds with a 300% efficiency (EHPA, 2021). This compares to efficiencies of around 90-96% for condensing gas or oil boilers, 70-80% for conventional gas or oil boilers, and 35-45% for direct electric heating.

Around 75% of the energy consumed by heat pumps is renewable, as it is capturing ambient heat from the atmosphere (EHPA, 2021). If heat pumps are powered by rooftop solar or a fully decarbonised electricity network, this number rises to 100% renewable energy. It is expected that 90% of global building heating demand can now be met using heat pumps with a lower carbon footprint than condensed gas boilers thanks to continued improvements in heat pump performance and cleaner power generation. This is a stunning increase from 2010, when this figure was at just 50% (IEA, 2021g).

## State of Play

As a proportion of total global buildings heating demand, heat pumps still meet only a small share overall (around 7% in 2020), but the total number installed has almost doubled in ten years to reach almost 180 million in 2020 (IEA, 2021g). Total global heat pump installations would need to more than triple by 2030 under the IEA's Net Zero Emissions scenario (Figure 7).

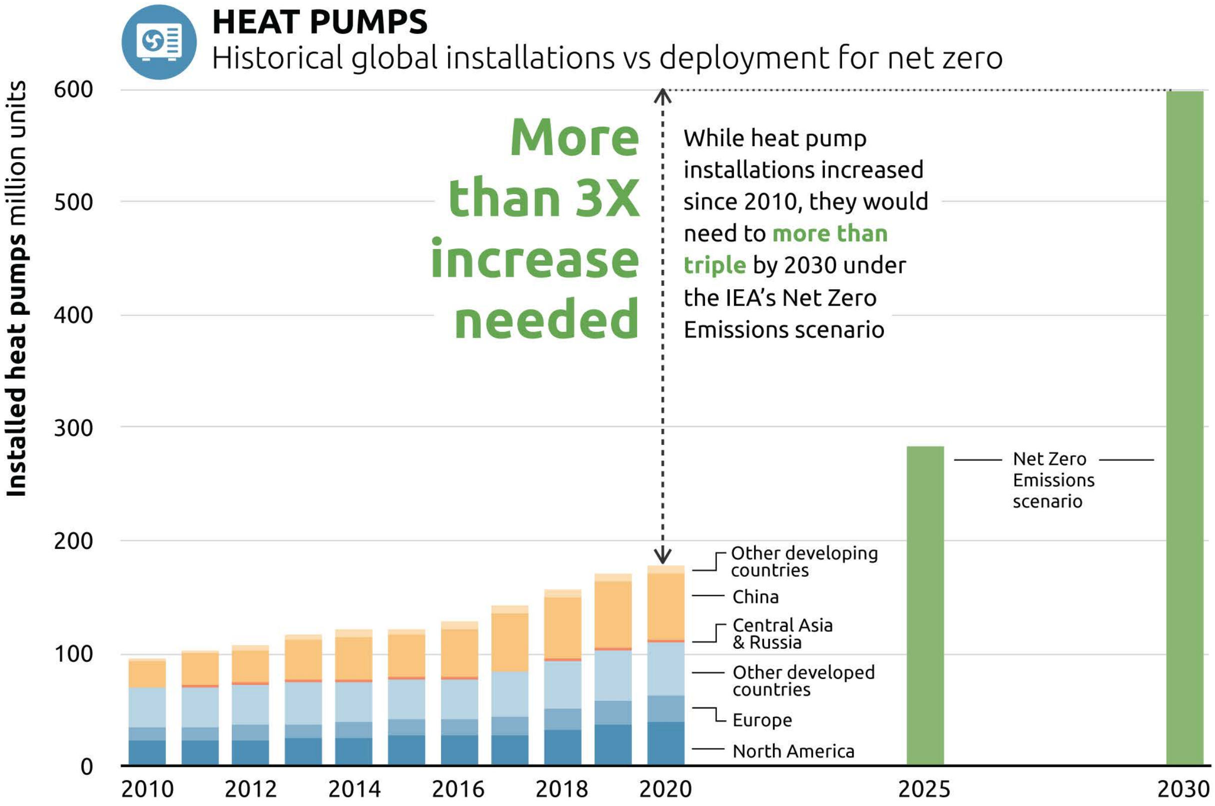


Figure 7: Historical regional makeup of global heat pump installations and future deployment in IEA's NZE scenario. Source: (IEA, 2021g)

In several regions around the world, demand is increasing rapidly, particularly in new buildings, and in 2019, nearly 20 million households purchased a heat pump globally. Global heat pump water heater sales have more than tripled since 2010, in large part due to Chinese demand, while EU sales, though starting from a low base increased fivefold over the same period and are projected to see a further fivefold increase to 2024 (EHPA, 2020; IEA, 2021g). Ground source heat pumps, while more costly to install and less common, are also on the rise, doubling in the US since 2010 to push global sales to 400,000.

Global household energy demand in 2018 made up roughly 15% of total energy demand, and as a share of total household energy demand, around 37% was from the combustion of fossil fuels. This combustion of fossil fuels generated over 2 billion tonnes of $CO_2$ emissions, roughly the equivalent of Germany's and Brazil's total GHG emissions that year combined (IEA, 2020f; Gütschow, Günther and Pflüger, 2021). In the US, space heating consumes roughly half of total household energy consumption, while in Germany and France, this figure rises to around two thirds (Ürge-Vorsatz, Eyre, *et al.*, 2012). As heat pumps generate no combustion emissions and are much more efficient than other forms of space heating, the potential emissions savings are large, as are the potential energy efficiency gains. The residential sector accounted for 75% of total heat pump sales in 2018, demonstrating that the demand for energy efficient appliances and space heating in homes has already begun to take off (Research and Markets, 2020).

## Box 2: Refrigerants with low global warming potential

Heat pumps rely on refrigerants to function, but these refrigerants are commonly greenhouse gases that can cause environmental problems when they leak during use or during disposal at the end of a product's lifetime. Emissions from refrigerants can be minimised by good maintenance of the products to reduce leaks and through proper disposal, but the long-term solution is to select refrigerants with lower environmental impacts.

In the mid-20th Century, common refrigerants were CFCs and HCFCs, which were listed for phasing out under the Montreal Protocol due to the damage that they do to the ozone layer. Unfortunately, the most common replacements were HFCs that are greenhouse gases with a very high global warming potential (GWP). Although currently a small contribution to total warming, that share could grow with the anticipated increase in demand for cooling over the coming decades. GHG emissions from refrigerants are responsible for around 26% of the total GHG emissions from stationary Air Conditioning (Dong, Coleman and Miller, 2021). The Kigali amendment to the Montreal Protocol requires an 80% reduction of high GWP HFCs by 2047, and there are good alternatives available.

The two main alternatives are lower GWP HFCs and a range of so-called natural refrigerants - propane (R290), ammonia, isobutane (R600a), carbon dioxide, water, and cold air.

Challenges to using natural refrigerants include the need to ensure appropriate training for safe handling, the need for corrosion resistant components when using ammonia or carbon dioxide, and updates to standards and regulations. However, natural refrigerants are relatively cheap and readily available in many places, and they can be made safe and usable with the right equipment and handling.

Ensuring maximum mitigation benefits from the use of heat pumps can be addressed through mandating the use of climate-friendly refrigerants in heat-pumps. Some jurisdictions are already putting appropriate regulations in place, commonly in line with the Kigali Amendment.

Recent examples include:

- The US EPA as announced the Significant New Alternative Policy (SNAP) regulation for HFC allowances that should ensure the reduction of high GWP HFCs by 85% over the next 15 years (EPA, 2021a). It came into effect on 1 January 2022 and applies to the production and imports of bulk HFCs (Garry, 2021). There is no explicit rule for ACs or heat pumps, but the regulations will likely impact them.
- The state of California retained regulations that were temporarily scrapped under the Trump administration and now goes one step further by applying limits to the GWP value of coolants used in ACs, essentially banning the use of certain HFCs. As of 1 January 2019, bans are being phased in across different types of equipment. The regulations are consolidated by the California Air Resource Board (CARB) and are part of the 2017 SLCP Reduction Strategy.
- In the EU, use of F-gases with a GWP higher than 150 has been banned in cars and movable AC equipment since 2017 (European Parliament and the Council of the European Union, 2006).
- The UK has additionally announced a ban on all F-gases from 2025 in AC and heat pumps containing less than 3kg of refrigerant (United Kingdom Environment Agency, 2021).
- The Montreal Protocol demands phase-out of high GWP F-gases more quickly in developed countries, but growth in cooling equipment is expected in developing countries with longer phase-out periods. Can the market be pushed for even quicker phase-out, and can support be provided to minimise leakage of high GWP gases in the short-term? Ensuring that costs for low GWP, natural refrigerants are competitive in developing countries will help those countries to leap-frog to the most sustainable options (Dong, Coleman and Miller, 2021).

## Barriers to diffusion

There are currently several barriers preventing the rapid and widespread diffusion of heat pumps that would contribute greatly to the mitigation of buildings sector emissions. Some are broad and overarching, while others are specific to whether systems are to be installed in new or existing buildings.

### Cost

A key barrier to the growth in heat pump sales is their higher upfront cost compared to other heating systems like gas and oil boilers (see Element Three – Financing). While both technologies are mature, with many components that are mass market products, a key difference in some locations is the relative lack of experience and size of heat pump installation companies. This leads to higher labour costs, contributing to the overall premium of heat pump installation over boilers, particularly in areas with low heat pump market penetration (UK Government, 2016).

Installation costs can also vary considerably depending on the building type and the existing heating system installed. Some high density or smaller residences do not have an appropriate location for the external unit, or for the water tank needed for an air-to-water heat pump system. If installation of a new ducting system is required, this adds considerably to the overall system cost. The cost premium is highest for retrofitting existing buildings due to the diverse range of building types and designs that must be accommodated by installers, as well as the need for additional building envelope upgrades.

## Box 3: Potential for hybrid systems

A hybrid heat pump is the combination of an electric heat pump and a gas- or oil-fuelled boiler or furnace under a single optimised control strategy. Due to their consumption of fossil fuels, a widespread adoption of hybrid systems is not expected; however, their use as a replacement for an existing boiler/furnace in specific circumstances could help to achieve the necessary rapid transition to low carbon heating (Figure 8). If renewable hydrogen eventually becomes available through the gas distribution network, or when synthetic fuels are widely available, a hybrid system could also become 100% renewable.

Some buildings will require retrofits to reduce heat loss before the replacement of a boiler with a fully electric heat pump system is feasible. Such high upfront costs may be prohibitive for some individuals and in this instance, a hybrid system could displace the sale of a conventional boiler after an existing one comes to the end of its life. Many small dwellings with combi-boilers may not have space for a water tank but could be replaced with a hybrid system that does not require one.

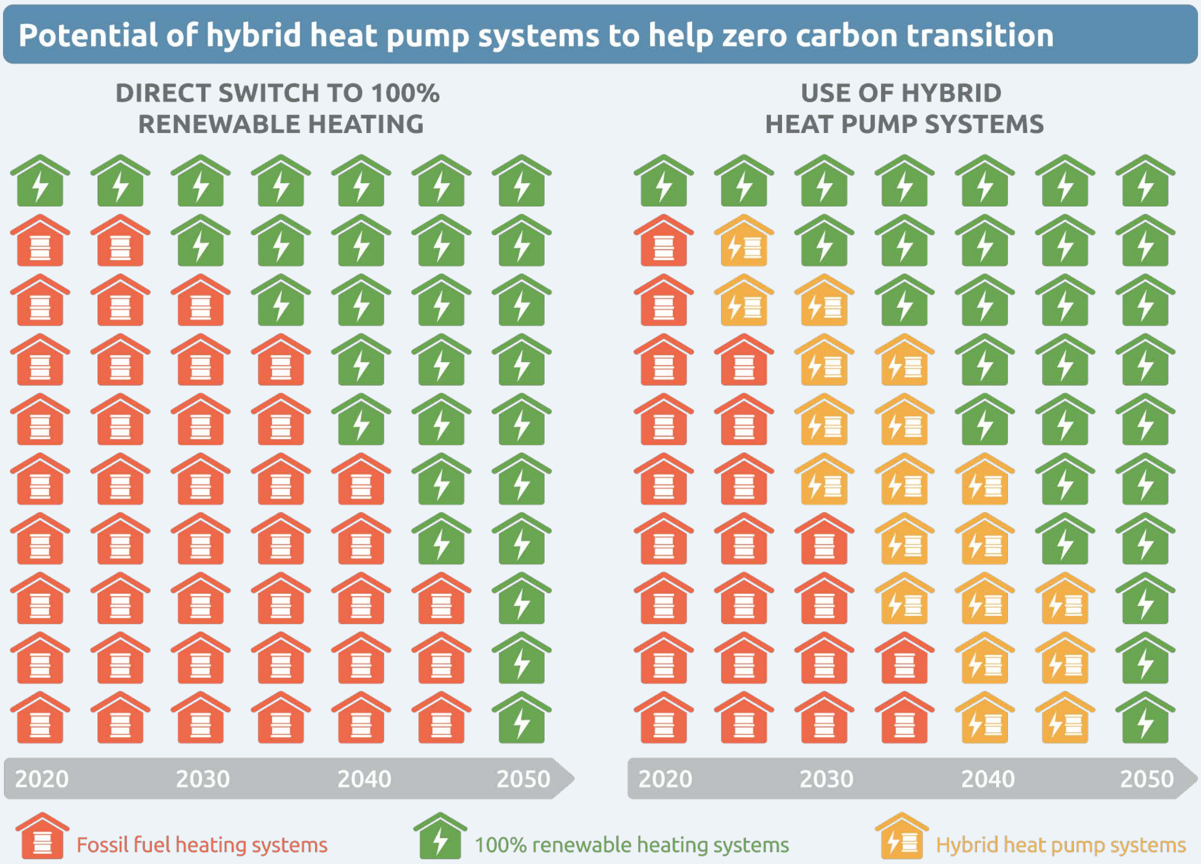


Figure 8: Switch to 100% renewable heating after building retrofit vs hybrid HPs as an intermediate solution. Source: IEA HPT, 2019

In cold climates the replacement of some fossil fuel systems with hybrids could help to reduce the grid redundancy required to accommodate the additional heat pump-induced power demand. In some locales, this may prevent the construction of gas peaker plants to accommodate higher demand peaks. Addressing potential heat-pump-induced demand peaks could also, however, be achieved through smart controls on purely electric models that avoid operation during periods of grid stress (Billimoria *et al.*, 2018)

A study from 2018 attempted to assess the likely future decline in heat pump price and found a large degree of uncertainty across the scenarios considered. Average unit cost declines ranged from 25% between 2015 and 2040 in the central scenario, and just 5% over the same period in the worst-case scenario (Element Energy, 2018). The economic case of heat pumps is further discussed in the Finance element (Box 8: The role and impact of energy prices – the example of heat pumps).

## Location

There are several location-specific barriers that can affect the adoption rate of heat pumps. Locations with very cold climates reduce the operating efficiency of heat pumps, as they must work harder to extract the necessary ambient heat to provide adequate warmth. Improvements in refrigerant technology and system design have reduced the severity of this barrier, however, with hundreds of systems now able to operate relatively efficiently at temperatures as low as -15°C (5°F) (Petersen, Gartman and Corvidae, 2019). In Norway, for example, over 50% of households now have a heat pump installed, while heat pumps as a proportion of total heater sales reached over 96% in 2020, compared to just 2% in the UK (EHPA, 2021). In Vancouver, Canada, which has a relatively cold climate, a legislative change proposed by the City government would mandate any new air-conditioning installations for entire houses to be a two-directional heat pump that also provides heat (City of Vancouver, 2022).

Installing a second stage, with an additional compressor, can solve the four key issues that arise in very cold climates: high compressor discharge temperatures, lower operating efficiency (coefficient of power, or COP), reduced heating capacity, and increased on/off cycling at higher ambient temperatures (Bertsch and Groll, 2008). An additional stage adds considerably, however, to upfront cost affecting the financial viability of such an option. There are also novel approaches emerging to combat frost formation on external units and piping that can increase overall system efficiency.

Locations with cold climates may also require a higher degree of electrical grid redundancy to accommodate the higher winter power demand that would arise from a widespread adoption of heat pumps that need to work harder at low temperatures. Such additional grid redundancy is currently often provided by natural gas peaker plants. By encouraging the inclusion of demand flexibility options with heat pump installations, demand peaks can be minimised by programming electricity use to occur during less busy, and usually cheaper, times of the day (Billimoria *et al.*, 2018).

## Information deficits

A lack of, or incorrect, information can act as a significant barrier to progress in several ways. Given the relative nascency of their use in many countries, it is not uncommon for individuals to be unaware of the existence of heat pump systems for providing residential heating (Shankleman, 2021). For those that know of them, some will be unaware of the potential cost savings compared to their existing boiler. Others still, may be unaware of the potential environmental benefits, believing that natural gas boilers are already environmentally friendly because they have lower carbon intensity than oil boilers.

Some individuals may simply have outdated information about heat pumps, believing them to be unsuitable for cold climates despite the significant progress made in this regard and their now widespread use in such climates. This also applies to those that believe heat pumps' use of refrigerants make them environmentally destructive, unaware that new refrigerants with lower global warming potentials (GWP) have been developed.

Research has found that the installation of a heat pump can have a significant positive impact on house prices, adding between a 4.3-7.1% price premium on average (Shen *et al.*, 2021). This information is likely unknown by many house-owners and builders that may otherwise have been convinced to invest in upgrading their heating system or choosing to install a heat pump over a boiler during construction of a new premise.

Installers that are inexperienced in heat pump installations are more likely to make mistakes on elements critical to ensuring the optimal functioning of a heat pump system like indoor airflow rate calculations, sizing of the system, or refrigerant charge level. Preventing or minimising these occurrences not only ensures the maximum potential energy and emissions savings of the system but reduces the risk of an unsatisfied customer spreading word of this experience to their social network and leading to reluctance in others to consider upgrading themselves (Forsén, 2005; Domanski, Henderson and Payne, 2014).

## Box 4: Heat Pumps vs Hydrogen for heating

A key policy debate over the choice of heating technologies for the low-carbon home of the future is beginning to gain steam as the issue of buildings decarbonisation comes into greater focus. The combustion of renewable or 'green' hydrogen is emission free and is therefore attracting significant interest as a potential solution, however its use for this application comes with both advantages and disadvantages.

Perhaps its greatest advantage over heat pump technology is its potential to utilise existing natural gas distribution and transmission infrastructure. Several countries have begun trials mixing hydrogen gas into their natural gas networks up to a 20% share, with some planning to eventually reach 100% (St John, 2020; IEA, 2021e). Blends of 20% or less are likely to be useable in existing gas appliances which means existing boilers could be made less carbon intensive over time, though potential emissions savings are limited (Gerhardt et al., 2020). Due to current high costs, a switch to 100% renewable hydrogen would require costly new appliances and upgrades to distribution and transmission infrastructure, diminishing its advantage in this regard.

A potential use of hydrogen for heating is in district heating networks, where the exclusive use of heat pumps can prove difficult due to the high temperatures needed for heating systems in buildings.

A key disadvantage of relying on combustion of hydrogen for heating buildings is the fact that it will increase inter-sectoral competition for what will be for many years to come a scarce supply of renewable hydrogen. Other harder-to-decarbonise sectors of the economy like heavy industry, aviation and shipping will begin to generate significant renewable hydrogen demand for use in the production of steel and e-fuels and in other industrial processes (Dolci, 2018). In addition, roughly 95% of existing hydrogen demand is met with fossil-fuel derived hydrogen and is therefore not an option given that buildings need to achieve zero carbon performance (IRENA, 2019).

Renewable hydrogen-based heating systems are found to consume a factor of 5 to 6 more renewable energy than heat pumps (Gerhardt et al., 2020). This will also increase inter-sectoral demand for renewable energy generation and has the potential to delay decarbonisation of the power sector and others.

Currently, producing renewable hydrogen is expensive, far more than that produced from fossil fuels, shown in Figure 9 (IEA, 2019d). The necessary increases in electrolyser economies of scale and associated cost decreases will take many years to achieve. This fact, combined with the cost of wholesale appliance switching (often before their end of life) and network upgrades means heating homes with renewable hydrogen will remain a much more expensive option for buildings decarbonisation for the foreseeable future.

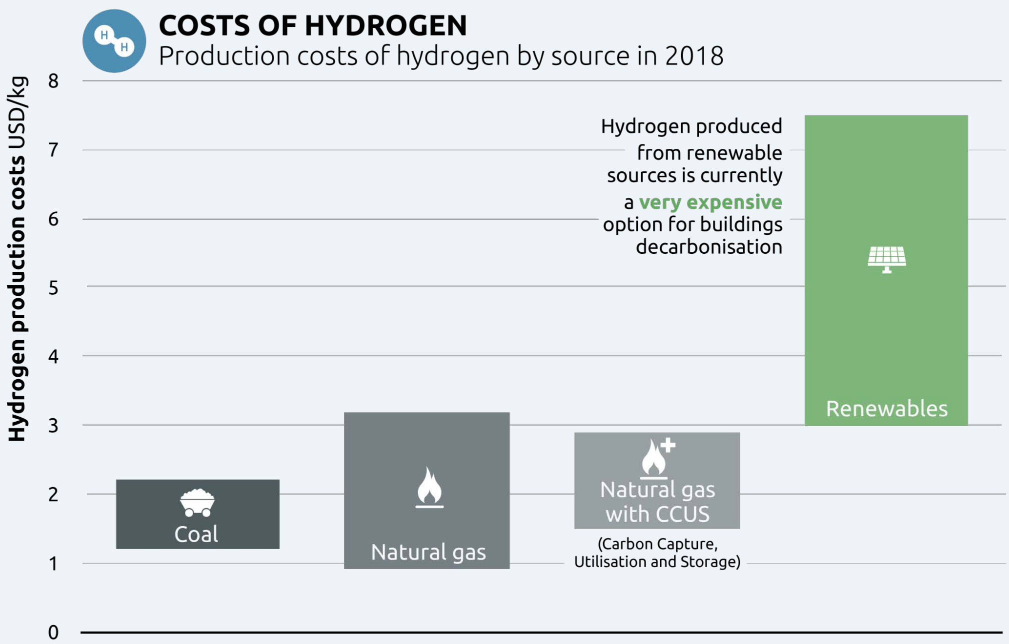


Figure 9: Global hydrogen production costs by source in 2018

*Source: IEA, 2019d*

## Case Studies

### Case Study 1: Sweden - mainstreaming heat pumps

A sustained commitment over numerous decades to supporting a domestic heat pump manufacturing industry has paid dividends for Sweden, which today is one of the largest heat pump suppliers to the European market. After the oil crisis of the late 1970s that resulted in historically high energy prices, Sweden began subsidising purchases of domestic heat pumps, leading to an uptick in demand (Kiss, Neij and Jakob, 2012). A steep decline in oil prices in the mid-1980s caused the heat pump market to collapse, leading to the failure of most of the 130 heat pump companies that had emerged to that time. Those that survived benefitted from the reintroduction of government support in the early 1990s.

A technology procurement programme was launched in 1993 with the objective to stimulate the development and commercialisation of heat pumps, and was combined with investment subsidies, information campaigns, and evaluations of heat pump installations. Sales of heat pumps subsequently doubled from 1995 to 1996, and with multiple rounds of funding for further subsidies until 2010, sales and increased at an average 35% per year to 2006 (Kiss, Neij and Jakob, 2012). A switch to government financial support for the installation of heat pumps (30% of installation costs), rather than the heat pump itself, corresponded with stagnating growth over the subsequent decade (Tognetti, 2020; EHPA, 2021).

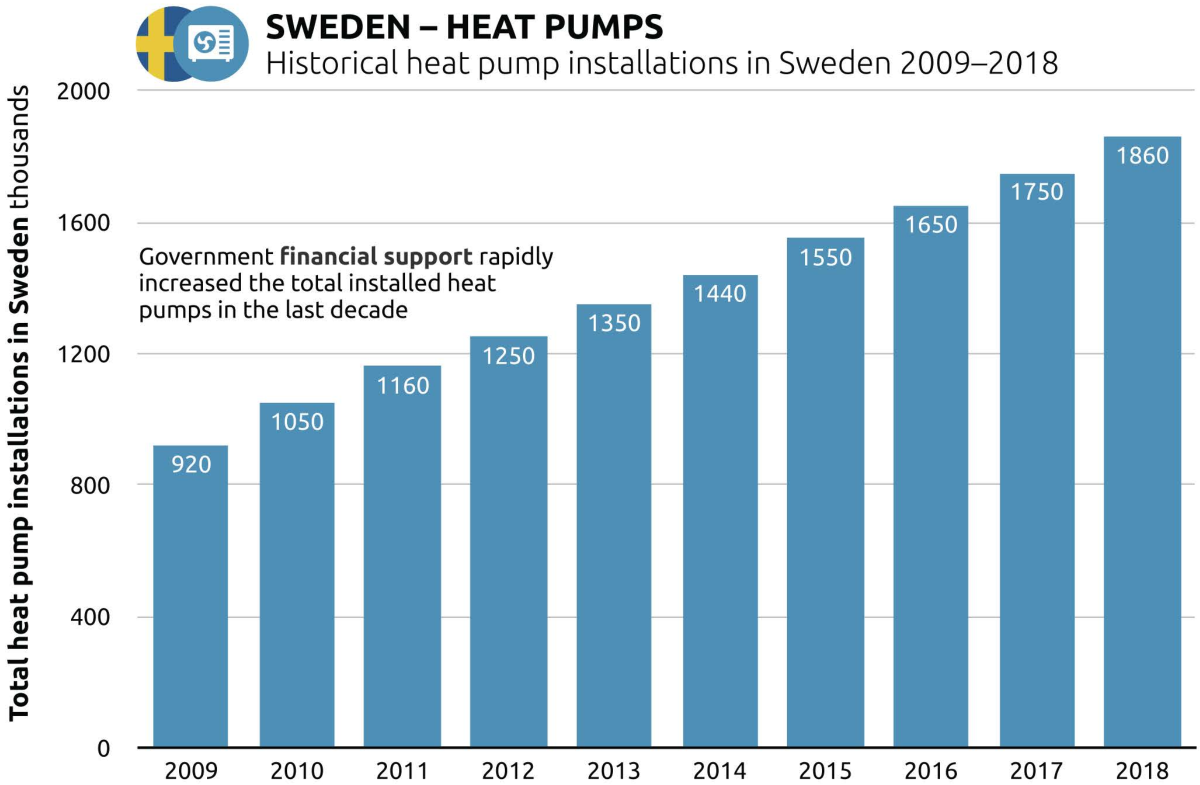


Figure 10: Total heat pump installations – Sweden (thousands). Source: EHPA, 2021

Early research and development (R&D) funding was instrumental in supporting the development of a local manufacturing industry in Sweden, with dozens of companies arising during the first phase of investment (Kiss, Neij and Jakob, 2012). The expertise that was generated during this first phase of government support was then available to drive the second growth phase of the Swedish domestic industry. This forty-year arc of mostly continuous government support has fostered the growth of domestic heat pump producer NIBE, which today is one of Europe's largest suppliers of heat pump technology, reaching over USD 3bn in annual sales in 2020, roughly half of which was generated by heat pump sales (NIBE, 2021). In the UK, NIBE was the third largest supplier of air-source heat pumps behind industry giants Samsung and Daikin, and the top supplier of ground-source heat pumps in 2019 (UK Government, 2020).

The net result of these policies domestically, is that roughly 40% of households in Sweden have a heat pump installed as of 2018, with total installations doubling between 2009 and 2018 (Figure 10) (EHPA, 2021). This is the second highest share of installed heat pumps in Europe, with only Norway achieving a higher share of just over 50%. These figures must, however, be contextualised, as neither country has ever utilised relatively cheap natural gas as a significant source of heating. Heat pumps have instead primarily replaced either expensive electric resistive heaters, district heating, or in the case of Sweden, oil boilers that were common in the 1980s (Figure 11) (Dzebo and Nykvist, 2017).

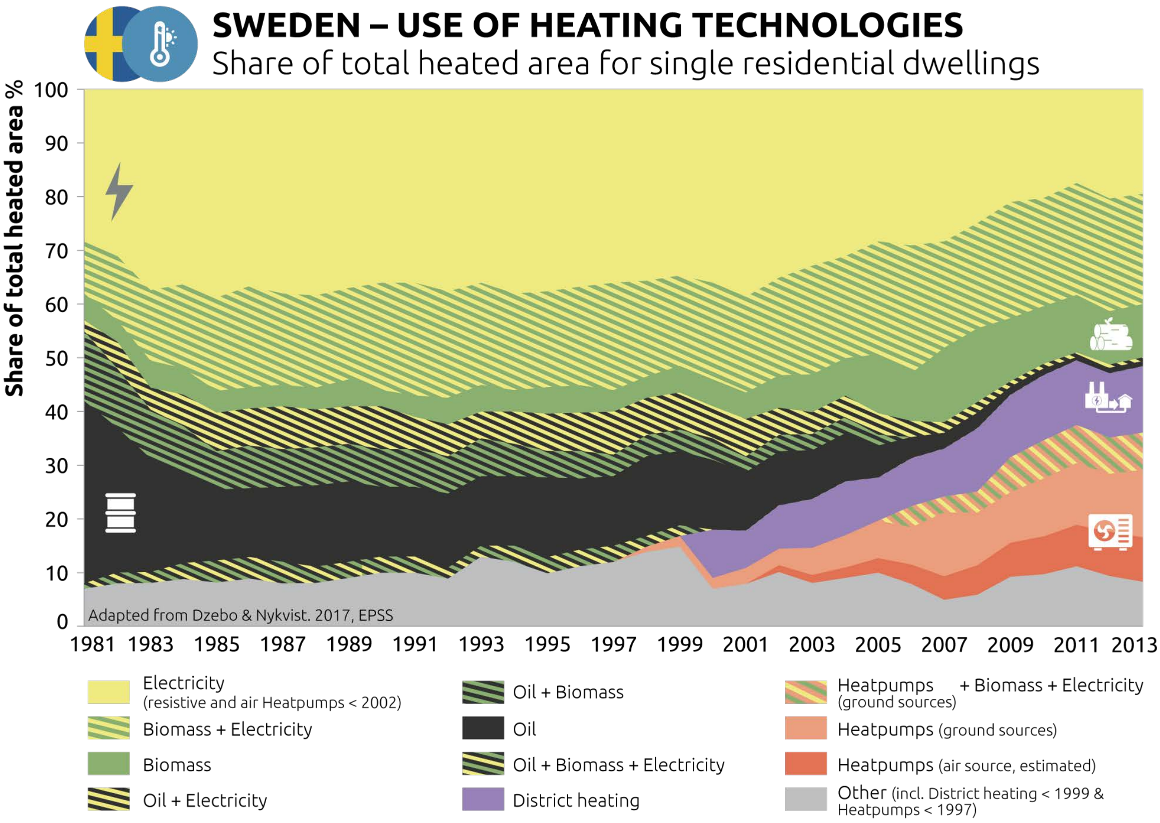


Figure 11: Share of total heated area for single dwellings in Sweden

*Source: Dzebo and Nykvist, 2017*

## Key Lessons

The decision to invest early and heavily in not only the incentivisation of heat pump adoption, but in R&D and support for the growth of a local manufacturing industry has helped make Sweden a global leader in heat pump adoption and production. Consistent funding to subsidise heat pump uptake sent a clear signal to industry participants that investing in the development of the sector was less risky than it would have been otherwise.

The even higher rate of adoption in neighbouring Norway despite less comprehensive government support is likely due in part to its low electricity price. This suggests that countries with similarly low electricity prices such as The Netherlands are likely to have a lower barrier to achieving increased uptake than those with expensive power.

## Case Study 2: The United Kingdom - A decade of poor scheme design

The history of heating policy in the United Kingdom (UK) is punctuated by unambitious, or ineffective measures that serve to illustrate what governments seeking to achieve a rapid decarbonisation of building heating should avoid. Throughout much of the 2000s and into the 2010s, the UK government placed a heavy focus on incentivising the uptake of efficient condensing gas boilers (Lowes, Woodman and Fitch-Roy, 2019). While condensing boilers are less carbon intensive than conventional boilers, they still burn fossil fuels and therefore fail to produce the decarbonised heating required to rapidly reduce buildings sector emissions.

When policy shifted to incentivising renewable heating sources with the 'Low Carbon Building Programme' (LCBP), the maximum grant to households for heat pumps and other technologies was reduced from GBP 15,000 to GBP 2,500 within the first year (Gardner *et al.*, 2011). It then remained at this amount until the scheme's conclusion in 2010, representing just 10-28% of the total equipment and installation cost.

### Renewable Heat Incentive

The successor to the LCBP was the 'Renewable Heat Incentive' (RHI), which started in 2011, and was designed to provide an ongoing tariff for the production for renewable heat. It was only available to non-domestic buildings for the first three years of the scheme, and to bridge the gap for households, an interim policy called the 'Renewable Heat Premium Payment' was introduced which provided capital grants.

When the RHI tariffs for households were eventually introduced, providing a fixed tariff for seven years, it led to far lower uptake than anticipated. A total of 513,000 new installations were planned by 2020, but by the end of 2017, just 78,048 installations had been delivered, with an expected 111,000 installations by March 2021 (UK National Audit Office, 2018).

Research undertaken to ascertain the weaknesses of the program found that tariffs would have needed to be higher to drive technology deployment, while a government survey found that the high upfront cost of low-carbon heating technologies was a key concern for 62% of domestic applicants (UK National Audit Office, 2018; Lowes, Woodman and Fitch-Roy, 2019). It also found that participants in the domestic scheme were more likely to be from high-income households.

In the non-domestic scheme, a strong majority of installations were biomass boilers. In the domestic scheme, biomass boiler installations were initially also common, but this changed after tariffs offered for these boilers were reduced leading to lower uptake. Overall, air-source heat pumps made up a majority of installations (Figure 12).

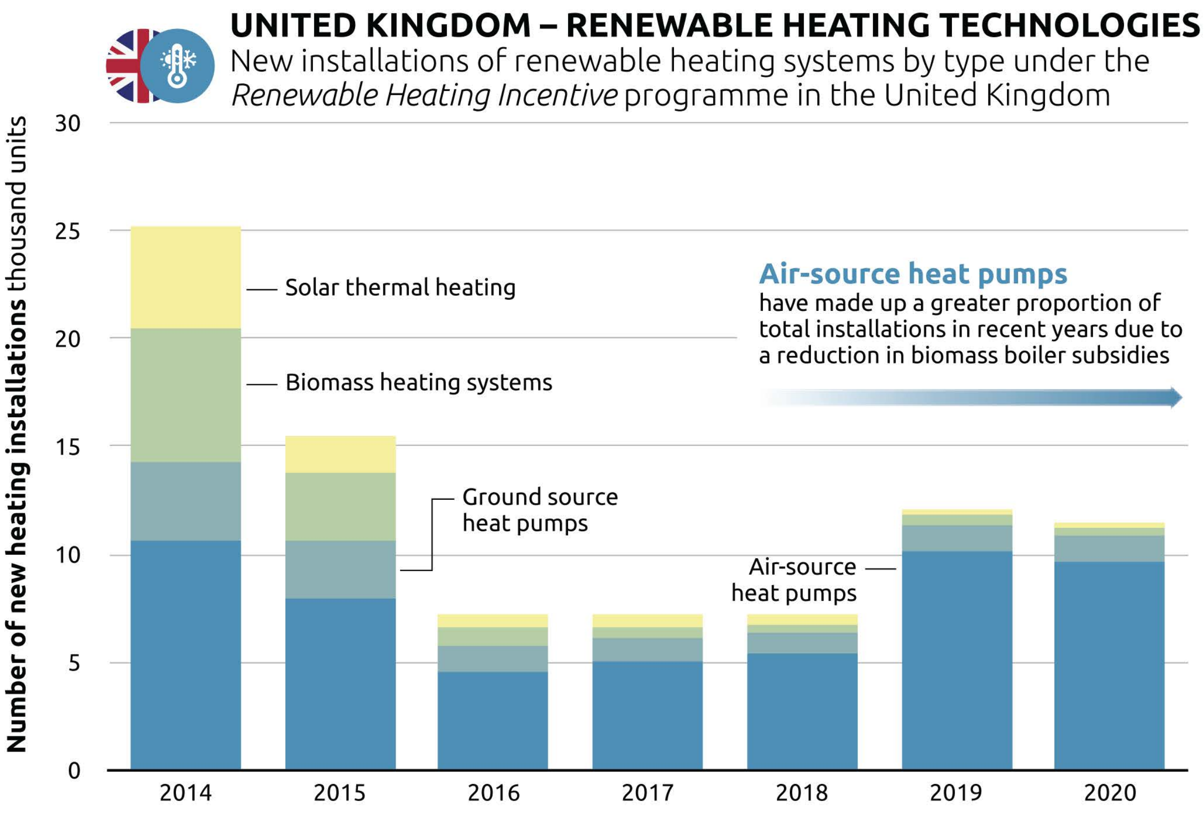


Figure 12: Domestic RHI installations by technology

*Source: UK Government, 2021*

## Green Homes Grant

As part of the UK Government's COVID-19 recovery package, GBP 1.5bn was announced for the Green Homes Grant that was to incentivise both housing envelope improvements and heat pump uptake. From the onset, the scheme was plagued by issues that led to its scrapping, just six months after its inception. A target of allocating grants for 600,000 homes fell far short, with just over 22,000 grants worth roughly GBP 94m issued by the time the scheme was scrapped at the end of March 2021.

Several key issues arose that led to the Green Homes Grant's failure.

1. The conception of the scheme was rushed, with an allocation of just 12 weeks to design the scheme, consult stakeholders, and procure an administrator.
2. Delays in reviewing applications led to quotes expiring and a slow overall rate of grant uptake (Figure 13).
3. Confusion over the sequencing of primary (insulation or heating technology) versus secondary (replacing doors and windows, draught proofing, hot water tank insulation) measures was widespread. Eligibility for secondary measure funding was conditional on implementing a primary measure.
4. A restrictive set of accredited installers meant that 84% of grant applicants could not find a suitable installer. The limited number of accredited installers was due primarily to:
    - An onerous and expensive accreditation process that particularly burdened small retrofitting businesses
    - A lack of consultation with the installer industry that led to a low sign-up rate of installers to the scheme

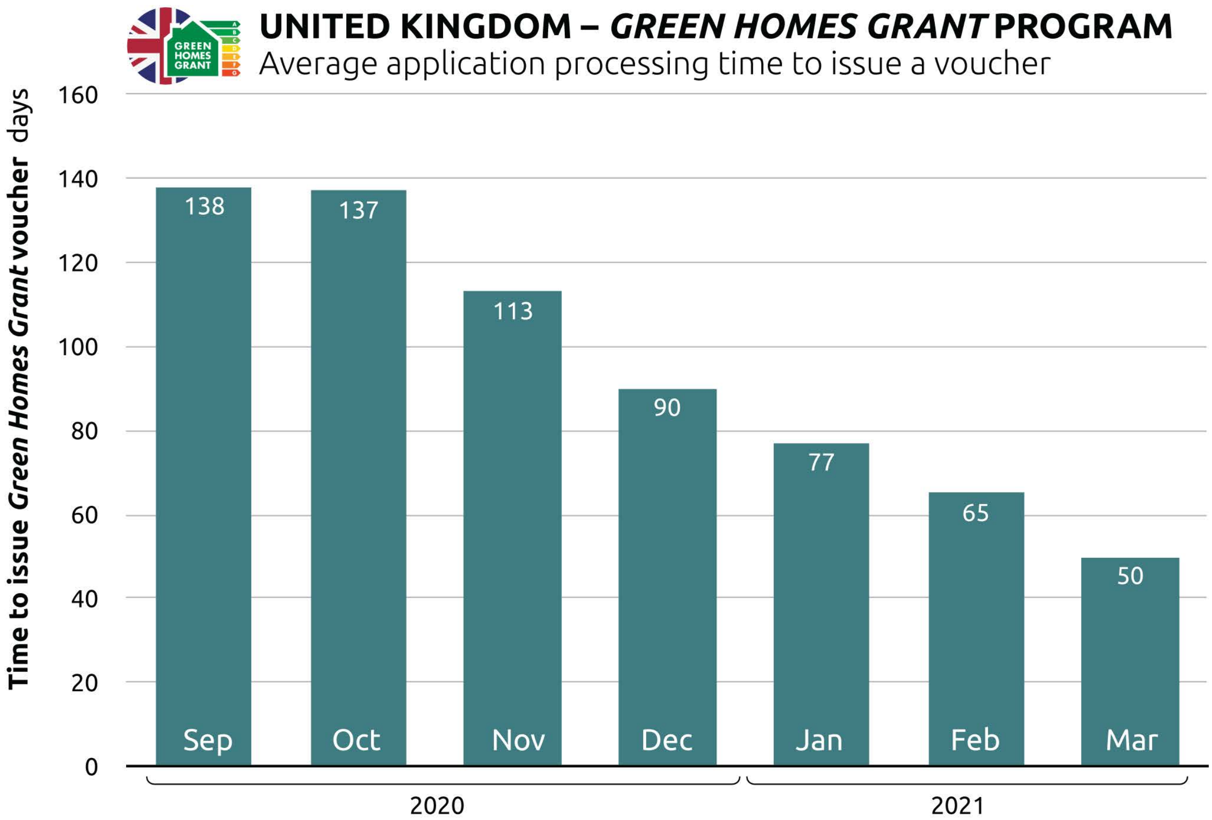


Figure 13: Time taken to issue Green Homes Grant vouchers

*Source: UK National Audit Office, 2021*

In addition to the above, the short timeframe of the scheme (September 2020 to March 2021) did not provide certainty to installers that may have needed to invest in new staff or equipment. The frustration caused to many grant applicants that were not able to secure funding or an installer to complete the work during the operation of the scheme may lead to hesitancy to apply for future funding streams.

## Boiler Upgrade Scheme

In late 2021, the UK government released its Heat and Buildings Strategy, which included a centrepiece policy to incentivise the replacement of fossil fuel boilers called the Boiler Upgrade Scheme. The scheme allocates GBP 450m over three years to replace fossil fuel boilers with low carbon-alternatives such as heat pumps (UK Government, 2021a). The GBP 450m in funding is a more than fourfold increase on the originally proposed GBP 100m but is expected to lead to only 90,000 heat pump installations compared to the government's target for 2028 of 600,000 per year.

## Key lessons

A common thread that runs through much of the UK's efforts at buildings decarbonisation is the short-term nature of the various schemes over the years. This fails to provide the certainty that encourages industry participants to invest in the human and physical capital that is needed to create the capacity for widescale heat pump installation.

The Renewable Heat Incentive, that will have spanned over a decade by its completion, from 2011 to 2022, failed to address the high upfront cost of heat pump technology compared to gas boilers. This has been shown to be a key issue preventing the wider adoption of heat pumps, and by persisting with this approach, the UK government has not achieved value for money over the duration of the scheme according to the UK National Audit Office (UK National Audit Office, 2018).

## Windows

To achieve buildings decarbonisation and an overall building stock of zero carbon buildings), improvements are needed across all facets of the building envelope as well as the choice of heating and cooling technology.  Replacing the technologies that are the source of these emissions with more efficient alternatives like heat pumps, however, will often not be feasible without considerable improvements to the building envelope.

Windows, which are known as the weakest link in the thermal envelope, are responsible for approximately 10% of building energy loss (Hart, Selkowitz and Curcija, 2019). Their significance as a single facet of the building envelope with large potential energy efficiency gains is a key reason for their selection for analysis in this report.

These potential energy savings through window improvements are due to the high amount of energy transfer associated with them. Windows can both lose energy through the transfer by air, such as via leaky window frames or poorly insulated window glass, as well as gain energy by allowing solar radiation to enter the building.

Several structural factors are considered when optimizing window choice for energy efficiency. The main window structure to consider is the number of glass layers, referred to as glazings or panes, that a window contains. Double and triple glazed windows, containing two and three glass layers respectively, are the most common choices for energy efficient windows. The number of panes influences the degree to which thermal energy can be transmitted via air through the windowpanes.

Another factor to consider is the degree to which window glass conducts thermal energy via light. Reducing the solar heat gain of a window is generally accomplished through the application of coatings on the outer windowpane to increase reflectivity and thereby reduce the absorption of solar energy. This can be accomplished either through tinting the exterior panes of the window with darker colours, thereby preventing some solar energy to enter the interior, or through low-emissivity (low-E) coatings, a transparent coating that can be used on the inside or outside of a window to reflect solar infrared radiation back into the interior of the building or away from the exterior, depending on energy needs of the building from the local climate (Amirkhani *et al.*, 2019).

Air leakage (L50) measures the degree to which air can pass through the window and window frame between the interior and exterior of the buildings with higher values having greater air leakage (European Commission, 2010). Measuring air leakage is important to reduce losses from heating and cooling systems through windows. Finally, many windows are also rated according to their visible light transmittance (VT), which affects how much natural light can enter a room through the windowpane. This metric plays a role in the need for interior lighting in rooms where windows are installed and can therefore also influence the consumption of electricity.

## State of Play

In the EU, the Energy Performance of Buildings Directive (EPBD) requires EU Member States to put in place minimum levels of energy performance for building envelope elements when they are retrofitted or replaced (see Box 6: EU Energy Performance Buildings Directive for existing buildings). However, each member state is free to set minimum standards as they see fit, leading to considerable variation in average window performance, overall and of retrofits, across the bloc. So far, most member states of the EU have set minimum standards for window U-values (level of thermal transmittance) for new windows installed in both new and retrofitted residential and commercial buildings. Many national window energy efficiency standards within the EU consider only U-value and no other metrics, even though the accepted best practice is to use an energy balance model that considers both the U-value and solar heat gain coefficient in a single value (Glass for Europe, 2017).

Various combinations of glazing, filling and coatings can be used to adapt to the needs of different climates and building demands, depending on the amount of heating vs. cooling demand days. The most suitable combination of glazing, filling and window coatings depends strongly on the local climate of the building's location, as this will determine the relative energy balance used in the building between heating and cooling and the degree to which solar heat gain is of concern.

However, some window technologies can be tailored to fit a range of climatic conditions. Low-E coatings, while most commonly used on outer panes to reduce solar heat gain in warmer climates with greater relative cooling demand, can also be used on the inside of glass depending on climate. Low-E windows with coating on the interior of the glass can help hold heat inside, and can also be beneficial in cooler climates with higher heating demand when combined with triple panes. Low-E coatings on double glazed windows may hold the most promise for both region types, as the coating can be applied to either the interior or exterior face of the glass depending on whether heating or cooling is the primary objective.

While preferences of national markets often reflect the unique geographies and climates present, the total cost of different energy saving window options has recently started to converge toward the most affordable options regardless of climate. For example, Low-E windows tend to be more cost-efficient than triple glazing, as the weight, frame size and total material used is greatly reduced. Overall, several studies show that double glazed low-E windows offer the most cost-effective energy savings of all combinations, regardless of climate type (Yang *et al.*, 2015; Amirkhani *et al.*, 2019; He *et al.*, 2019). In one US-based study, thin triple glazing did show a 16% increase in energy savings for heating dominant regions compared to low-e windows, but at greater cost; benefits of only 7% were noted for the same switch in cooling dominated parts of the US (Hart, Selkowitz and Curcija, 2019).

The strategy for addressing the role of windows in a building's energy profile should differ between constructing new buildings and renovating old buildings. The overall window-wall ratio (WWR), also referred to as the window volume of a building, plays a role in both the energy savings of a building as well as the cost for retrofits. The volume of windows in the building envelope can play a major role in cost-effective retrofit decisions. Therefore, for new construction, evaluating the need for greater window volume from the perspective of future energy efficiency from the beginning can avoid energy losses. One study found that changing windows is around 3 times more expensive than insulating exterior walls to reach similar savings in transmission losses (Hummel *et al.*, 2021).

The optimal WWR differs depending on the climate in which the building is located and directional orientation of the windows. Some studies find that overall, window volume in the building envelope tends to be higher in colder climates than in warmer ones, due to differences in both lighting needs and heating/cooling needs as well as cultural factors (Hummel *et al.*, 2021). These climatic and cultural differences may require different considerations for prioritising window renovation over renovation in other areas depending on the window volume in the existing building stock. At times, reducing the overall window-wall ratio in a building's envelope may result in overall greater energy savings than replacing all of the existing windows.

### Heating-dominant climates (cooler year-round temperatures)

Heating-dominant climates are characterized by the greater need to reduce the transmittance of air from between the interior and exterior of the building to minimize heat loss in cold temperatures, coupled with a desire to maximize the availability of solar heat gain through allowing solar energy to enter the interior of the building, thereby reducing the overall amount of heating needed to be generated from the building's heating system. For this reason, emphasis in these climates is placed on minimizing air transmittance via the use of an increasing number of panes, coupled in some cases with the use of inert gases between panes.

In one study of the US market between 2000-2010, the number of heating degree days (HDD) was the largest statistically significant predictor of choosing energy efficient window options over standard options, indicating the colder climates may have the largest positive influence on window adoption (Koebel *et al.*, 2015).

The most efficient combinations found by studies on windows in heating dominant climates are triple paned windows or double paned windows combined with low-E coatings on the inside of the glass and occasionally with filling of inert gas to further reduce thermal transmittance of air. Studies have shown that both triple pane glass and double paned glass with low-E coatings provided the best retrofitting strategy for energy efficiency gains in heating-dominant climates. The choice between these two combinations largely rests on the relative cost, with several studies agreeing, that while triple paned glass may provide marginally improved energy efficiency compared to double-paned glass with low-E coating, the extra cost due to extra material and weight required often cancels out energy efficiency benefits.

### Cooling-dominant climates (warmer year-round temperatures)

Cooling-dominant climates are characterized by the greater need to reduce solar heat gain through windowpanes to the exterior of the building, as well as the need to reduce air transmittance, in order to reduce the overall temperature of the building and thereby the amount of energy needed to cool it. Therefore, tinting and window shading are of primary importance in cooling-dominant climates to reduce the solar heat gain coefficient of window glass.

Window position also has a strong effect on solar heat gain in warmer climates dominated by cooling demand. Studies have shown that focusing on installation of low-E windows in facade areas which are exposed to the most solar heat can increase overall cost-effectiveness of window installation (Serghides *et al.*, 2015; Yang *et al.*, 2015). In studies of warm climates in China, changing the air conditioning mode of operation had comparatively little effect on energy savings compared to reducing the overall window-wall ratio (Yang *et al.*, 2015). A similar finding was found in one US-based study showing that, when comparing the relative strength of the effect of changing WWR on variables, such as heating demand, cooling demand, lighting and ventilation, it was found that optimized WWR had the greatest overall effect on cooling demand, followed by lighting (Troup *et al.*, 2019). Given the strong influence of solar heat gain on cooling demand, optimizing WWR may be particularly important in warmer climates with larger amounts of annual solar irradiation.

For cooling dominant climates, combining windows with adequate shading and light blocking devices, in addition to window coatings, is important. In a study on improving energy efficiency in Mediterranean buildings, horizontal sunshades made of aluminium framing and fabric were placed on the exterior of the building over south-facing windows to increase the efficacy of low-E windows (Serghides *et al.*, 2015). The use of external sun shading systems is found in some studies to have overall more importance in retrofitting strategies aimed at improving energy efficiency in cooling dominated climate than even window glazing or thermal transmittance. This was found in a study in Egypt, where retrofitting strategies focused on sun shading improved energy efficiency by 23% while strategies focusing on improved glazing improved energy efficiency by only 8%.

### Mixed climates (both hot summers and cold winters)

Mixed climates face the challenges of both cold winter and hot summers, and therefore require windows that balance the needs of both reducing air transmittance and reducing solar heat gain to a high degree. Multiple panes, fillings and coatings are needed in combination to meet these demands.

Some studies indicate that mixed climates benefit the most from implementing window retrofitting characteristics of warm climates. A study by He et al. (2019) compared the relative benefits to energy efficiency from different window retrofitting strategies on a model building across heating-dominant, cooling-dominant and mixed climatic regions in China. They found that Low-E window tinting offered the most energy efficiency benefits for both the cooling-dominant and mixed climates. Reducing the WWR of buildings in mixed climates also provides significant energy efficiency benefits, particularly in situations where low-E coatings are not available or cost effective.

A complete view of a building's life cycle energy use should be considered when prioritising windows before or after other retrofit options. While heating system replacement has the greatest impact on overall energy use for buildings, windows are integral for minimising the need for heating and cooling technologies in the first place, together with insulation of the building envelope. Life Cycle Analysis studies of building retrofit measures indicate that heating system replacement is the most influential factor in reducing energy use (in terms of $kgCO_2eq$) and cost (in terms of net present value - NPV), followed by exterior wall insulation and then window replacement (Serghides *et al.*, 2015; Galimshina *et al.*, 2020). Therefore, window choice and design are among the top three most important factors for reducing overall building energy use. Still, if energy inefficient choices are made regarding the heating & cooling mechanisms or insulation of a building, it will be difficult to improve the energy use profile drastically solely by upgrading windows.

## Barriers to Diffusion

While the options for energy efficient retrofitting of windows continue to increase and improve, their uptake in the global buildings market remains relatively low. Major barriers to diffusion for more efficient window types include high costs and a lack of incentive for installation relative to mainstream window types.

This is particularly true given the higher amount and cost of materials required to produce more efficient window types. For example, in the case of triple pane windows, the main barrier to diffusion is their high cost of production and material. Increasing economies of scale as demand increases may reduce costs in the future (Wei *et al.*, 2021). Comparatively, double glazed windows with low-E coatings or keeping existing windows while installing sun shading systems are usually lower cost options and yield a quicker return on investment, resulting in their preference across most climate types rather than options with an increased number of panes.

In the US, windows manufactured with Low-E coatings typically cost about 10 percent to 15 percent more than regular windows, but they reduce energy loss by as much as 30 percent to 50 percent (U.S. Department of Energy, 2021b). Current statistics from the US Energy Star initiative estimate that US consumers can save between USD 125 - 340/year when switching to modern, more energy efficient Energy Star rated windows compared to old single pane varieties and up to USD 70/year when switching compared to uncoated double pane windows in both new and retrofitted construction.

Total costs regarding window retrofitting are also linked to issues of window to wall ratio across different building styles and national trends. European studies have found that WWR tends to be higher in colder climates with longer or colder winters, given the increased need for infrared radiation and visible light during this season. With greater WWR, the overall cost for window retrofitting an existing building increases as the number of windows needed is greater. This difference in building structure, coupled with the comparatively lower energy savings of window retrofitting compared to other retrofitting options such as heating systems or insulation, may make window retrofitting a less cost-effective option for certain climates and building styles.

While most studies show that energy efficient window retrofits save money through reducing the need for heating and cooling over the long term, the average payback period differs across markets and therefore plays a role in either incentivising or disincentivising installation of energy efficient windows.

Studies on barriers to diffusion of sustainable technologies in buildings done in both China (Du *et al.*, 2014) and Australia (Dadzie *et al.*, 2018) showed similar attitudes of reluctance towards the initial investments for a variety of sustainable building technologies from different stakeholders in the construction industry, including investors, architects, contractors and purchasers.

## Market dynamics

The choice of heat pumps and windows for deeper analysis was in part driven by the difference in the nature of the markets for each product. Whereas the bulk of global heat pump demand is supplied by a handful of mainly Japanese and South Korean multinationals, window markets are highly fragmented and largely consist of local suppliers. I

The top four companies for market share of heat pump sales in the US in 2017 were Daikin, Mitsubishi Electric, Panasonic, and Fujitsu, all Japanese companies (Market Study Report, 2019). Globally, the top four companies by market share in 2020 were: Daikin, Mitsubishi Electric, Fujitsu, and LG Electronics (Absolute Reports, 2021).

Significant demand growth is expected from the Asia-Pacific region, which accounted for 41% of the global heat pump market in 2018 and is projected to grow at over 9% per year until 2025 (Grandview Research, 2019). This is in part due to growing residential and commercial construction activities in developing countries in the region. North America was the second largest market in 2018 and is expected to grow at 7% per year until 2025. This geographic concentration of growth is likely to consolidate the dominance of Japanese and Korean producers on the global market. For the European region, ASHPs remain well behind conventional boilers for space heating, with sales of ASHPs just one fifth the volume of boiler sales in the EU (European Heat Pump Association, 2019). The strength of sales varies considerably though across countries, with Norway and Finland both seeing sales of more than 46 heat pumps per 1,000 households, compared to less than 2 per 1,000 households in the UK (EHPA, 2021).

With increasing demands for climate-friendly technologies, energy efficient windows are poised to increase in market importance and share over the next decades. Studies indicate that the combination of energy prices and climatic conditions play the greatest role in either encouraging or deterring consumers and builders from adopting energy efficient window choices (Koebel *et al.*, 2015).

The fragmented and localised nature of the market for energy efficient windows creates opportunities for significant economic co-benefits for incentivising their uptake. Government funds used to stimulate demand will primarily remain in the country, helping to grow local businesses and creating prosperity domestically. In the US alone, domestic suppliers made up more than four fifths of the market at the end of the 20$^{th}$ century including more than 2,000 small businesses with highly localized reach (Eto, Arasteh and Selkowitz, 1996).

## Box 5: Role of district heating and cooling

### District heating

District heating supplies around 8-9% of global buildings heating energy demand (IEA, 2021b). This contribution varies substantially between countries with some, including Russia, Denmark and Sweden, relying on district heating for 45% or more of their heating needs.

District heating generally works well in densely built areas with consistent heating needs. Here it can be particularly useful as other low carbon options, including heat pumps, may be restricted due to lack of space.

District heating systems have evolved to use different energy sources and to distribute the heat in a more efficient manner. Older systems transport heat at very high temperatures and predominantly rely on coal or gas (Werner, 2017b). These systems therefore have quite high emissions intensities and a future for district heating relies on decarbonisation of the heat source.

Newer systems that incorporate industrial heat pumps and heat storage can run with transport temperatures as low as 50-60°C and utilise alternative heat sources, including biomass, renewable energy, low temperature geothermal sources, or waste heat from novel sources.

Renewable hydrogen is one possible source of energy for district heating systems and may work well with existing systems due to the ability to produce higher temperatures. However, as with direct hydrogen heating in buildings (Box 4: Heat Pumps vs Hydrogen for heating), the competition for cheap, renewable hydrogen means that the availability of hydrogen for district heating networks will likely be limited.

### District Cooling

District cooling works on similar principles to district heating but is not so widespread in use. District cooling has a substantial advantage over distributed cooling in that it avoids the heat production from AC's that can exacerbate local heat island effects. District cooling can also reduce and balance out peak load for electricity demand and can be more cost-efficient.

Direct cooling relies on an appropriate cold supply resource. Options include natural resources, such as lakes or sea waters, excess cold produced as a by-product of industrial processes, or the use of absorption or mechanical compressor chillers (Werner, 2017b). In some cases, district heating and cooling can be combined in the same complementary system.

### Future role for district heating or cooling

District heating and cooling have similar advantages and challenges when it comes to their future role in thermal comfort of buildings. Both are planned and organised in a co-ordinated manner that can overcome the multi-actor challenge to deliver transformative change at the city scale (Element Four — A multitude of actors).

However, the construction phase can be lengthy and initial infrastructure costs high. New networks are more likely to be viable when established alongside new builds. The high up-front costs mean that viability relies on extensive uptake and a guarantee of connections to the network (UNEP, 2021b).

Governments need to carefully assess whether district heating or cooling makes sense in their jurisdiction. They need to consider the costs, whether there is an appropriate renewable heat or cold source, how it would fit with existing infrastructure, and the time frame for (re)-construction. District heating or cooling should also be considered as part of a broader heating, cooling, and power strategy due to its potential role in energy storage.

The IEA Net Zero Emissions by 2050 Scenario sees a growth of district heating to cover 20% of final energy demand for space heating in 2050. In the near-term, decarbonisation of energy sources for district heating is a priority (IEA, 2021b).

## Lessons Learned

This chapter has focused on the current status and key benefits of heat pumps and energy efficient windows as two effective options to greatly improve buildings' energy efficiency. A key finding is that these technologies are mature and can be rolled out across the vast majority of climatic conditions.

A number of key considerations relating to the future of these technologies are also explored throughout the chapter. Hybrid heat pumps are shown to have the potential to catalyse faster heat pump adoption, while it appears increasingly unlikely that hydrogen will be used extensively for building heating given the various competing use-cases emerging in other sectors and the lack of green hydrogen production capacity. The use of high global warming potential refrigerants is on the decline but must be substituted for safe alternatives as rapidly as possible, in line with the Kigali amendment to the Montreal Protocol.

The following sections outline the key factors that could expedite the necessary uptake of these and other energy efficient technologies.

### The cost barrier is key

Heat pumps and efficient windows, while being mature technologies ready for widespread dissemination and reducing energy consumption and associated costs, remain more expensive than their less efficient alternatives. Finding ways to bridge this gap through financial (dis)incentives is an urgent priority for governments (Element Three – Financing). Lowering power prices is particularly important for encouraging heat pump adoption.

### Climatic variation can be an important factor, but not always

Recent developments in refrigerant technology mean that heat pumps can now be used in cold climates where it was previously not feasible. Estimates show they could supply 90% of the world's heating demand but it is currently just 7%.

Technical requirements for efficient windows also vary across climatic regions, but double-glazed windows with low-emissivity coatings have been shown to provide the most cost-effective energy efficient solution regardless of the climate. Local climatic conditions are, however, the greatest determining factor affecting the adoption of energy efficient windows. They are least utilised in hot climates.

### Supply chains vary significantly with technology

The highly globalised market for heat pumps is dominated by Japanese and Korean companies, with slight regional variation (Absolute Reports, 2021). This renders the establishment of a local industry challenging, likely requiring longstanding and significant government support, as in the case of Sweden. The production and supply of windows is far more localised, implying the barriers to entry for new local market entrants is far lower, likely requiring less government support and intervention.

### Technologies are only one piece in a large and complex buildings decarbonisation puzzle

Without a well thought out approach to expediting the uptake of key technologies, whether through incentivisation, regulation, or both, efforts can be wasted. Examples of this can be seen over the last two decades in the UK. In addition, a holistic whole-of-building approach is necessary to ensure the adoption of heat pumps, a key technology, is possible. Devising means to encourage or mandate building owners to invest in building envelope upgrades before purchasing a heat pump is critical to achieve their maximum potential efficiency gains.

This can be achieved through mandatory energy performance standards (MEPS), novel means of maximising the provision of finance, and ensuring key actors are involved in the development of government measures and targets. The following sections will cover these elements in detail.

# Element Two — Minimum Energy Performance Standards

Minimum energy performance standards (MEPS) regulate the energy-related requirements of specific building components, of individual technologies, or of an entire building, and are the most effective policy instruments to reduce energy demand and emissions of buildings (Urge-Vorsatz *et al.*, 2020). MEPS have also been identified as a good candidate for increasing the frequency and depth of energy retrofits (Hinge and Brocklehurst, 2021). The IEA recommends that building codes mandating the construction of zero-carbon buildings be in place in all countries by 2030 at the latest (IEA, 2021h).

Building energy codes and MEPS are only effective when implemented and enforced. Governments therefore need to develop effective enforcement strategies and implement them. Governments also need to create an enabling environment to facilitate the rollout of ambitious building energy codes over time, such as financial support (see Element Three – Financing) and support to all stakeholders involved in the lifetime of a building (see Element Four — A multitude of actors).

MEPS can reduce a building's emissions intensity for space heating and cooling by mandating the reduction of energy needs through improving the building envelope (**energy sufficiency**), the installation of highly energy efficient space heating and cooling systems (**energy efficiency**) and the installation of on-site **renewable energy** systems.

Components of the building envelope, such as windows or doors, are often part of a MEPS for the entire building, often referred to as a building energy code. Energy intensive technologies, such as heat pumps, gas boilers or air conditioners, are often regulated by a technology-specific MEPS. In Table 1 we provide an overview of these three approaches to decarbonise space heating and cooling, highlight typical MEPS, their measurement unit, and a real-life example. We also highlight an all-encompassing MEPS of a building's space heating and cooling needs.

In this section we assess how to roll out ambitious MEPS at the global scale, in a timely manner, and with high enforcement levels by

1. describing some key components to consider when developing MEPS,
2. reviewing the current state of play of energy regulations in the buildings sector,
3. assessing the MEPS and enforcement strategies of three jurisdictions: China, the US, and New York City, and
4. deriving key lessons learned and recommendations for the way forward.

## Aspects to consider in designing MEPS

### Prescriptive versus performance-based MEPS

Building MEPS can be separated into those following a prescriptive approach and those that are performance-based.

The **prescriptive approach** sets minimum energy performance requirements for each individual component of the building. Components of the building envelope, such as windows, roofs, or walls, need to adhere to certain insulation requirements. Heating or cooling equipment, such as heat pumps or air conditioners, are subject to minimum energy consumption levels. Some building energy codes may also entail certain requirements for minimum shares of on-site energy production from renewable energy technologies in a building's final energy consumption.

The **performance-based approach** is a holistic assessment of a building's energy performance. It can be measured as energy intensity per floor space, emissions intensity per floor space, or a less prevalent metric - energy cost per floor space (IEA & UNDP, 2013; Nadel and Hinge, 2020). Energy intensity metrics put a focus on energy efficiency but may, in and of themselves, be insufficient to support a decarbonisation transition. On the other hand, emissions intensity standards can be dependent on grid emissions intensity factors which are beyond the control of the building owners unless they can install their own renewable energy on-site (Nadel and Hinge, 2020). One possible solution could be to start with energy performance metrics and transition to emissions intensity metrics in the long-term, assuming a rapidly decarbonising power grid.

Prescriptive-based codes are often regarded as a more restrictive approach to regulate building energy use that can leave less flexibility for architects and engineers to innovate and maximise a building's energy savings potential. The performance-based approach is more flexible with regards to the design of a building (IEA & UNDP, 2013).

One option is to combine the two approaches so that a performance-based building energy code also includes some prescriptive requirements for single building components and technologies. Typical prescriptive elements relate to the insulation level of building envelope components, or the energy efficiency levels of space heating and cooling technologies, to avoid cases in which the minimum performance standard is met by extensive on-site renewable energy technologies alone. Possible other prescriptive components include the banning of specific fossil-fuel based technologies (Box 7: Banning new installations of fossil fuel equipment for heating). The Zero Code, an international building energy standard for the construction of zero carbon buildings, includes mandatory on-site generation or procurement of renewable energy (Architecture 2030, 2021). The combined approach allows some flexibility for architects and investors while ensuring that certain standards and approaches are met, which can support market shifts toward more sustainable technologies.

Table 1: Energy related measures to decarbonise space heating and cooling. Source: Authors.

| | Building envelope | Low carbon cooling and heating | On-site energy production | The whole building (all components) |
|---|---|---|---|---|
| **Objective** | **Reduce energy needs**: The building envelope keeps produced heat and cooling within the building, reducing the need for space heating and cooling. | **Reduce energy consumption:** Energy efficient technologies produce space heating and cooling more efficiently, lowering a building's energy consumption. | **Reduce energy demand from the grid:** Integrated renewable energy systems produce energy for on-site consumption and may also feed electricity into the grid. | **New and existing buildings consume as little energy as possible** through a combination of design and technological solutions. |
| **Regulation** | MEPS for building envelope components | MEPS for heating and cooling equipment, e.g. heat pumps. | Requirements to include renewable energy systems in (new) buildings | Mandatory or voluntary building energy codes |
| **Measurement /unit** | Insulation levels are typically calculated in terms of heat loss, expressed in U-values with units of watts per square metre-kelvin ($W/m^2K$). | Energy efficiency levels of space heating /cooling technologies are typically expressed in Energy-Efficiency Ratios (EER). EER is the ratio of cooled or heated air in terms of thermal energy generated per hour (BTU/h) to required electricity (measured in watts). | Regulations may mandate the installation of certain renewable energy systems or mandate that a certain percentage of energy consumed by a building is produced through on-site renewable energy. Energy production is typically measured in kilo-watt hours (kWh). | The overall energy performance of a building is typically measured as consumed energy per floor space per year ($kWh/m^2a$) and/or emitted greenhouse gas emissions per floor space per year ($CO_2/m^2a$). However, building energy codes may include requirements specific to the building envelope, low carbon heating/cooling technologies, and on-site renewable energy production. |
| **Example** | South Korea introduced an MEPS for windows in 2012, allowing U-values of maximum 2.0 and 2.8 $W/m^2K$ for windows in residential and non-residential buildings respectively (Kim, Jeong and Cho, 2019). | The US Energy Star voluntary certification scheme requires an Energy-Efficiency Ratio (EER) of at least 12 for air conditioners (Energy Star, 2021). | Barcelona's Solar Thermal Ordinance from 1998 mandates a 60% share of running hot water from renewables in all new buildings or retrofitted buildings (IRENA, 2021). Spain added this requirement to its national Technical Buildings Code (CTE) in 2006 (Ministry of Housing of Spain, 2006). Since the 2019 CTE, large buildings and buildings with high energy consumption must use on-site renewable energy for water heating needs and for a given share of electricity needs (Ministerio de Fomento, 2019). | The voluntary passive house standard certifies net zero energy buildings by requiring strong energy efficiency of the building envelope (< 15 $kWh/m^2$) combined with low carbon technologies and on-site renewable energy production (Passive House Institute, 2021). |

## Adapting building MEPS to the building's context

Specific energy requirements for building components, technologies, or on-site renewable energy may differ depending on a building's context. Most prominently, MEPS typically need to be adapted to local climatic conditions because these conditions influence a building's energy demand and thermal comfort. Cooling and heating needs directly correlate with differences in temperature and humidity between indoor and outdoor areas (Urge-Vorsatz *et al.*, 2020).

A review of existing zero carbon buildings worldwide finds that space **heating** demand can be as low as 15 kWh/m$^2$ /year in essentially any climate, including for buildings in Antarctica. In contrast, space **cooling** demand of zero carbon buildings in hot and humid climates, such as in parts of the Amazon region or Southeast Asia, currently still requires 80-90 kWh/m$^2$ /year (Urge-Vorsatz *et al.*, 2020).

Despite the implications of different climatic conditions, the voluntary passive house standard applies the same MEPS of 15 kWh/m$^2$ /year for all buildings in all climates. This is because energy sufficiency measures (reducing space cooling needs), such as natural shading or passive radiative cooling, can displace the need of energy efficient space cooling technologies (Raman *et al.*, 2014; Urge-Vorsatz *et al.*, 2020). However, passive cooling measures tend to be in the research and development stage and not yet available at large-scale (Urge-Vorsatz *et al.*, 2020). Singapore, located in a hot and humid climate, has pilot projects to erect and mainstream zero energy buildings (Wong, 2019; BCA, 2021).

It is common that large countries such as the US or China, but also smaller countries, such as Montenegro, differentiate their building energy code by climate zones. In China, space heating in 'cold zones' ranged between 80 and 100 kWh/m$^2$ but 100–130 kWh/m$^2$ in 'severe cold zones' so that China has implemented diverging energy requirements by region (Urge-Vorsatz *et al.*, 2020).

International energy efficiency standards differentiate energy requirements depending on the climatic zone. The ASHRAE Standard 90.1-2019 or the International Energy Conservation Code (IECC) 2021 (Case Study 4: US - A voluntary framework for local mandatory codes), provide a framework code that can be adapted based on certain climatic indicators such as sunlight, humidity or temperature levels (Architecture 2030, 2021).

A building's local environment can also influence its energy needs. For example, trees can bring shading to a building, reducing its cooling needs. A building's orientation towards the sun can both reduce cooling and heating needs for different parts of the given building (UNECE, 2020). The passive house standard has a strong emphasis on such considerations (Passive House Institute, 2015). However, considerations of a building's local environment mainly relate to land use and urban planning policies rather than MEPS (GlobalABC/IEA/UNEP, 2020) (Box 10: Urban Planning).

Finally, whilst evidence shows that space heating and cooling needs can be as low as 15 kWh/m$^2$/year for new buildings, some old buildings may be technically challenging or expensive to retrofit to such levels. In such cases, on-site renewable energy may help to reduce the energy demand from the grid that cannot be displaced through energy sufficiency and efficiency measures alone. Codes developed for existing buildings should push for stringency in reducing energy requirements while realising that there may be limitations and allowing for flexibility in addressing those limitations.

## Enforcement of MEPS

MEPS for entire buildings, as well as for specific building components or technologies, can be enforced before a building or product "enters the market", for instance before a building is occupied or a product is sold, or "during the operation lifetime" of a building, building component, or piece of equipment.

### Before and at market entry

MEPS for the entire building can occur in the planning and construction phase and ensure that new buildings are well designed and insulated, include energy efficient space heating and cooling technologies, and potentially also include requirements to install on-site renewable energy technologies.

In parallel, or as part of, a building energy code policymakers often develop a compliance mechanism before a building 'enters the market' and can be occupied or sold. Such compliance checks can occur at three stages before a building is occupied: before construction works commence, during the construction phase, and the end of the construction phase (IEA & UNDP, 2013):

- During the **planning phase** of a building, a building code official, a government representative, or a third-party reviewer, evaluates the architect's plans including test reports of proposed construction materials and energy demand calculations and related assumptions. The reviewer then chooses to release a construction permit or not.
- In the **construction phase** of a building, the reviewer can perform at least one "random on-site check" to assess whether the buildings is being constructed as planned and chosen materials meet the proposed thermal values. The reviewer should also evaluate potential test reports of changes to the original plans and perform insulation checks.
- At the **end of construction,** the reviewer should perform final checks of insulation performance (e.g. blower-door test), evaluate a building's energy system, and, in the case of prescriptive-based elements in the building energy code, the reviewer should assess whether all components and space heating and cooling technologies meet the minimum energy performance requirements. Depending on the outcome, the reviewer can hand out an occupancy permit, ask for revision in the case of non-compliance, or refuse to release an occupancy permit until said requirements are met.

MEPS need to be coupled with monitoring, reviewing and evaluation mechanisms. Governments, public entities, or third-party reviews need to check compliance with building energy codes to ensure that buildings meet minimum energy performance requirements "on the ground" and not only "on paper" (IEA & UNDP, 2013). Governments need to put in place the sufficient institutional capacities both in public entities as well as through capacity-building of the construction industry, especially when introducing a first building energy code but also with subsequent code updates (see Element Four — A multitude of actors).

In the case of voluntary MEPS, similar steps should be taken to ensure that a "green", "sustainable", or "zero energy" building is not mislabelled. Therefore, certification schemes from third-party reviewers are essential for trustworthy building energy standards, especially when accessing financial incentives or sustainable finance instruments such as green bonds.

MEPS for single building components or technologies typically occur before companies are allowed to place a product onto the market. Technology-specific MEPS also require a monitoring and review mechanism to ensure compliance in reality and not only in the product design and production phase.

Complementary policy instruments to building and technology-specific MEPS are energy efficiency labels to enhance transparency in the market. Energy labels are common and implemented in many countries such as in the EU, Tunisia, or Japan. Moreover, voluntary best in class standards such as the Energy Star label or the Zero Code, a voluntary zero energy building code, also exist (IEA & UNDP, 2013; EPA & U.S. Department of Energy, 2019; Architecture 2030, 2021). Voluntary standards and labelling schemes could shift the market toward the better end of the efficiency range, providing substantial energy and emissions savings on top of mandatory MEPS (UNEP & IEA, 2020).

### During the operational lifetime

Most energy use for space heating and cooling occurs during the operational lifetime of a building or single building component. Therefore, compliance schemes are crucial to ensure that buildings and building components also conform with MEPS in their operational phase and not only at market entry.

Compliance checks during the operational phase can avoid a "performance gap" between the market entry and use of a building or building component. A "performance gap" occurs when the planned, projected or reported energy performance of a building (or technology) differs from the "actual" energy performance in the operation phase of a building. Evidence suggests that the performance gap can range from 10 to 30% and tends to be higher in non-residential buildings where performance gaps of 50 to 250% were identified in individual cases (Urge-Vorsatz *et al.*, 2020).

The performance gap does not mean that reaching low energy and emissions intensity levels is not possible in the operational phase of a building but rather that monitoring and assessment of buildings in their operational phase is needed. For example, many buildings certified by the passive house standard have shown to perform as well in the operational phase as was planned in the design phase. Furthermore, evidence shows that occupants' behaviour has a lower impact on a building's energy performance in buildings with (very) low energy intensity (Urge-Vorsatz *et al.*, 2020).

In Sweden, MEPS compliance checks occur every two years after a building is occupied. The compliance check procedure is established before a building is occupied at which point only an interim occupancy permit is handed out. In case of non-compliance, a building may either not be allowed to be occupied anymore until corrections are made or the building developer may be subject to fines, or both. Moreover, each building requires an energy label (often referred to as an energy performance certification (EPC) based on measured energy consumption (IEA & UNDP, 2013).

MEPS for all existing buildings, not only newly constructed ones, can be used to push for higher retrofitting rates. For example, when space heating or cooling equipment is replaced or when a building retrofit occurs. Existing building MEPS differ in many ways from those for new buildings with regards to the building types covered, the stringency, the timing of application, and the enforcement mechanisms. Analysis of existing policies suggests that it is important to build on existing standards, to consult with local stakeholders in designing the MEPS, and that substantial resources are necessary for education, enforcement, and technical assistance to ensure successful implementation (Nadel and Hinge, 2020).

Identifying and utilising "trigger points" for MEPS to be enforced can help to increase the rate at which existing buildings undergo deep retrofit. Possible trigger points for applying and enforcing standards for existing buildings include a specified point in time, at the signing of a rental contract, or during property sales. In defining the standards to be met and the timing of trigger points, it's important to strike a balance between stimulating a rapid retrofit rate increase while allowing sufficient time for the retrofits to occur at an affordable cost (Nadel and Hinge, 2020). Setting clear, long-term targets with gradually increasing stringency can help to establish certainty and encourage renovators to go for more stringent energy performance standards where feasible (Sunderland and Jahn, 2021).

## State of play

### New buildings

In 2020, just over 80 countries, roughly 40% of all countries, regulated energy-related aspects of new buildings[1] (GlobalABC/IEA/UNEP, 2020; UNEP, 2021a). However, we find that building MEPS cover more than 60% of the global population (see IEA, 2021i; World Bank, 2021).

Developed countries first implemented building energy codes decades ago but most developing countries do not (yet) have mandatory building energy codes in place (IEA, 2021i). Furthermore, the stringency of codes in place varies and many currently implemented MEPS need to be revisited in order to achieve the energy efficiency levels required to meet the 1.5°C Paris Agreement temperature limit (GlobalABC/IEA/UNEP, 2020; UNEP, 2021a).

Several governments have recently developed and implemented updated MEPS ensuring that new buildings are zero carbon or are in the midst of developing such standards. For example, the State of California has released the 2022 Zero Code for all buildings except low-rise residential buildings (Eley *et al.*, 2020). The EU stipulated that as of 2021 all new buildings should be constructed as "nearly zero-energy buildings" (Directive (EU) 2018/844) (The European Parliament and the Council of the European Union, 2018). These requirements have been in force for new public buildings in the EU since 2019. However, the roll-out schedule and ambition level of EU Member States' national building energy codes

1 A map of building energy codes can be found in the 2021 Global Status Report for Buildings and Construction on page 21 (UNEP, 2021a).

is unclear. Spain, for example, postponed the entry into force of its updated building energy code to January 2022 due to the COVID-19 pandemic (Epp, 2020).

Increasingly, countries integrate minimum energy requirements for on-site renewable energy and/or the procurement of renewable energy into their building codes and standards. The most common on-site renewable energy technologies for buildings are rooftop solar thermal or solar photovoltaic (PV) panels and countries benefitting from above-average sunny days, such as Israel or Spain, integrated on-site solar energy technology requirements early on. However, recent codes from several countries with much lower sunlight levels have also introduced minimum energy production requirement from renewable energy. For example, Norway's building energy code stipulates that all buildings should meet at least 40% of energy demand through on-site (renewable) energy[2] and Germany aims that all new buildings have rooftop solar systems installed (UNECE, 2020; Appunn, 2022).

### Role of voluntary standards and certification schemes in pushing the envelope

Despite the lack of building energy codes, there are many net-zero, nearly-zero energy, and certified passive house buildings all over the world across climate and geographic regions. The majority of those buildings are in Europe, followed by the US, Canada, New Zealand, South Korea, Japan, China, and India (Urge-Vorsatz *et al.*, 2020). In some low- and middle-income countries that lack or have outdated building codes, voluntary MEPS have been used to certify more energy efficient buildings. In fact, 2020 has seen continued growth in the number of "green " and "sustainable" building certifications (UNEP, 2021a).

Voluntary MEPS and certification schemes can help to drive more ambition in energy sufficiency, energy efficiency, and on-site renewable energy measures in buildings and may increase the acceptance of more stringent building energy codes, build capacities and knowledge amongst building owners, occupants, construction companies, public entities and/or financial institutions. For example, some provinces in China introduced voluntary building standards which have led to thousands of buildings built with higher insulation and efficiency standards than the minimum energy performance standard in place (see Case Study 3: China - A coordinated top-down policy package and a comprehensive enforcement strategy).

## Existing buildings

MEPS are applied to existing buildings in several countries, and are becoming more common, but still have a much lower coverage than for new buildings. The need for existing buildings to comply with an MEPS is usually triggered during retrofit work or when equipment is replaced. The precise thresholds for when an energy code applies differs between countries and regions but is often tied to the extent of the retrofit in terms of volume or share of floor area (Hinge and Brocklehurst, 2021).

The EU Renovation Wave includes mandatory MEPS for buildings as a key component of a strategy to ramp up retrofit rates and they are likely to feature in many of the renovation strategies that EU member states are expected to prepare (Box 6: EU Energy Performance Buildings Directive for existing buildings). MEPS for existing buildings are already in place in France, the Netherlands, and the UK where energy performance certificates are used to identify and ensure upgrades of the worst-performing buildings by a given date (Hinge and Brocklehurst, 2021). MEPS can also be enacted at the city level, as is already the case in Tokyo, New York City, and Washington DC, among others (Nadel and Hinge, 2020).

However, extensive retrofitting of the building stock does not yet occur at a sufficient pace to achieve the energy performance improvements needed (Boehm *et al.*, 2021).

[2] Large buildings with more than 500m$^2$ floor space should meet at least 60% of energy requirements through on-site renewable energy.

## Box 6: EU Energy Performance Buildings Directive for existing buildings

In December 2021, the EU Commission released new recommendations for EU member states to align the buildings sector with the European Green Deal and achieve a zero-emission building stock by 2050 as part of the "Fit-for-55" package (European Commission, 2021b, 2021a). The recommendations are based on the perceived needs to eliminate direct emissions from buildings by 2040 and to prioritise retrofits to achieve that.

Key features of the recommendations include:

- As of 2030, all new buildings must be zero-emission, that is no on-site emissions. The same restriction applies to public buildings three years earlier, in 2027.
- The worst-performing 15% of building stock is to be upgraded from Energy Performance Certificate class G to at least class F by 2027 (non-residential) or 2030 (residential).
- Energy Performance certificates are to become more transparent, harmonised, and comprehensive, and required for a broader set of buildings.
- Building renovation plans developed by member states will need to include roadmaps for phasing out fossil fuels in heating and cooling by 2040 at the latest.
- Member states will have a legal option to ban fossil fuel use in buildings.

The requirements will be backed up by additional funding being made available, particularly to lower income housing.

The Commission's recommendations include many of the strategies identified in this report. The approach sets out clear goals and uses building codes and standards to outline a path toward that goal. Support will also be provided to ensure the necessary enabling environment.

The recommendations also include some signals that upgrade requirements will continue in the coming decades; Class E needs to be attained by 2033 and "higher energy performance classes" by 2040 and 2050.

Ideally, retrofits are deep retrofits and buildings should leap-frog to higher energy classes rather than stepping through the energy classes over an extended time-period. Single, deep retrofits have higher up-front costs but are more cost-efficient and less disruptive in the long term. National roadmaps could incentivise deep retrofits to further strengthen the directive.

## Individual building components or technology-specific standards

The energy efficiency of space heating and cooling equipment can vary substantially. Across multiple countries, the market average sits toward the lower end of the typically available efficiencies, and the "best available" is generally two to three times more efficient (UNEP & IEA, 2020). For example, energy efficient air conditioners have the potential to reduce energy demand from space cooling by half (IEA, 2021a). While energy efficient ventilation should largely be incorporated in the construction of and retrofitting to zero carbon buildings, they are still largely purchased separately and often consume more energy than the best available technology standard. In the short to medium term, and especially because best available technologies exist at comparable prices, it is important to install energy efficient cooling systems.

To regulate energy and emissions intensity of energy intensive space heating and cooling technologies many countries release technology-specific MEPS. For instance, more than 80 countries have MEPS for air conditioners and at least 20 more are currently developing one (UNECE, 2020; IEA, 2021a). In climate where both heating and cooling are needed air conditioners should allow to both cool and heat a building, as proposed in Vancouver (City of Vancouver, 2022). However, thus far the stringency of existing MEPS is doubtful and several countries in hot and humid zones have no MEPS for air conditioners (IEA, 2021a). Further, many countries have compliance checks in place for boilers and/or air conditioners; however, the level of data from these checks is very low so that the effectiveness of these schemes is unclear (UNECE, 2020).

## Box 7: Banning new installations of fossil fuel equipment for heating

One regulatory option for steering space heating towards climate-friendly options is a direct ban on the installation of new equipment that relies on fossil fuels, including new gas grid connections, and new gas or oil burners. The IEA suggests no new sales of coal or oil boilers as of 2025, globally, to meet their 1.5°C compatible scenario and that any gas boilers sold after 2025 should be capable of burning 100% hydrogen (IEA, 2021h).

Multiple states and cities in the US have revised, or have announced their intention to revise, buildings codes to eliminate fossil fuels for heating. California, Seattle, and Missouri use the route of establishing limits on the intensity of energy use that will require a switch from gas to efficient electric alternatives. In December 2021, New York City announced an outright ban on natural gas in newly-constructed buildings, coming into effect from 2027 for buildings with seven stories or more and 2023 for any other building (New York City Council, 2021). San Jose and San Francisco are considering similar regulations (Shivaram, 2021). Other States have established action plans that would also require the elimination of fossil fuels from heating energy, if implemented (Gruenwald and Lee, 2020).

However, these efforts have not gone without resistance and other states are pre-emptively enacting legislation to prevent such a ban being put in place. As of September 2021, twenty states have pre-emption bills that have been enacted into law or were awaiting final signature, and four more states introduced bills during 2021 (Cunningham and Narita, 2021).

Fossil fuel equipment phase-out regulations are emerging in other countries too. For example, in 2018, the Netherlands amended its Gas Act so that new builds can no longer be connected to the gas grid, with some exceptions for public buildings of general interest (Ministry of Economic Affairs and Climate, 2018).

France's new building energy code (Réglementation Environnementale 2020 – RE2020) will limit the emissions intensity of space heating and cooling systems to an extent that fossil-based technologies will not be able to meet. The intention being to ban gas and oil boilers. As of 2022, single detached houses need to comply with the 4 $kgCO_2$/m2/year limit and multi-family housing with 14 $kgCO_2$/m2/year (allowing for gas boilers only in very efficient buildings) and 6.5 $kgCO_2$/m2/year by 2025 (Ministry of Ecological Transition, 2021).

Ireland – In its 2019 Climate Action Plan, the Irish government outlines the phase out of fossil fuel heating, with oil burners in new buildings banned from 2022 and gas boilers from 2025 (Government of Ireland, 2019).

In its 2021 Heat and Building Strategy, the UK government outlines plans to ban gas connections in new buildings from 2025, phase out new oil burners from 2026, and ban installation of new gas boilers in existing buildings from 2035 (UK Government, 2021a).

Such regulations are important to ensuring the decarbonisation of building energy supply and a necessary addition to the energy efficiency improvements stipulated by most building codes. Bans announced with sufficient lead time also send strong signals that allow industries to adjust and prepare for new technologies.

## Case studies

We explore the implementation of MEPS in three jurisdictions. First, we explore MEPS and related policies in China, the largest market of new buildings and air conditioners. Second, we review the US building energy code as that can be adapted to various climate zones. Third, we assess the MEPS and related policies of the City of New York to decarbonise existing buildings. For each case study, we highlight good practice aspects as well as weaknesses.

| Consideration | Guiding question |
| --- | --- |
| **Key components of the building energy code** | ▸ What is the scope of the building energy code(s)?<br>▸ What is the ambition level of the building energy code(s)?<br>▸ What is the enforcement strategy of the building energy code(s)?<br>▸ Do(es) the code(s) apply to existing buildings or is there an equivalent code, and how does it work? |
| **Mitigation potential / impact** | ▸ What is the emissions mitigation potential and impact of the policies? |
| **Replicability / Scalability** | How easy is the action to replicate in other conditions, such as climate or governance context, and to scale up? |
| **Equity considerations** | In a transition to net zero emissions buildings, it is important to also reduce global and national social inequalities. How were equity considerations included (or not) in the case study? |

## Case Study 3: China - A coordinated top-down policy package and a comprehensive enforcement strategy

China has a comprehensive policy package to increase energy efficiency of new and existing buildings. The policy package consists of energy conservation targets set in a top-down approach, minimum energy performance regulations, voluntary building energy standards for "green" buildings, incentives for the installation of renewable energy systems in buildings, a governance mechanism to monitor and evaluate energy performance of buildings, and policy targets and incentives to increase the rate of energy retrofits of existing buildings.

### Key components of the building energy code

#### Building energy codes, standards, MEPS and renewable energy policies

China's State Council releases development plans with policy targets every five years. The Five-Year Plans entail overarching national energy conservation targets, which are broken down into sectoral targets. For example, China's 13th Five-Year Plan stipulates that mandatory commercial and residential building codes should aim for a 65% higher efficiency level compared to the 1980 baseline and 75% for cold climates (Zhou et al., 2020). The Ministry of Housing and Urban-Rural Development (MOHURD) translates these Five-Year Plans into sectoral plans for the buildings sector and local governments translate them into local policy goals and regulations (Yuan *et al.*, 2017; Feng *et al.*, 2019; Shen and Faure, 2021).

Table 2: Overview of building energy codes in China.

| Building type | Climatic zone(s) | Code | Authority |
|---|---|---|---|
| **Commercial and public buildings** | All | *GB 50189 – 2015:*<br>Design standard for energy efficiency of public buildings | MOHURD |
| **Residential buildings** | Hot summer and warm winter zone | *JGJ 75 – 2012:*<br>Design standard for energy efficiency of residential buildings in hot summer and warm winter zone | General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ), MOHRUD |
| **Residential buildings** | Moderate climate | *JGJ 475 – 2019:*<br>Standard for design of energy efficiency of residential buildings in moderate climate zone | MOHURD |
| **Residential buildings** | Hot summer and cold winter zone | *JGJ 134 – 2010:*<br>Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone | MOHRUD |
| **Residential buildings** | Severe cold and cold zones | *JGJ 26 – 2018:*<br>Design standard for energy efficiency of residential buildings in severe cold and cold zones. | MOHURD |

At the national level, China differentiates building energy requirements by commercial and public buildings (referred to as public buildings) and residential buildings. MOHURD last updated the national mandatory building energy code (GB 50189) in 2015. It is applicable to all commercial and public buildings in China. In comparison residential buildings are differentiated by at least four climatic zones and regulated by 'industrial' or 'professional' standards (JGJ) (see Table 2). These codes are also mandatory but would be superseded by a national code (GB) (Yu *et al.*, 2019).

China has had mandatory minimum energy performance standards for new buildings in place for decades. These codes strongly focus on energy sufficiency measures, such as building design and insulation levels, but also include energy efficiency requirements for heating systems, such as coal, oil or gas-fired boilers (Yu *et al.*, 2019). China promoted energy efficiency in commercial and public buildings with the "Civil Building Energy-Saving Design Standard, (JGJ26-95)" released in 1995. In 2005, MOHURD strengthened the code to a national mandatory code and raised the minimum energy performance standard to halve buildings' annual energy use (Design Standard for Energy Conservation of Public Buildings GB 50189-2005) (Yuan *et al.*, 2017). The latest update to this code took effect in 2016 and aims to reduce energy use further. It includes a clause on the installation of renewable energy and is also applicable to the renovation of public buildings (Design Standards for Energy Efficiency in Public Buildings GB50189-2015) (MOHURD, 2022).

China's building energy code for residential buildings in severe cold and cold zones (JGJ 26 – 2018) has been updated several times in the past. The 2010 version (JGJ 26 – 2010) was at a similar stringency level to the international code ASHRAE 90.1-2010 (Yu *et al.*, 2019). The residential codes in other climates have undergone far fewer updates and are less stringent.

China also has national MEPS for heating and cooling technologies such as the "Minimum allowable values of the energy efficiency and energy efficiency grades for room air conditioners" (GB 21455-2019) reported and implemented by the National Technical Committee (SAC) on Energy Fundamentals and Management Standardization (TC20) (IEA, 2020c). It came into force in 2020 and is much more ambitious than the previous MEPS of 2010 and 2013 (IEA, 2020c).

China has several policies to support the uptake of on-site renewable energy in buildings. The Implementation Opinions on Accelerating the Application of Solar Photovoltaic Buildings released in 2009 first specifically aimed to promote on-site renewable energy. MOHURD's 13th Five-Year Plan for Building Energy Efficiency and Green Building Development specifically aimed to increase the share of renewable energy in total energy use in urban buildings from 4% in 2017 to 6% in 2020 (Zhou *et al.*, 2020).

China's strategy to pull the buildings sector towards zero carbon buildings entails the introduction and implementation of voluntary "near zero energy building" standards. For example, MOHURD formulated the policy goal that half of all new urban buildings would be certified as "green buildings", as part of the 13th FYP for Building Energy Conservation and Green Building Development (Feng *et al.*, 2019; Shen and Faure, 2021).

The voluntary Near Zero Energy Building Energy Efficiency Standard (GB/T 51350-2019) provides design requirements and performance targets for buildings to achieve nearly zero energy performance as well as a technical performance index and an evaluation system (IEA, 2019c; Zhou *et al.*, 2020). The alternative voluntary standard for "green buildings" (Assessment standard for green buildings, GB/T 50378 - 2019) has more lenient energy conservation requirements (IEA, 2019a). It was first released in 2006, updated in 2016 and 2019 (Zhang, Wu and Fang, 2020).

To increase the share of near zero energy buildings, the national government supports pilot / demonstration projects in cities and/or regions (Feng *et al.*, 2019). For example, Beijing's "Action Plan for Promoting the Development of Ultra-Low Energy Buildings" aimed to build 300,000 $m^2$ of "green buildings" between 2016 and 2018 (Shicong, Yijun and Wei, 2021). By the end of 2017, nine "ultra-low energy consumption" demonstration projects with a total floor area of 100,000 $m^2$ existed in the city (Feng *et al.*, 2019). Cities with such demonstration projects as found in Beijing or Shanghai have become a hub for the rollout of buildings with lower energy intensity levels (S. Zhang *et al.*, 2021; Yiting, 2021).

### Enforcement strategy

At the highest level, the Ministry of Housing and Urban-Rural Development (MOHURD) formulates and develops energy related policies and plans for the buildings sector and supervises their implementation (Yuan *et al.*, 2017). Local construction bureaus under MOHURD perform evaluation and checks on construction sites. For example, the Standard for Acceptance of Energy Conservation Building Construction (GB 50411-2007) entails detailed energy efficiency requirements as well as field inspection standards and quality control, evaluation and acceptance of building energy-saving performance (Yuan *et al.*, 2017). This means that a public official assesses the compliance of a new building and essentially hands out a construction permit.

The National Energy Conservation Center, an entity hosted by the National Development and Reform Commission (NDRC), is responsible for, among other tasks, energy auditing of public buildings – it therefore supervises buildings' energy conservation (Yuan *et al.*, 2017). This suggests that China's public buildings are subject to energy audits on a regular basis and in the operational phase of a building.

The National Government Offices Administration is specifically responsible for the management and supervision of public buildings, including the oversight of their energy consumption (Yuan *et al.*, 2017).

**Application to existing buildings**

MOHURD developed the JGJ 176-2009 "Technical code for the retrofitting of public building on energy efficiency" in 2009 for non-residential buildings. More recently, the ministry's 13th Five- Year Plan for Building Energy Conservation and Green Building states that China would retrofit 0.6 billion $m^2$ of existing buildings during 2017-2021, equivalent to an annual retrofitting rate of around 0.2% (S. C. Zhang *et al.*, 2021).

## Mitigation potential and impact

Residential, commercial, and public buildings in China consumed 18.5 million terajoule in 2019 (IEA, 2020f). This represents 21% of China's total final energy consumption and a 32% increase in ten years (IEA, 2020f). The main sources of energy in China's buildings sector are electricity (30%), which mainly relies on coal (65%), biofuels and waste (18%), followed by natural gas, oil products and coal products, each with just over 10% (IEA, 2020f). Building energy codes could significantly reduce energy consumption from buildings and avoid direct and indirect emissions from the combustion of fossil fuels.

The average energy intensity of China's buildings has stagnated since 2008 at around 80 $kWh/m^2$ (Climate Action Tracker, 2021). China's building energy codes at the regional level and MEPS at the national level have room for improvement with regards to the ambition level. Positive signs of more stringent regulations can be observed. First, China has put in place a stringent MEPS for air conditioners with significant emission mitigation potential because the Chinese AC market accounts for 40% of the global market (IEA, 2021a). Second, China has shown a good track record of enforcing minimum energy requirements so that the rollout of building energy codes and zero carbon building standards at the provincial level could reduce the sector's energy and emission intensity. Third, China's various building energy standards and enabling policies have led to significant roll-out of nearly zero-energy buildings (Urge-Vorsatz *et al.*, 2020).

On the other hand, not all new buildings in China are zero carbon buildings and whilst it is encouraging to see that China has energy requirements for existing buildings as well as retrofit targets in place, a retrofit rate of 0.2% will not be sufficient to meet the Paris Agreement targets (Climate Action Tracker, 2020).

## Replicability / scalability

- Climate: China is a large country with diverse climatic conditions including cold and warm climate zones, both of which are covered by the building energy codes.
- Governance: China's governance system is unique and not directly applicable to other countries. Nevertheless, the development of a comprehensive policy package for and around the building energy code, as well as its implementation strategies at different levels of governance can inspire building energy code strategies in other countries.
- Building type: Building energy codes exist for residential, commercial and public buildings.
- Track record:
  - Policies to enhance energy efficiency of buildings were prioritised in 1986 and have further developed since, reflecting a rather consistent track record of China's building energy codes and related policies. For example, provincial and city-level policies are further being adopted (Green Building Academy, 2021).
  - The monitoring and evaluation schemes that China put in place both for mandatory and voluntary building energy requirements seem to have led to a successful track record of decreasing energy intensity of "standard" buildings and increased the number of certified buildings. For example, the number of certified green buildings exponentially increased from 40 million square meters (253 buildings) in 2011 to 800 million square meters (10 927 buildings) in 2017 (Zhang, Wu and Fang, 2020). As a reference point, in 2017, Beijing had roughly 1 000 million $m^2$ of total floor space (Feng *et al.*, 2019). Moreover, green buildings certification is a key criterion to access financing through green bonds: the 2021 Green Bonds Endorsed Projects Catalogue, a taxonomy of sustainable investments, includes certified "green" buildings.

## Good practice aspects

- Enforcement strategy: The Chinese central government's growing emphasis on code enforcement and compliance has driven energy efficiency improvements (GBPN, 2018)
- Voluntary standards beyond ambition of national regulation (green certification) in relation to meeting corporate social responsibility (CSR) standards and access to green bond financing

## Weaknesses

- The mandatory building energy code could be more stringent – currently the near zero energy building standard is not mandatory so not all new buildings are highly energy efficient
- Current retrofitting rates and retrofitting targets are too low

## Case Study 4: US - A voluntary framework for local mandatory codes

In contrast to China's top-down building energy policies, different jurisdictions in the US adopt and develop their own codes and regulations (Hu and Qiu, 2019). Most jurisdictions use the International Energy Conservation Code (IECC) developed at the national level (Department of Energy's Building Technologies Office, 2021). The IECC and technology specific MEPS are more stringent in the US than in China but final energy consumption by square metre is higher by close to 50 kWh/m2 on average in 2017 (this is also accounting for electricity consumption from electronic appliances other than space heating and cooling) (Hu and Qiu, 2019; Climate Action Tracker, 2021).

## Key components of the building energy code

### Building energy codes, standards, MEPS and renewable energy policies

The US does not have a national mandatory building energy code but most individual States do (IEA, 2021i; UNEP, 2021a). The voluntary standard at the national level is the IECC. The IECC acts as a template building energy code that can be adapted and applied by provincial and local authorities to determine building codes characteristics depending on the climatic zone of the jurisdiction such as temperature, humidity or sunlight levels for residential and commercial buildings (ICC Digital Codes, 2015, 2021). The majority of States based their mandatory building energy code on the 2009 edition of the IECC (Figure 14), however, the IECC is updated every three years so that several new versions are available (Office of Energy Efficiency and Renewable Energy, 2022).

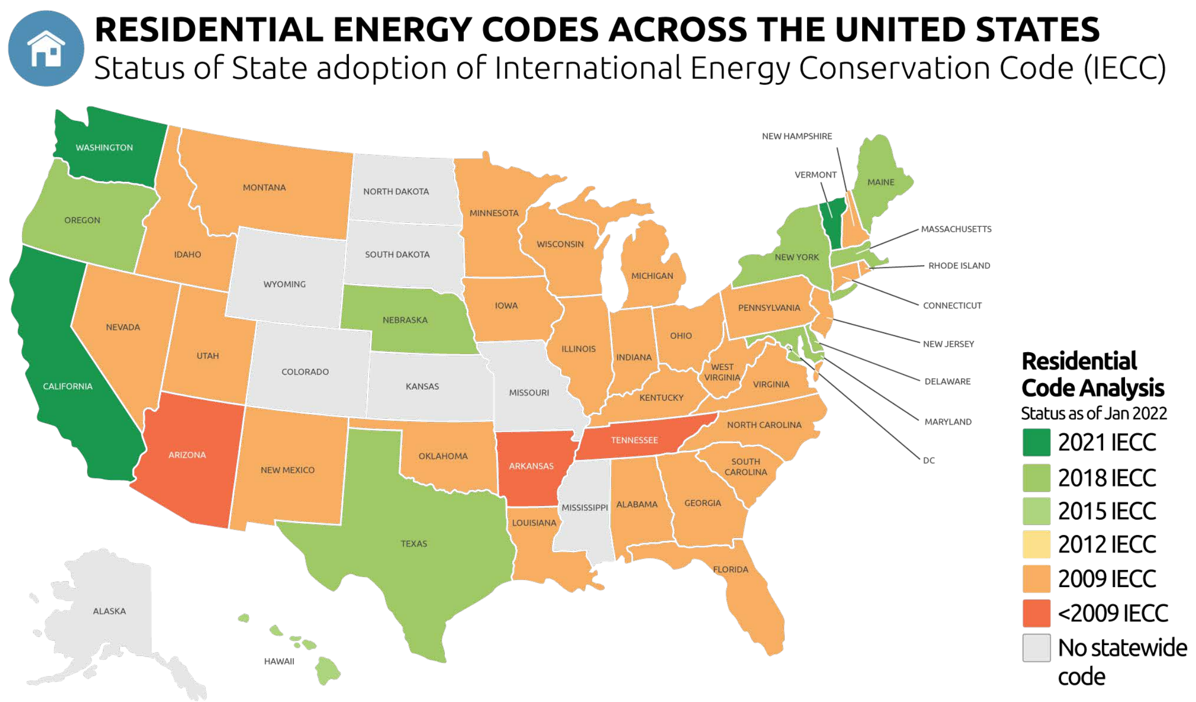


Figure 14: Status of State Energy Code Adoption by State in the US residential buildings sector.

*Source: (Office of Energy Efficiency and Renewable Energy, 2022)*

The 2021 edition of the IECC includes a specific section on net zero buildings for residential buildings (RC102). It stipulates those new residential buildings can only reach the status of a net zero energy building (an energy rating index (ERI) score of "0") by integrating on-site renewable energy technologies (ICC Digital Codes, 2021). Without on-site renewable energy, a building can only reach an ERI score of 40 – whereby 100 is the equivalent of the 2006 IECC requirements. All new commercial buildings need to source energy from renewable energy, either on-site or through energy procurement, to comply with the 2021 IECC (ICC Digital Codes, 2021).

While there is no mandatory overarching building energy code, the Federal Government releases a "Code of Federal Regulations" on an annual basis which includes minimum energy standards for space heating and cooling technologies (Regulation 10 CFR § 430.32 - "Energy and water conservation standards and their compliance dates") (Office of the Federal Register; National Archives and Records Administration, 2021). The regulation already entails a planned update of current energy efficiency requirements for air conditioners and heat pumps that will be applicable as of January 2023.

### Enforcement strategy

States and cities can choose to enforce the IECC in their jurisdictions. Builders adhere to the code in the construction or retrofit process, and can choose between three compliance approaches:

1. the prescriptive approach, in which the values of different building components are evaluated,
2. the performance approach, in which a building total final energy consumption is evaluated, or
3. the Energy Rating Index (ERI) approach. Compliance with the latter is measured on an energy efficiency scale between 0 to 100 where 0 is equivalent to a net-zero energy home and 100 is equivalent to a home compliant with the 2006 IECC.

A public "code official" verifies the first two approaches while a certified third-party "energy professional" can certify the ERI approach (CBEI, 2015; Baulding, 2016). The code official evaluates the construction plans and construction companies can only start the project upon approval of the plans

In the 2018 IECC and earlier versions, a code official needed to "approve" a building before it could be occupied. The 2021 IECC includes more lenient language "permitting" code officials to approve a building's third-party review with no more requirement for such an approval before a building is occupied (ICC Digital Codes, 2021). This shift in the enforcement process suggest that the International Energy Conservation Code is now a standard, which is not evaluated by a public entity before a building can be occupied.

**Application to existing buildings**

Since the 2015 version of the IECC, the code includes a chapter on existing buildings both for residential and commercial buildings. Residential and commercial buildings need to comply with the IECC when a retrofit occurs or at a change of occupancy type, such as from commercial to residential. A change of occupancy is defined as space undergoing a change that would result in an increase of energy demand for fossil fuels or electricity, or a reconversion of a building to a residential floor space. Prescriptive components are the same as requirements for new buildings but the performance based criteria allows for 10% higher energy consumption than new buildings (ICC Digital Codes, 2021). See the case study below on how New York City applied the 2018 IECC for existing buildings for more information.

## Mitigation potential and impact

Residential, commercial, and public buildings in the US consumed 20.4 million Terajoules in 2019, a figure that is more or less stagnant in the last two decades and represents 23% of the country's total final energy consumption (IEA, 2020f). Buildings energy use majorly relies on natural gas and coal either as direct energy use (41% and 5% respectively) or as indirect energy through the electricity grid, which also largely stems from natural gas (38%) and coal (24%) (IEA, 2020f). Buildings' energy demand was responsible for 21% of national GHG emissions in 2019 (EPA, 2021c).

The US has developed stringent building energy codes at the national level. Because the IECC is updated every three years it has gradually increased the stringency of energy requirements. Whilst the code is very ambitious on paper and would most likely bring the buildings sector on a path towards zero emissions both for new and existing buildings, building energy codes are of voluntary nature and many states have not enforced a building energy code or still have outdated versions in place. Among other factors such as occupancy behaviour, lacking and outdated building energy codes have barely reduced the energy intensity of the country's buildings at around 130 $kWh/m^2$ in 2017 Climate Action Tracker, 2021a This value is higher than energy intensity in China for example, despite the fact that China has less stringent energy requirements "on paper". Occupant behaviour is largely not evaluated. The 2021 IECC standard includes several prescriptions to rely on control functions for shading, temperature control, air fans and lighting depending on the use of the buildings, e.g. when a room is unoccupied (ICC Digital Codes, 2021).

## Replicability / scalability

- **Climate:** The US includes several diverging climatic zones with varying humidity, temperature and sunlight levels. Both the IECC and mandatory MEPS for space heating and cooling are replicable to a wide range of climatic conditions. The IECC provides "template" values to define the proper climatic zone, based on climatic characteristics such as humidity or temperature that are essential to determine building energy code characteristics. The user can thus easily derive the proper climate zone category based on key climate characteristics and derive recommended building code requirements.
- **Governance:** In the US, building energy codes have a bottom-up governance approach in which states and cities can adapt the national framework voluntary standard into a local mandatory building energy code. This governance approach is particularly relevant for large and federal countries, such as India. However, the voluntary nature of the IECC has led to the fact that eight States have no mandatory building energy code (Department of Energy's Building Technologies Office, 2021).
- **Building type:** The IECC covers residential and commercial buildings.
- **Track record**: The International Code Council (ICC) first developed energy conservation codes for new buildings in the 1970s (ICC Digital Codes, 2020). As of January 2021, eight States still have no mandatory code in place for any type of building. For commercial buildings, 17 States still enforce the IECC 2007 or an older version of the code (U.S. Department of Energy, 2022). Building energy codes for residential buildings are even less stringent than commercial buildings: most states enforce old IECC versions so that only eleven States enforce the more recent (and stringent) 2015 or 2018 IECC (U.S. Department of Energy, 2022). The 2021 IECC represents a larger leap in ambition level than previous IECC updates; however, with most states enforcing "outdated" versions of the IECC energy consumption from the buildings sector remains high.

## Equity considerations

As in other countries, energy efficient new buildings and energy retrofits can lead to more expensive housing, so that first time buyers and low-income households may not be able to afford to buy or rent a low-energy home. At the same time, energy bills disproportionally affect low-income households. Energy intensity and energy expenditure by square metre is higher in low-income households (earning less than USD 20,000) at 13.1 Btu/$m^2$ in 2015 at an average cost of USD 0.33/$m^2$ than the national average at 11.7 Btu/$m^2$ at an average cost of USD 0.28/$m^2$. High-earning households (more than USD 60,000 per year) benefitted from a lower energy intensity than the national average; however, due to larger homes a high-earning household consumed 4 to 44% more energy than the national average (EIA, 2018).

## Good practice aspects

- The 2021 IECC is ambitious and includes existing buildings
- The code is revised every three years to reflect latest developments
- The building energy code developed at the federal level can be adapted and applied to many jurisdictions – States and cities can make use of it but also other countries, such as Canada or Mexico, have used the IECC. Moreover, the IECC is also the basis of the international net zero building standard ASHRAE

## Weaknesses

- The IECC is voluntary and not applied in all States
- The IECC is a non-governmental entity that has been influenced by lobbies from the construction sector and the code update process disfavours stakeholders with limited resources. First, the 2021 IECC development included more building industry stakeholders and fewer local government representatives that blocked more stringent energy requirements[3] (Flavelle, 2019; Bresette, 2020). Second, the 2021 IECC was downgraded to a "standard" so that that it may not be mandatory when applied by governments (NBI, 2021).
- The 2021 IECC for commercial buildings calculates a building's energy performance based on a building's energy cost rather than energy consumption so that unpredictable energy costs and cheap subsidised fossil fuels can negatively affect the ambition level of the code (ICC Digital Codes, 2021).

[3] The National Association of Homebuilders (NAHB), the Leading Builders of America (LBA), the American Gas Association (AGA), the American Public Gas Association (APGA), and the Air Conditioning, Heating, and Refrigeration Institute are building industry stakeholders that have actively weakened the climate ambition of the 2021 IECC by rejecting 1) that new residential and commercial buildings need to accommodate electric vehicle chargers, 2) that new residential buildings rely on fully electric technologies, and 3) higher efficiency standards for gas furnaces and water heaters (Bresette, 2020).

## Case Study 5: New York - Building energy code for existing buildings

Enforcement of building energy code occurs at the State and city-level in the US. We describe the building energy code and its enforcement strategy for existing buildings in New York City (NYC). NYC enforced the 2018 IECC and complemented it with local laws to create a long-term decarbonisation strategy, establish a dedicated department for planning monitoring and enforcement rules.

### Key components of the building energy code

#### Building energy codes, standards, MEPS and renewable energy policies

The NYC council based the 2020 New York City Energy Conservation Code (hereafter 2020 NYC Code) on the 2018 version of the International Energy Conservation Code (IECC) (ICC Digital Codes, 2020). Since the 2015 version of the IECC, chapter 5 of the code specifically addresses energy conservation of existing buildings (ICC Digital Codes, 2015). NYC has largely implemented the IECC standard with slight amendments to exclude historical buildings from the 2020 NYC Code (ICC Digital Codes, 2020). This means that all existing buildings undergoing an "alteration, repair, addition and change of occupancy[4]" shall comply with the 2020 NYC Code. Buildings need to conform with prescriptive requirements of the code or consume at most 10% more energy than the performance requirement of new buildings, whereby the performance-based approach is applicable at a change of occupancy or use of a building (ICC Digital Codes, 2020).

NYC's Local Law 97 of 2019 introduces a building performance standard which imposes GHG emissions caps for the city's buildings. The requirements change become more stringent over time and are differentiated between ten building types dependent on the use / occupancy of a given building. The standard first sets emissions intensity restrictions <u>per unit of energy</u> consumed between 2024 and 2029. After 2029, buildings receive an emissions intensity cap <u>by square foot of floor space</u>[5]. Although subject to future revisions, the law already defines a benchmark for the period after 2030 at 0.0014 $tCO_2e$ per square foot per year (New York City Government, 2019).

Moreover, in December 2021, New York City announced an outright ban on natural gas in newly constructed buildings, coming into effect from 2027 for buildings with seven stories and 2023 for any other buildings (New York City Council, 2021) (see Box 7: Banning new installations of fossil fuel equipment for heating).

#### Enforcement strategy

The same enforcement rules apply for the 2020 New York City Energy Conservation Code as in the 2018 IECC.NYC enforced a set of complementary laws to ensure compliance. Most prominently Local Law 95 of 2019 mandates the public disclosure of the Building Energy Efficiency Rating of buildings with more than 2,300 $m^2$ and Local Law 97 of 2019 introduced an "Office of building energy and emissions performance" to implement laws, monitor energy use of buildings, enforce building energy policies, review annual energy reports submitted by building owners and draft penalties for non-compliance (Government, 2019; New York City Government, 2019). The Local Law No. 97 also mandates building owners to prepare annual energy efficiency, energy use and GHG emissions reports once a year (New York City Government, 2019).

More recently, the city of New York released the Local Law 126 of 2021 Construction Codes Revision Bill, which will come into force as of November 2022 (New York City Goverment, 2021). It provides the emissions caps per square meter along the same 10 building occupancy types and stipulates that the annual energy and GHG emissions report shall be "certified by a registered design professional" and submitted as of May 2025. In case of non-compliance in 2025, a building owner has up to one year

4 Change of occupancy is defined as space undergoing a change that would result in an increase of energy demand for fossil fuels or electricity or a reconversion of a building to a residential floor space (ICC Digital Codes, 2020).

5 "For calendar years 2024 through 2029, a deduction shall be authorized for up to 10 percent of the annual building emissions limit" (New York City Government, 2019).

to reach the emissions cap provided it shares a plan on how the cap will be reached. Afterwards, building owners will be subject to financial penalties calculated by multiplying the "difference between the building emissions limit [...] and the reported building emissions", measured in ton of $CO_2$ of a given year, multiplied by USD 268. Penalties will also occur in the case of non-reporting (USD 11 per square $m^2$ per month) or false claims (up to USD 500 000) (New York City Goverment, 2021).

## Mitigation potential and impact

There are about one million buildings in NYC accounting for half a billion $m^2$ of floor space (Mazria, 2015). Buildings' direct energy consumption and indirect (electricity) demand, which also includes consumption of appliances, were responsible for over 60% of the city's total GHG emissions. Over 90% of emissions from NYC's buildings came from natural gas consumed for space heating and cooling and electric appliances (NYC Mayor's Office of Sustainability, 2021).

## Replicability / scalability

- Climate: Because NYC's geographical area is small, therefore its building energy code and related policies are adapted to the city's micro-climate and may not be easily transferred to many jurisdictions. However, NYC both faces hot summers and cold winters and the local code must accommodate both of these.
- Governance: Cities and regions in the US enjoy great political independency. NYC has implemented more stringent building codes, including on safety requirements, for many decades (REW, 2021). Jurisdictions of other countries may need to adhere to national policies.
- Building type: The 2020 NYC code covers residential, commercial and public buildings. NYC is generally a dense urban area and encompasses several skyscrapers. Nevertheless, construction permits issued in 2020 were for buildings with an average of 4.1 floors whereby many buildings have 1 to 4 floors and only a few buildings more than 40 floors (Ogorodnikov, 2021).
- Track record: NYC has had local building energy codes in place for many decades – the stringency of the policies have gradually increased. The building performance standard is expected to result in a 40% reduction in GHG emissions from the city's buildings sector by 2030 compared to 2005 levels (EPA, 2021b).

## Equity considerations

Local Law 126 of 2021 stipulates that buildings for "income-restricted housing" face laxer requirements, for example, such buildings are exempt of energy caps and emissions caps until 2035 and from the reporting requirements (New York City Goverment, 2021). While these exemptions reduce the short-term costs of rents, they also mean that low-income households are subject to higher energy prices in the long-term (see Case Study 4: US - A voluntary framework for local mandatory codes) and a lower housing standard in terms of thermal comfort.

## Good practice aspects

- The establishment of a wider strategy to decarbonise the buildings sector coupled with long-term goals to 2050 and beyond that provide a clear mitigation pathway.
- NYC put in place a committee specifically to plan for, monitor, evaluate and enforce the emissions reduction pathway towards zero emissions in the buildings sector and the building energy code.

## Weaknesses

- NYC currently enforces the 2018 IECC and not yet the latest 2021 IECC so that new buildings in NYC are not necessarily zero-carbon buildings.
- "Change of occupancy" does not mean that existing buildings or parts thereof must comply with the 2020 New York City Energy Conservation Code when a change of hands occur – it only applies to a change of occupancy that results in higher energy demand. This represents a missed opportunity because there are around 26,000 buildings bought and sold in New York City each year (Mazria, 2015).

## Lessons learned

### The world needs MEPS in more places…

MEPS need to be in place in essentially all countries by 2030 at the latest because they are the most effective policy instruments for reducing energy and emissions intensity of buildings. Currently, roughly 40% of countries have MEPS in place, covering around 60% of the global population.

Energy requirements are context specific, mainly due to climate conditions. The International Energy Conservation Code (IECC), on which the Zero Code or the ASHRAE code are largely based, is a helpful resource for countries to develop building energy codes because it allows the user to define energy requirements based on climatic conditions, such as sunlight, humidity, or temperatures levels.

MEPS need to also be adapted to apply to existing buildings to scale up energy retrofitting rates, particularly in countries with much of their building stock already established. Decarbonising existing buildings is more difficult, but there are several trigger points, such as when a change of ownership occurs. Governments need to roll out energy labelling schemes to increase transparency and seize trigger points to mandate energy retrofits.

MEPS for space heating and cooling equipment are important for improving energy efficiency and shifting toward electrification. Countries in different regions are imposing increasingly stringent MEPS for air conditioners, with more than 25 countries currently having such regulations.

### With more ambition…

Much more ambition in building MEPS is needed.  Even in countries where MEPS have been in place for decades, reductions in energy intensity have been too slow and are not Paris-Agreement compatible. (Figure 15). There are already some good examples of zero carbon codes and standards that could be adopted or modified by others (the IECC 2021 in the US, California's 2022 zero code, the EU's Energy Performance of Buildings Directive requiring that all new buildings were nearly zero-energy by the end of 2020).

MEPS could mandate zero carbon buildings with a space heating energy demand from the grid of the Passive House standard of 15 kWh/m$^2$/year in any climate, with remaining demand to be met by energy efficiency measures and on-site renewables. Reducing needs for space cooling to similar energy requirement levels is more difficult, especially in hot and humid areas, but substantial improvements on current levels are possible.

Ideal building codes are performance based but also include prescriptive requirements to ensure stringency of insulation and energy efficiency measures - so as to limit the reliance on on-site renewables while allowing flexibility for designers and engineers. Prescriptive elements can also ensure a transition to fossil fuel-free heating and cooling equipment by banning the installation of fossil-boilers or by including emissions thresholds on top of energy performance thresholds.

### And enabling better compliance

Several complementary public interventions are needed for governments to develop and implement ambitious and stringent MEPS.

Enforcement strategies and compliance checks in the operational life of buildings and technologies are crucial for MEPS to work. For example, while the U.S. building energy code is rather stringent on paper, in practice, US buildings consume much more energy than their counterparts in China, despite similar climate conditions. Several review cycles along the lifetime of a building are needed to ensure compliance.

Governments need to set up enforcement structures that incorporate a facilitative and supportive element. A dedicated public entity to enforce building codes is a good starting point. Further, there needs to be penalties for non-compliance. Sweden reviews the Energy Performance Certification of buildings every two years, and landlords that do not comply with the current MEPS may not rent out their properties until they meet compliance.

A long-term vision to decarbonise the sector can accrue compliance with MEPS – for example with phased thresholds for energy and/or emissions levels. Long-term plans that are clearly communicated can achieve compliance even before the deadline is met, as seen in Flanders (Jankovic *et al.*, 2022).

Earlier compliance cycles for public buildings, also including publicly supported social housing, can trigger transformation and acceptance of more stringent MEPS in other building sub-sectors.

Finally, an enabling environment around building MEPS is needed to ensure that it's possible to meet the codes, such as appropriate financing (Element Three – Financing), and support for all actors involved, such as capacity-building (Element Four — A multitude of actors).

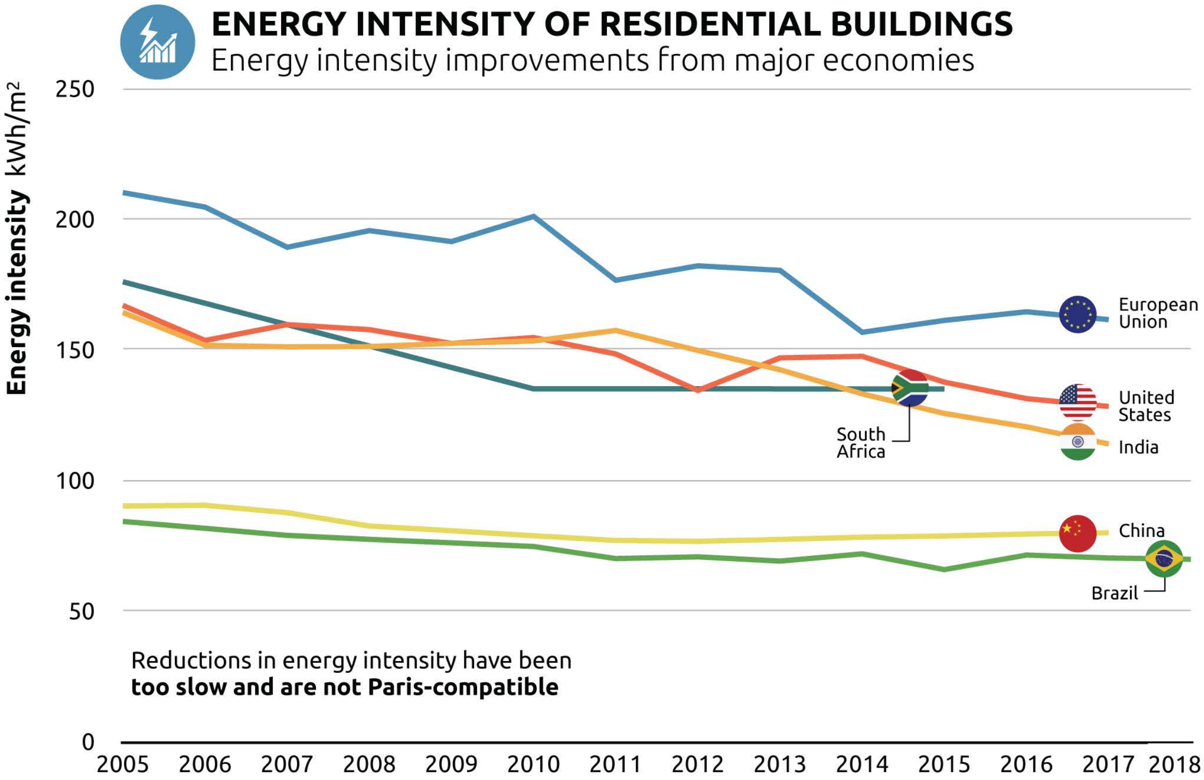


Figure 15: Energy intensity (per floor area) in residential buildings of six major economies.

*Source: Climate Action Tracker, 2021*

# Element Three – Financing

Decarbonising space heating and cooling of buildings in line with the Paris Agreement requires large-scale and timely investments. The IEA estimates that additional investments of USD 14 trillion between 2018 and 2050, or close to USD 440 billion annually, are required to decarbonise the buildings sector.[6]

Additional investments needed to construct new, and retrofit existing, buildings as zero carbon buildings are, however, relatively small compared to conventional finance flows in the global buildings sector. Whilst additional annual investment needs are in the order of billions, trillions are spent each year in the buildings sector. In 2019, USD 3 to 3.6 trillion were spent on the construction of buildings and USD 2 to 2.4 trillion on energy-related spending, including capital investments in energy systems as well as operational spending, for example on energy bills (IEA, 2019b).

Decarbonising the global buildings sector requires a shift of finance flows. Current finance flows in inefficient or energy intensive and often fossil fuel-based buildings and technologies need to be redirected towards better design, better insulation, energy efficient space heating and cooling technologies as well as the installation of on-site renewable energy systems.

Such a shift of finance flows leads to substantial energy cost savings including in the short-term. The IEA estimates that shifting finance flows away from fossil fuel heating and cooling systems and operational spending on fossil energy and towards energy efficiency measures would reduce annual energy costs for households and companies globally – with household spending on energy cut by half by 2050 (IEA, 2019b). A ten-year delay in the shift of finance flows, however, would result in a missed opportunity and cost up to USD 2.5 trillion more than a timely shift of investments (IEA, 2019b).

Governments, international donors, and the finance sector need to mobilise finance for energy efficiency measures and renewable energy systems. And real estate developers, landlords, and prospective house buyers must be made aware of the principal measures and associated financing options. Information exchange and closer collaboration between actors of the building sector is needed to enable the transformation which is addressed under Element Four — A multitude of actors. So far, existing policies and finance instruments have been unable to initiate a transformational wave in the buildings sector.

To inform how to roll out large-scale and timely investments to decarbonise the global buildings sector we:

1. review the current state of play to finance the construction and retrofitting of buildings including key actors influencing finance flows, financial characteristics of decarbonisation measures, current funding streams to support investments in these measures, and the key challenges that impede these investments;
2. analyse successfully implemented policy instruments used by countries to strengthen the implementation of MEPS and incentive investments in decarbonisation measures;
3. highlight three case studies to roll-out investments;
4. draw out key lessons learned and propose a set of recommendations to pursue.

6 These estimations include investments in appliances other than space heating and cooling. Because investments in energy efficient building envelopes and space heating and cooling make up the large share of those investments the estimates provide an order of magnitude required to decarbonise the global buildings sector.

## State of play

According to the IEA, in 2019 roughly 40% of the USD 5.7 trillion spent in the global buildings sector was energy-related, including on operational spending such as energy bills, but only 3% went to energy efficiency measures (IEA, 2019b, 2020e). This suggests that a large amount of finance in the buildings sector is directed at non-efficient energy measures as well as spending on energy bills.

According to CPI, a thinktank that tracks annual climate finance flows, investments into renewable energy systems make up the large majority of finance flows and climate finance in the transport sector is rapidly growing. In contrast, "mitigation investments", such as energy efficiency measures, in the building and infrastructure sector are lagging with USD 27.7 billion in 2021 (Buchner *et al.*, 2021). This figure is far off the USD 440 billion required each year until 2050 to decarbonise the buildings sector (IEA, 2020e).

Table 3: Residential versus non-residential buildings. Source: (IEA, 2019b).

| | **Residential** | **Non-Residential** |
|---|---|---|
| **Type of buildings** | Single detached or multi family buildings | Commercial, industrial and public buildings |
| **Share of total buildings** | >75% | < 25% |
| **Share of total energy consumed** | >70% | < 30% |
| **Share of total energy efficiency investments** | 50% | 50% |

## Actors influencing finance flows

Policy makers need to be aware of the type of actor targeted by their intervention, and account for their characteristics, resources and investment context to design effective instruments. We review a set of actors in residential buildings and non-residential buildings separately, as the type of actors largely vary between these two sub-sectors.

### Residential buildings

The landscape of actors in the residential sub-sector is fragmented – it consists of many small-scale actors that take a multitude of investment decisions related to the construction, purchase or retrofitting of buildings, or the purchase of space heating and cooling equipment. Therefore, any intervention aimed at supporting transformation in residential buildings needs to be carefully targeted at specific actors in order to be effective.

An important distinction to make in the residential sector is between building owners that live in the building themselves (homeowners) and those that rent out the building or apartment (landlord) for which policy instruments need to be adapted. Homeowners may be more willing to invest in zero carbon buildings and energy retrofits despite higher upfront cost knowing that they will benefit from significantly lowered energy costs in the future. In countries where renting of flats and buildings is more common, the investor landscape typically consists of fewer but larger investors. While fewer investors can be more easily targeted through policy instruments, the landlord - tenant relationship can pose additional challenges. When tenants pay for energy utilities there is little incentive in terms of energy and costs savings for landlords to make efficiency improvements to the building (See The Landlord-Tenant Dilemma).

Tenants also play an important role in the decarbonisation of the buildings sector. First, tenants may choose to invest in space heating and cooling systems in the case they are not provided by landlords and are not directly integrated into the building, such as air conditioners. Second, tenants often pay the energy bills of the building they occupy and are thus directly affected. Third, tenants' willingness, or lack of it, to accept higher rents for more energy efficient floor space enables or impedes investments in zero carbon buildings and retrofits.

Property companies, such as real estate developers, and more recently real estate investment trusts (REIT), are growing players in the global buildings sector in terms of market share. They differ from individual landlords in the sense that they are corporations, likely with more capacity to act on a larger scale and manage large properties such as building complexes. They buy and/or construct buildings to sell and/or rent floor space. Property companies are particularly relevant in the United States, Japan, the UK, China and Germany (MSCI, 2020). The IFC expects that property companies will particularly play an increasingly important role in the construction of buildings in large urban centres of developing countries, particularly in East Asia, the Pacific, and South Asia (IFC, 2019). Therefore, policy instruments should carefully consider the impact on property companies in these regions.

Property companies take the investment decisions of the buildings they construct or retrofit. Similar to individual landlords, the split incentive may impede property companies from deploying energy efficiency and on-site renewable energy measures (Figure 16). Because property companies seek their main business operations from the selling and renting of floor space, they are, however, susceptible to react to public interventions such as financial incentives. At the same time property companies do not face the same challenges as other investor types, such as lack of capacity, or access to finance to construct or retrofit buildings. Therefore, fiscal (tax-related) and regulatory instruments may be more effective than financial incentives to trigger investments in energy efficiency and renewable energy in buildings operated by property companies.

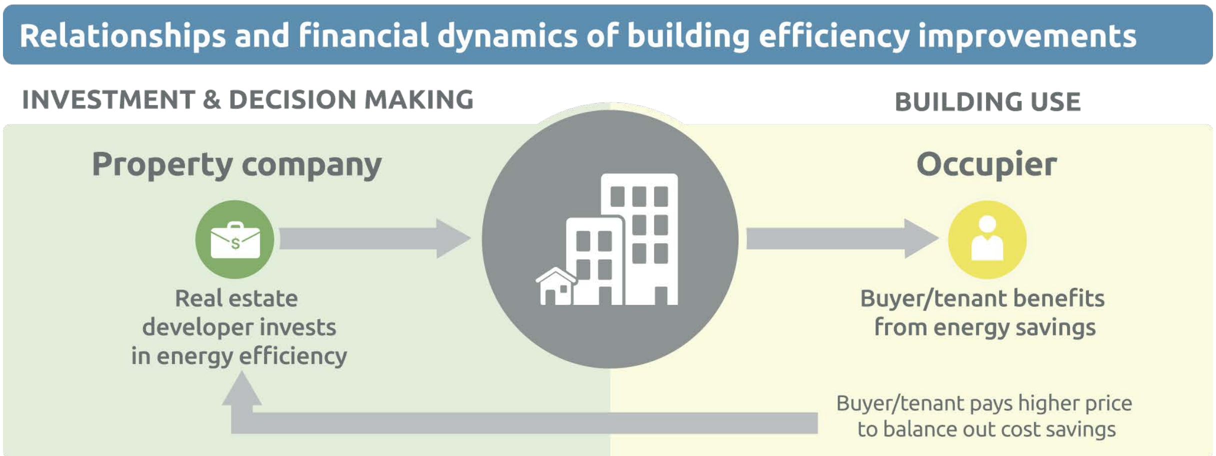


Figure 16: Financial relationship between property companies and buyers / tenants with regards to energy related costs.

### Non-residential buildings

The non-residential sector comprises of commercial, industrial and public buildings. Corporate actors, including property companies, likely represent a large share of actors in this sub-sector, which are often fewer but larger actors. Policy instruments targeting the economic viability of energy efficiency and renewable energy measures may directly influence companies' energy related spending (that is often higher than in residential buildings, see Table 3) as these translate into cost reduction measures – both if the company owns and rents the property. On one hand, companies tend to have more resources than individual building owners to invest in higher upfront costs, prepare business cases for energy efficiency investments, and seek public support schemes. On the other hand, investments in buildings that reduce energy costs are not core business investments and may be a lower priority among investment opportunities, even in the case of a favourable return on investment. A survey of companies in the EU and US reveals that companies spent at least 10% of total investments on energy efficiency measures in 2019 (EIB, 2020).

Public entities, governments, municipalities or public housing companies, own or rent buildings providing public services, such as hospitals, as well as government offices. National or local governments may also operate a public housing entity or sub-contract real estate developers to construct social housing units (Jonathan Woetzel *et al.*, 2014). Considering both social housing and public buildings, governments and municipalities can influence a significant share of the buildings sector. They can play a first-mover role in seeking the construction of and retrofitting of buildings and drive down costs through bulk procurement.

## Characteristics of investments to decarbonise buildings

Substantially scaling up investments to decarbonise the global buildings sector requires investments in three core decarbonisation measures better insulation of the building envelope, the installation of energy efficient space heating and cooling systems, and the installation of on-site renewable energy systems (see What needs to happen to reduce buildings sector emissions in line with the Paris Agreement?). These investments lead to lower energy requirements (**energy savings**) and therefore **reduced energy costs**.

Inefficient buildings and/ inefficient space heating and cooling technologies typically have lower upfront costs but have significant operating costs because they require the purchase of substantial amounts of energy, most often of fossil fuel energy. Energy efficient buildings, space heating and cooling systems and on-site renewable energy systems tend to have **high upfront costs but no to significantly lower operational costs**. Upfront costs are the sum of capital costs for technologies and components and, when applicable, the installation costs (professional services).

Zero carbon buildings are often cost effective in the long run because they lead to significant energy savings (IFC, 2019). Zero carbon buildings typically bear higher upfront cost than 'conventional' buildings – although it some cases the construction of well-insulated and electrified buildings has proven cheaper than the construction of a 'conventional' building that requires a new gas connection, as seen in California (Wei et al., 2021). As is the case for 'conventional' buildings, the price range of a zero carbon building vary greatly through regions and depending on the building type. For example, in the UK these additional costs are between 3% to 5% of the total construction costs of a new building (Currie & Brown and AECOM, 2019).

**Better insulation** is a cost-effective way to reduce emissions from space heating and cooling in most cases, particularly for heating in cold climates (McKinsey, 2020). In instances where insulation components are very affordable and the loss of energy is significantly reduced, the energy cost savings can rapidly outweigh the upfront costs. The availability of real-world cost data is fairly limited and there are many variables that can influence the costs making it difficult to put clear figures on possible costs or benefits. Retrofits to the building envelope can be particularly challenging, and expensive, due to the highly varied nature of existing building stock (GlobalABC/IEA/UNEP, 2020).

**Heat pumps** for space heating have high upfront capital and installation costs (Currie & Brown and AECOM, 2019). The price of new heat pumps varies by technology type and across regions. Ground source heat pumps have an average price of USD 24,000 in the EU and USD 13,000 in the UK, partly due to high installation costs (Currie & Brown and AECOM, 2019; McKinsey, 2020). Air source heat pumps are more easily installed and significantly more affordable because they do not require the installation of pipes in the ground. Capital costs, energy prices, installation costs differ between countries and therefore so do payback periods on the investments. We compare the purchase of a heat pump with the purchase of a gas boiler and the effect of energy prices in Box 8 below.

The IEA estimates that energy efficient **air conditioners** have reached cost parity with conventional air conditioners in most markets. Because of the importance air conditioning appliances will play in the future, and because of their relative affordability, it is important that governments offer financial and/or fiscal incentives for energy efficient air conditioners allowing compliance with minimum energy performance standards (MEPS) that have spread across countries in the past years (IEA, 2022b). Countries, especially developed countries, should have a system in place to handle old and inefficient equipment to ensure such appliances are recycled instead of sold at low prices in countries with no or less stringent MEPS where these appliances often outcompete more efficient appliances but lock users in higher energy spending.

The installation of **on-site renewable energy systems** has rapidly fallen in the last decades, and depending on roof area and shading can eliminate net electricity demand from the grid and even generate a positive cash flow if excess electricity can be sold to the grid. With energy payback periods of less than two years in many instances, on-site renewable energy systems have an increasingly short payback period (Fraunhofer ISE, 2021). Installing on-site renewable energy systems in a building can thus enhance the cost competitivity of a zero carbon building. For example, in Spain the payback period of a solar powered ground source heat pump lays between two and five years (Sánchez Molina, 2022).

## Box 8: The role and impact of energy prices – the example of heat pumps

The relative price of electricity and of emissions intensive fuels are a key determining factor of cost savings and therefore payback periods of electrification of space heating, or even whether the intervention results in overall cost-savings at all. We illustrate the impact that energy prices and carbon prices have on the return of investments with the key example of heat pump installation.

A key barrier to the growth in heat pump sales is their higher upfront cost compared to other heating systems like gas and oil boilers. In 2019, close to 60% of space heating technologies sold were fossil-fuel based and gas boilers account for a large share of fossil-based equipment (IEA, 2020b), thus we compare the case of heat pumps to gas boilers.

We compare an air source heat pump with a capital and installation cost of USD 8 000 with a gas boiler with an equivalent price of USD 2 000. We assume a household's average annual space heating needs to be 20 000 kWh. The air source heat pump has an efficiency level of 350% and the gas boiler has an efficiency level of 100%. In other words, the heat pump produces 3.5 times more heat than it consumes electricity while the gas boiler produces the same amount of heat than its fuel consumption.

In a scenario with '**frozen energy prices'** for natural gas and electricity – not reflecting the current spike in gas and electricity prices[7], we use the average price of natural gas in June 2021 of USD 0.06 per kWh (Valev, 2021). Global electricity prices vary but are typically twice the per kWh price of natural gas, and even more in some regions, so we assume the price of electricity to be USD 0.12 per kWh (IEA, 2020a).

In the 'frozen energy prices' scenario, cumulative costs of a heat pump, composed of the initial investment and fuel costs over 20 years, even out with those of a gas boiler as of the eleventh year (Figure 17). The energy cost savings from installing a heat pump take a long time to compensate for the initial investment. It is important to note that a gas boiler may need to be replaced after 10-15 years, in which case the heat pump, with a lifetime of around 20 years, would be more cost-effective.

7 By the end of 2021, the price of natural gas spiked to record high levels in Europe and Asia (IEA, 2021d). Higher natural gas prices led to significantly higher electricity wholesale prices in many regions, also particularly affecting Europe (IEA, 2022a).

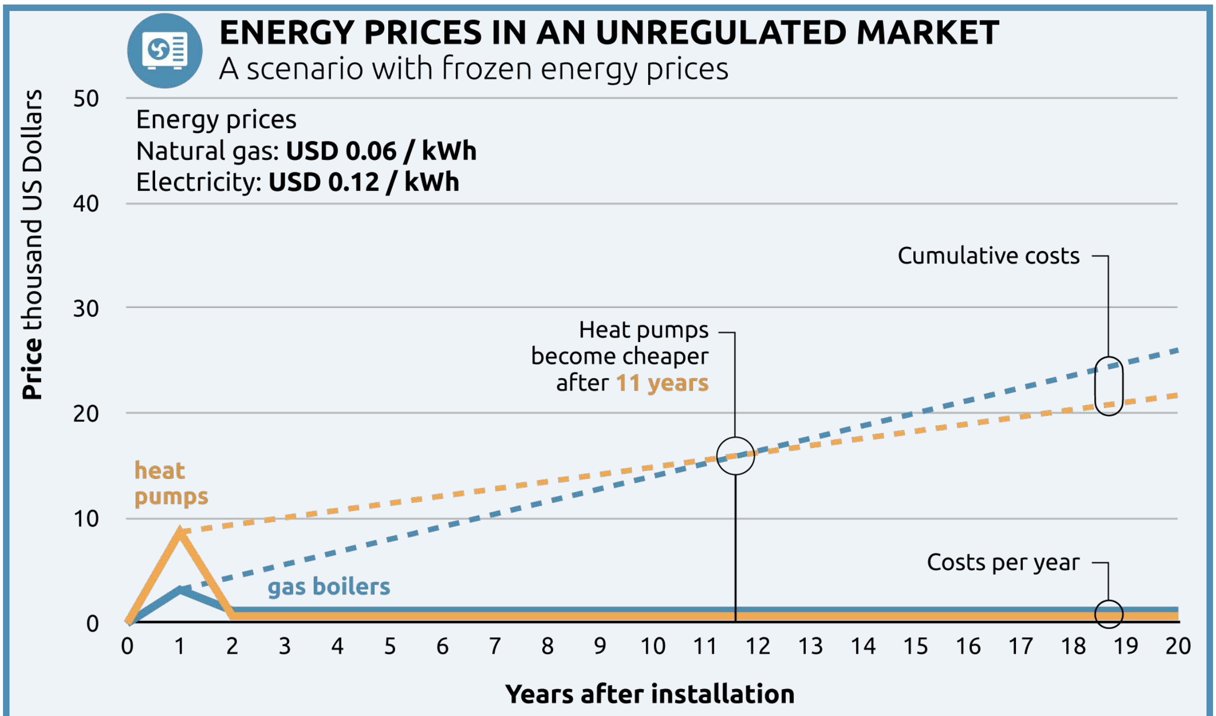


Figure 17: Financial comparison between an air heat pump and a gas boiler in an 'unregulated energy market'. Source: Authors.

In the context of a '**level playing field of energy prices'**, with a price of USD 0.12 per kWh for electricity and natural gas, we find that the cumulative costs of a heat pump are lower than those of a gas boiler as of the third year after installing the heat pump (Figure 17). A heat pump is more economically competitive with a gas boiler when emissions intensive fuel prices are at the same price as electricity due to the much shorter payback period.

Levelling the costs of electricity and direct fossil fuel energy supplies is a key component of improving the cost-competitiveness of zero carbon buildings. Carbon prices are one policy instrument that can be used to achieve this.

## Current funding streams to support investments

Investments in energy efficiency and renewable energy in buildings can be made using a range of funding streams. Actors may use their own funds, take on debt from a bank or issue a green bond. More recently investments in decarbonisation measures can also be made through contract financing, whereby an energy service company (ESCO) performs the measures in exchange for a recurring fee. Each financing option has its own advantages and disadvantages and use case (Table 4).

The most straightforward and simplest option to finance the construction of a zero carbon building or energy retrofits is with one's **own funds**,if sufficient financial resources are available. Low-income households and households in countries with a high cost of capital (for example with high transaction costs or high interest rates on debt instruments) use their own funds to build houses (Independent Evaluation Group, 2016). Making use of one's own funds is also generally the preferred option for small energy retrofits, such as the purchase of an air conditioner.

**Debt**, in the form of housing loans and mortgages, is the most common means of financing the construction, purchase of a building in countries with low cost of capital, developed countries. Total outstanding housing debt was equivalent to over 250% of GDP in the US in 2020 (BEA, 2021; Federal Reserve Bank of New York, 2021) and 83% of GDP in the Netherlands in 2013 (Badev *et al.*, 2014). In contrast, housing debt accounted for less than 1% of GDP across many low- and lower-middle-income countries in Asia and Africa (Badev *et al.*, 2014). Global debt data for the non-residential sector in generally not available.

Borrowing of capital is particularly relevant in the context of financing high-upfront costs because it spreads the financial burden over a set period of time. However, the debt comes at a cost (in the form of fees and/or interest rates) and often requires the provision of a collateral in case of a default. This cost of capital is an important factor and can be decisive as to whether or not loan payments end up cheaper than what would have been spent on energy bills.

**(Green) bonds** are an alternative type of debt instrument used to finance the construction and retrofitting of buildings. Instead of borrowing from financial institutions, bonds are a financial instrument to raise funds from capital markets. Green bonds differ from traditional bonds by the commitment of the issuer to use the bond's proceeds exclusively for green purposes (European Commission, 2016). Green bonds are particularly suitable for the construction and retrofitting of large-scale residential, commercial, or public buildings.

The explicit labelling of bonds as green can facilitate the connection between green projects and the increasing demand for green investments (European Commission, 2016). Green building certification, which serves as a verification instrument to assess the 'greenness' of bonds, is key to mobilise capital through green bonds (UNEP, 2021a).

According to the Climate Bonds Initiative, more than USD 1 trillion green bonds have been issued globally between 2014 and 2020, of which more than half was issued in 2019 and 2020 alone. The buildings sector is second to the energy sector in terms of debt volumes issued with 27% of total bond issuance (CBI, 2021). The US, China, and European countries are the largest issuers of bonds and specifically green bonds (ICMA, no date; Çelik, Demirtaş and Isaksson, 2020; CBI, 2021). In China, investors issued USD 5.2 billion worth of green bonds to finance "low carbon buildings" [8] and energy efficiency measures in buildings in 2020 – double the amount invested in 2019 (CBI, 2021).

**Contract financing schemes** are new business and finance models that have emerged in the built environment in recent years. The schemes differ in the contractual setup and terminologies, such as energy performance contracts (EPC), energy services agreements (ESA) or leasing agreements, but all follow the basic principle of an energy service: the contracted company, often referred to as an energy services company (ESCO), performs building modifications such as a deep energy retrofit, or the installation and operation of a solar panel or air conditioner, for which clients pay recurring fees according to a contract and over a defined period of time. So far, this type of financing has been mainly used for the financing of energy retrofits, and to a lesser extent solar panels, but could be used for the financing of zero carbon buildings (Kachi *et al.*, 2020).

The details of such energy service contracts may differ from one provider to the next but generally the contractor, or the ESCO, links the recurring fee to the actual energy savings resulting from the building modifications.

In a *shared savings* model, the ESCO bears all technical and financial costs, including capital and transaction costs, and receives a recurring fee from the client – in some instances the ESCO may also cover the client's remaining energy costs. In theory, the energy cost savings are higher than all costs of the building modifications whereby the clients' recurring fees are lower than their previous energy costs and the ESCO is able to make a profit – therefore the shared savings model (Figure 18).

The strongest benefit of such an agreement is that the risk of non-performance of energy efficiency measures is borne by the contractor, not the client, whereby ESCOs have the know-how of energy retrofitting and can efficiently monitor the equipment and energy savings (Bertoldi *et al.*, 2019). ESCO may also have access to debt at better conditions than individual building owners thus lowering the overall costs of the retrofit. To maximise the profitability of projects and tap into economies-of-scale benefits, ESCOs tend to target large-scale projects in energy-intensive buildings. As a result, EPCs are most often implemented in non-residential buildings. EPCs have, however, also occurred in the residential sector, for example for deep energy retrofits in large multifamily buildings and social housing (Bertoldi *et al.*, 2019). Because the client only needs to pay a recurring fee, contract financing is accessible to a larger share of the population than debt financing.

[8] Following the definitions of the Climate Bonds Initiative.

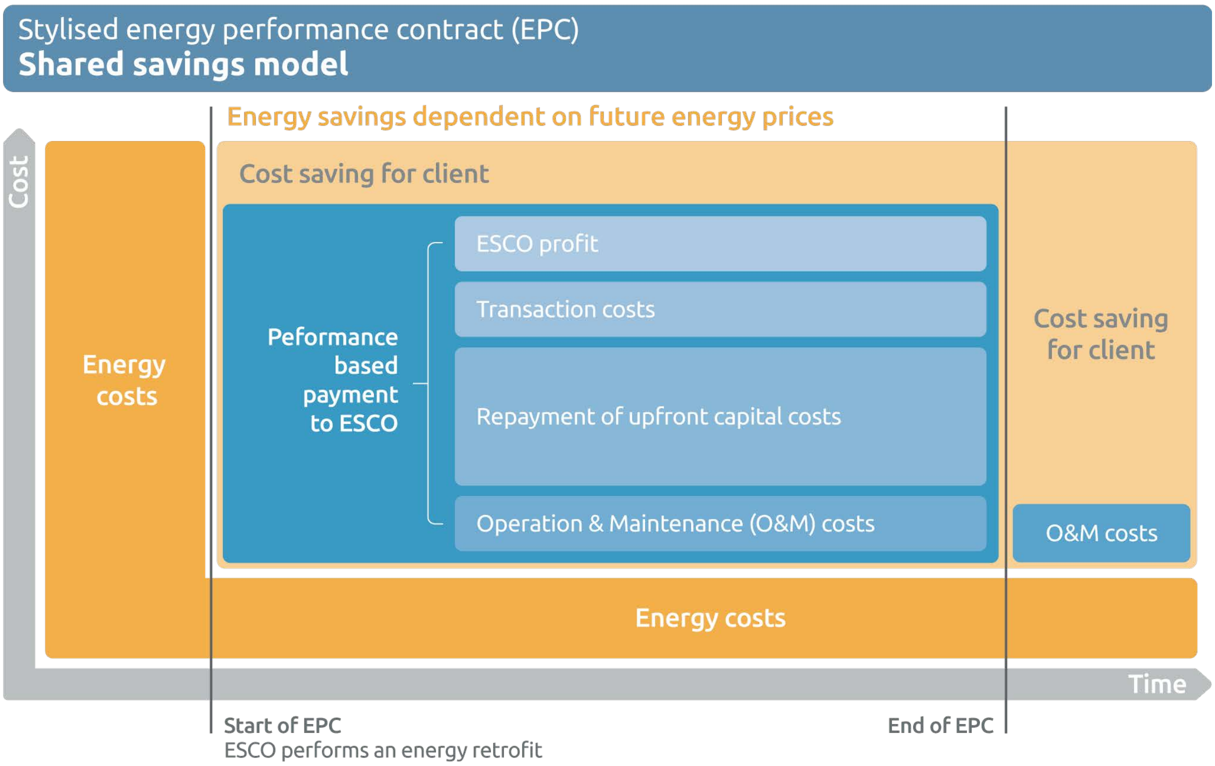


Figure 18: Stylised energy performance contract (EPC) with a shared savings model, whereby the ESCO does not cover clients' remaining energy costs. Source: Authors.

Because the shared saving model is linked to energy savings, fluctuating energy prices have historically undermined the profitability of EPCs – for example when energy prices are lower than expected (Global ESCO Network, 2020). As an alternative, ESCOs have developed the *guaranteed savings* model. ESCOs guarantee a certain level of energy savings on the client's energy bills but only bear the technical risk and not the financial risk. In other words, as per the contract, ESCO are responsible to ensure energy savings as defined before the building modifications occur but do not link the recurring fees to energy prices – they are, however, subject to penalty fees if energy savings are lower than contractually defined. Therefore, the clients pay a recurring fee to the ESCO, which should be lower than in a shared savings model, but are responsible for financing the project (IEA, 2018).

Figure 19 visualises a stylised EPC with a guaranteed savings model, in which the client borrows capital from a bank to finance the project and pays the ESCO a fixed fee. The EPC and bank loan are independent from each other and have divergent contract timeframes.

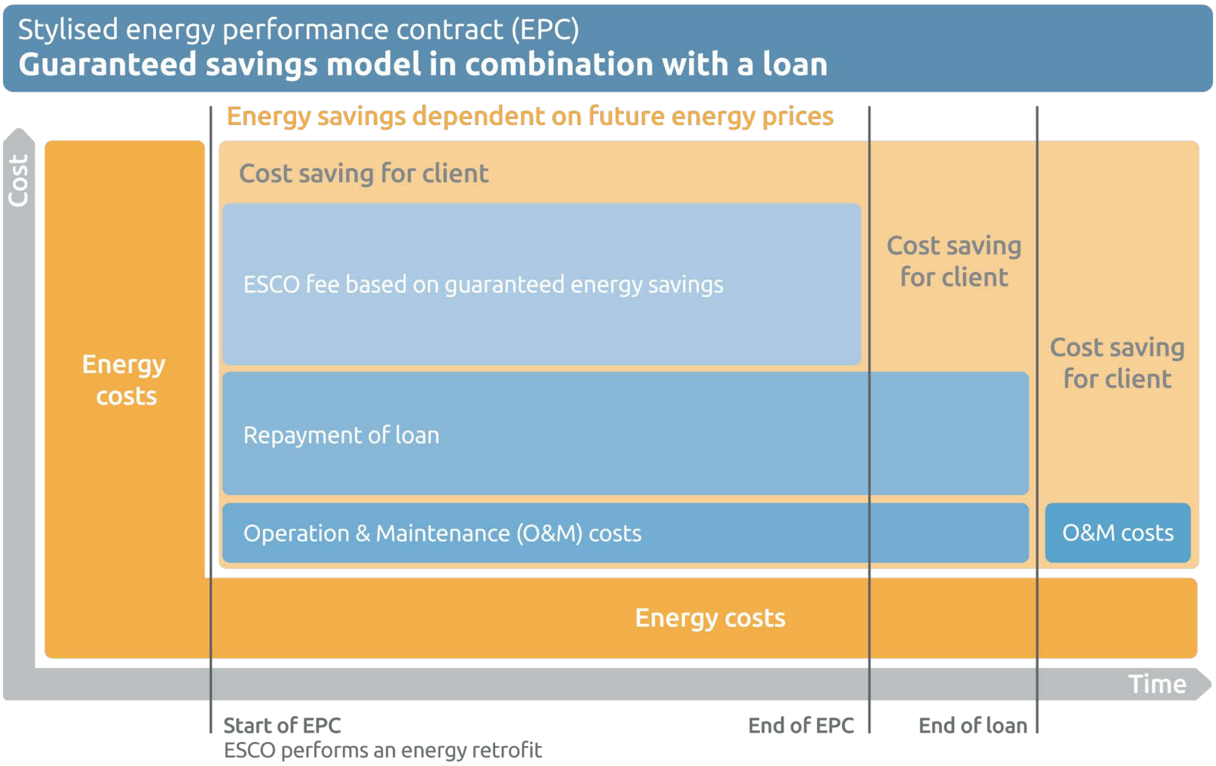


Figure 19: Stylised energy performance contract (EPC) with a guaranteed savings model and in combination with a loan. Source: Authors.

As a response to the lack of guarantees and general uncertainty of future energy savings, some financial institutions, companies, and insurance companies have devised the concept of an **energy savings insurance (ESI).** Relying on an energy savings insurance (ESI) can reduce the risk associated with energy services and thus enable access to affordable finance options for investors or ESCOs (IEA, 2018).

Typically, EPCs have been focussed on the retrofitting of inefficient buildings to enable more efficient heating. Global space cooling demand, however, has tripled since 1990 to represent 8.5% of global electricity demand in 2019 and is expected to grow further significantly. China, India, Indonesia and Mexico accounted for roughly half of air conditioners purchased globally in 2019 and the majority of purchased appliances are inefficient. Energy efficient air conditioners have the potential to reduce energy demand from space cooling by half (IEA, 2021a).

Cooling as a service is a type of contract financing scheme dedicated to the installation of energy efficient cooling systems. It transfers high-upfront costs of energy efficient cooling equipment to affordable monthly payments. The Cooling as a Service Initiative (CaaS) aims to mainstream this finance model worldwide. The core difference between the CaaS Initiative compared to EPCs is the fact that users pay for the electricity used at the price per unit of electricity agreed upfront instead of paying for the energy savings (CaaS, 2021). Such simple pay-as-you-go financing schemes enable a wider share of the population to have access to affordable and energy efficient air conditioners, reducing the overall cost of space cooling and increasing the willingness to pay for efficient air conditioners.

As of September 2021, over 65 companies had joined the CaaS Initiative. While the initiative also covers cooling equipment other than space cooling (such as cold storage) there is evidence that companies integrate CaaS for space cooling needs.

Table 4: Financing options for the construction or purchase of Zero Carbon Buildings and energy retrofits.

*Based on (Aditya, 2018)*

| Finance type | Own funds | Debt | Green bonds | Contract financing |
|---|---|---|---|---|
| **Description** | Actors make use of their own funds. | Actors borrow capital from a bank or a financial institution. | Actors borrow capital from lenders by issuing a bond. | Actors pay a monthly/annual fee to a contractor. |
| **Advantages** | No administrative procedures and no interest rate. | High upfront costs are spread over a period of time. | Access to a larger pool of borrowers and thus larger sums of capital. | Contractors take on the administrative burden so that actors need only pay a monthly fee and do not need to take on debt. Predictability of energy costs (in the case of fixed payments) |
| **Disadvantages** | Own funds are often insufficient Opportunity cost of using own funds can be a disadvantage, especially for companies | Potentially lack of creditworthy potential recipients. Interest rates may increase. Lenders perceive energy retrofit loans as high-risk and are wary of loan defaults. | Potentially lack of creditworthy potential recipients. Relatively high transaction costs. Not applicable in a restrictive financial system (with high collateral requirements or lack of creditworthiness rating). | Energy price fluctuations impact Lack of capacities in the industry. Lack of clients' trust in energy service providers |
| **Frequency of current use** | Frequent | Frequent | Emerging | Seldom |
| **Actor type** | All actors | All actors, particularly for residential and commercial/industrial buildings | Large-scale actors such as real estate developers, large companies, or public entities | Large-scale actors for whom debt is not attractive (lack of access or split incentive). More recently, smaller residential projects have also used contract financing. |
| **New building / energy retrofits** | Both, most often for energy retrofits | Both | Both, most often for new buildings | Energy retrofits, although also applicable to new buildings |
| **Project size** | Small, such as for the installation of an air conditioner | All sizes, most often for larger endeavours, such as new construction or full deep retrofits. | Large-scale projects, such as multi-family, industrial, commercial or public buildings | Most suitable for projects that can be repaid through energy savings such as through deep energy retrofits |

## Box 9: Implications for energy utilities

The potential of energy efficiency and electrification in buildings, the increase in distributed electricity generation, and the more active role of prosumers / consumers, are unstoppable trends that are gaining ground globally (Hamwi and Lizarralde, 2017; IRENA, 2020). This transformation has different implications for energy utilities – whether the transformation represents an opportunity or a risk to energy utilities depends largely on countries' regulatory framework.

From a purely volumetric perspective, energy efficiency measures and on-site renewable energy systems result in lowered energy use in the buildings sector. The decarbonisation of the building sector will also mean a shift towards electricity, although zero carbon buildings should have very low electricity demand. Seeing that most energy utilities source their core income from the direct remuneration of energy production and the delivery of that energy to the end consumer, these transformational trends will result in reduced income. The inevitable reduction in energy consumption requires a reformulation of current business models towards new business models that will gain value in the transformation process, such as efficiency measures, smart home systems, increased system reliability or increased flexibility in the system to integrate renewable energy.

Reduced energy consumption can also lead to cost savings for utilities. Typical peak energy loads can be costly for energy utilities when they need to produce energy from more expensive energy sources to satisfy demand peaks. The remuneration scheme of utilities and the design of the electricity tariffs, such as price caps, will determine the extent to which consumers manage their energy consumption and effectively shed peak loads. A forward-looking design of regulation and tariffs that anticipates this transformation is key to exploit the benefits of demand-side management, both for consumers and utilities. In this sense, energy utilities should be understood as the backbone that allows the exchange of growing a number of services and enhance information and knowledge across a wide range of actors.

Energy utilities can take advantage of their position and embark on this transformation by reformulating their business models to offer and monetise from energy services such as smart energy management of buildings, energy saving services, additional services such as energy storage, or selling electricity to the grid.

Energy utilities may also have a role to play when considering new finance models such as Energy Performance Contracts (EPCs). A study conducted in several European countries found that in 2015, providers of energy efficiency services were mostly energy utilities, although overall EPCs were still very low (Labanca et al., 2015). In the US, state regulations often mandate energy utilities to guarantee low energy prices through the cheapest measures available, which has often been through energy efficiency measures instead of investment in new energy generation facilities (RAP, 2011). As a result, the on-bill financing scheme, a type of EPC in which utilities' clients remain in the same energy contract as before but utilities offer energy efficiency services, has existed in the US for many years (Bertoldi et al., 2019).

However, the need to modify billing systems, the role of utilities as financial institutions (financing energy retrofits and collecting repayment through energy bills), clients' default risk, and possible complications when a property transfer occurs have proven to impede the mainstreaming of on-bill financing schemes (Bertoldi et al., 2019). Similar issues are likely to impede energy utilities in upscaling and shifting to other types of contract financing schemes.

## Challenges to upscaling and shifting current finance flows

From the subset of countries for which data is available, it is apparent there are large discrepancies in the availability of funds (OECD, 2022). A large share of the global population, companies and public entities lack the means to redirect monthly spending on fossil fuels to upfront investments in low carbon measures. Funders are therefore needed to spread out these upfront costs through monthly payments. Further, awareness of those low carbon measures and of financing options are also needed, which we cover in Element Four — A multitude of actors.

Even in the case of economic benefits, investors do not always opt to construct or retrofit buildings as zero carbon buildings and may choose to invest in energy consuming technologies to avoid higher upfront costs or for non-financial reasons We review key financial and non-financial barriers impeding the uptake of energy efficiency and renewable energy measures in the buildings sector.

## FINANCIAL BARRIERS

### Inability to pay for upfront costs

Income levels vary between regions, countries and within countries and while the material and labour costs also vary it is likely that low-income households and companies are not able to afford the upfront capital costs required for decarbonisation measures in the buildings sector. In the absence of quantitative data to assess the share of the population, companies and governments that are not able to pay for the required upfront costs energy poverty is an indicator.

Households, and potentially also companies, for whom energy expenses already pose a financial burden, often referred to as energy poverty, are unlikely to have the means to invest in relatively high-upfront costs. At the same time those suffering from energy poverty benefit the most from lowered operational energy expenses because energy spending represent the higher share of their monthly spending, but cannot afford the investments that would help them out of the energy poverty trap (IEA IRENA UNSD World Bank WHO, 2021).

Energy poverty remains a major challenge and the decline in welfare due to the COVID-19 crisis may exacerbate energy poverty. More than 110 million people in developing Asia and Africa may have lost the ability to afford an *essential and extended bundle of electricity services* by the end of 2020 (IEA IRENA UNSD World Bank WHO, 2021). For instance, in an informal settlement of Nairobi, nearly 15% of households that used liquefied petroleum gas (LPG) as a primary cooking fuel before the COVID-19 crisis reverted to using kerosene because they could not afford the high upfront cost of a full cylinder of LPG. Kerosene is not only a more polluting fuel it also has a per-meal fuel cost almost 60% higher than LPG (IEA IRENA UNSD World Bank WHO, 2021).

Energy poverty also remains a challenge in more developed nations. A study in **China** found that 19% of households cannot afford modern energy and 46% are sensitive to energy prices. Due to energy poverty, these households consume less electricity than required for a "basic demand" (Lin and Wang, 2020). A survey conducted in **EU countries** in 2019, found that close to 7% of Europeans stated they cannot afford to heat their home sufficiently (Eurostat, 2021). In the **US**, the US Energy Information Administration estimated that in 2015 more than 14% of households received a delivery stop notice and over 21% of households reduced food and medicine expenses to pay energy bills (Bednar and Reames, 2020).

### Lack of access to finance and high capital costs

High-upfront costs can often not be financed through households' or companies own funds and thus access to capital is of crucial importance. However, a large share of the population, companies, and public entities worldwide face a lack of access to capital. In many low and lower-middle-income countries, there are only a few thousand housing loans per country in a year, or a few hundred in some cases (Badev *et al.*, 2014), and housing debt is frequently unaffordable to all but the top earners (Independent Evaluation Group, 2016). Housing loans amount to less than one percent of GDP across many low- and lower-middle-income countries in Asia and Africa (Badev *et al.*, 2014).

There are several drivers behind this lack of access to finance. On the demand-side, informal and irregular income, the cost of capital (transaction costs and interest rates), high taxes and down payment requirements prohibit borrowers from accessing affordable finance options. Large discrepancies in countries' average interest rates exist. For example, between 2016 and 2020 interest rates were as low as 3.5% in North America and the EU+UK but over 15% in Sub-Saharan Africa (Figure 20).

On the supply-side, a lack of liquid capital markets, access to long-term local currency (in parts due to high inflation rates) or the absence of policy and governance frameworks (for example around property rights and to assess clients' creditworthiness) prohibit lenders from providing affordable long-term housing debt. A large determining factor is countries discount rate, or the interest rate provided by a country's central bank to financial institutions, which are the lowest interest rates in the country as they represent risk-free debt. However, discount rates used in the profitability assessment of investments to determine the net present value of the sum of future cash in- and outflows differs between countries when adjusted for risk. This is because the creditworthiness and thus the risk of default differs from one country to the next – factors such as political stability, corruption levels or maturity of the financial system impact the discount rate used in financial analyses.

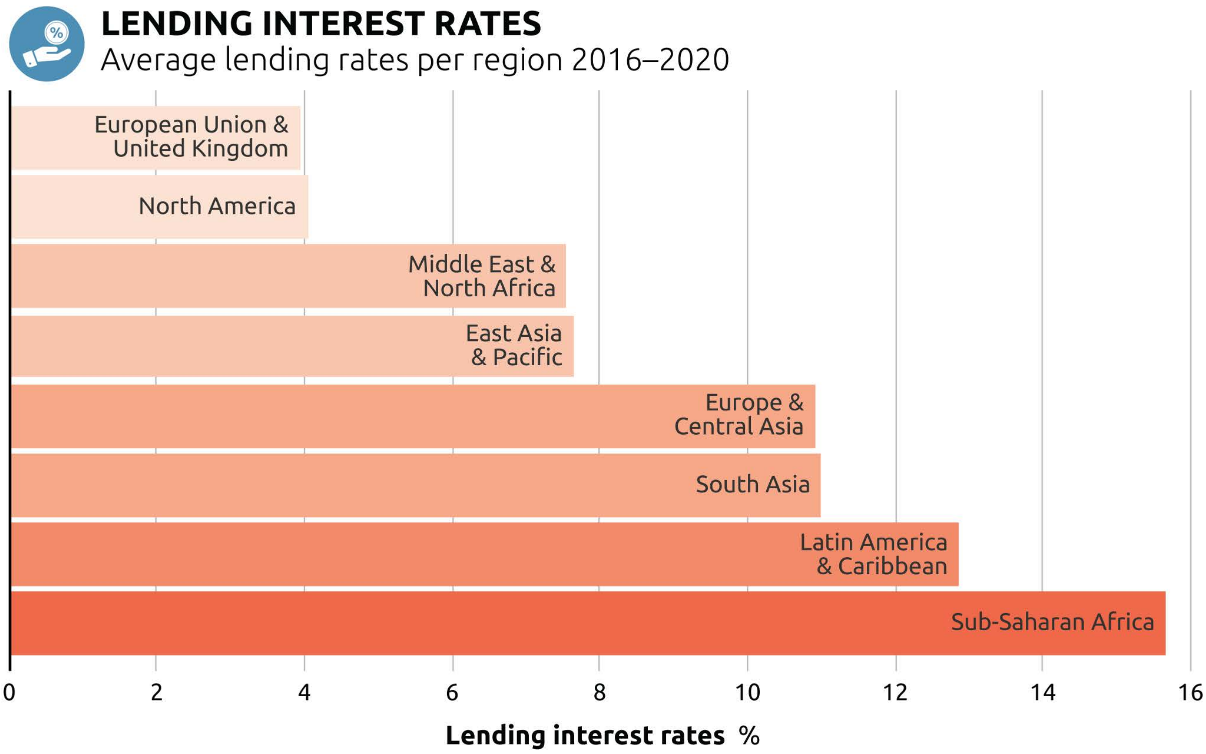


Figure 20: Average interest rate for all purposes per region. Lending rates for real estate tend to be lower. Interest rates are counted as the average interest rates of commercial banks for which data is available. Data source: (IMF, 2021)

### Fluctuating energy prices

Energy prices significantly influence the cost of space heating and cooling. Earlier, we visualised the impact of energy prices on the investment of a heat pump compared to a gas boiler (Box 8: The role and impact of energy prices – the example of heat pumps) The cost savings that energy efficiency measures can bring are directly linked to future energy prices. The fluctuations and uncertainty of future energy prices poses a risk to the financial viability of energy efficiency investments. Lower energy prices than originally expected lead to lower energy cost savings and longer payback periods. The difficulty of accurately predicting energy savings translates into uncertain monetary energy savings.

## NON-FINANCIAL BARRIERS

### Lack of awareness of opportunities

Actors that are not aware of alternatives to fossil-fuel based and/or energy intensive buildings and/or technologies will not consider investments in energy efficiency and renewable energy measures, nor are they likely to invest in zero carbon buildings. Whilst financial instruments are unlikely to help overcome this barrier it is important to highlight that this barrier affects investment levels towards decarbonisation measures – further analysis is provided in Element Four — A multitude of actors.

### Competition with other investment priorities

Households and especially companies may not value energy related investments as a priority, despite a favourable return on investment. Even for companies that seek to reduce costs, investments in energy efficiency or renewable energy compete with other investment options particularly with core business investments such as business expansions. Energy-related investments also represent an opportunity cost as they require capital that is not available anymore for other activities and may impede the willingness to invest even in the case of profitable investments with short payback periods.

**Time preference**

Actors may be unwilling to invest in decarbonisation measures despite their economic benefit in the long run, even in the case of a positive net present value, because present rewards and risks are weighted more strongly than future ones, a phenomenon referred to as 'time preference' (Frederick, Loewenstein and O'Donoghue, 2002; Gillich and Sunikka-blank, 2013; IEA, 2019b).

**Perceived risk of energy efficiency investments**

A lack of confidence and lack of guarantees that energy cost savings recoup upfront investments strengthen the reluctance to invest in energy efficiency upgrades and renewable energy systems. Funders may perceive investments in energy efficiency measures as risky because future energy savings are conditional on building occupants' behaviour and on energy prices. The perceived risk translates into higher interest rates for borrowers and increases the challenge of accessing financing (Bertoldi *et al.*, 2019).

**Lack of awareness of funding options**

Lack of access to capital can stem from the financial inability to borrow capital from a financial institution but it can also stem from a lack of awareness of funding options. Companies and households, and sometimes also municipalities, may not be aware of (public) financing options available to them.

**Split incentive**

The split incentive between landlords and tenants hinders the willingness to invest in energy efficiency and/or renewable energy measures (see also The Landlord-Tenant Dilemma). Landlords may be reluctant to invest in energy measures they do not benefit from; tenants may be reluctant to accept higher rents for energy measures they have no control over (Gillich and Sunikka-blank, 2013). For example, the purchase of zero carbon buildings can be up to 31% more expensive than of conventional buildings and rents may be 8% higher than conventional buildings (IFC, 2019).

Further challenges, such as a lack of capacities in the market, mistrust in construction and/or energy service providers (Przepiorka and Horne, 2020), a lack of understanding of the benefits of energy efficiency, and renewable energy investments (IEA, 2019b) may further accrue the hesitance to invest in low carbon measures (see also Element One — Technologies and Element Four — A multitude of actors).

## Policy instruments to unlock investments

Governments can play a key role in rolling out investments towards zero carbon buildings and energy retrofits by developing policy instruments addressing the challenges reviewed above by 1) making the construction and purchase of zero carbon buildings and energy retrofits economically attractive, 2) granting a larger share of the population, companies and public entities access to affordable financing options when own funds are insufficient, and 3) discouraging investments in emissions intensive technologies.

We review policy instruments aimed to unlock investments to decarbonise the buildings sector as grants and debt instruments, tax instruments and regulatory instruments (Table 5). The first two can influence the willingness to pay and invest in technologies and services that are not (yet) commercially viable or discourage investments in emissions intensive technologies.

Regulatory policies can mandate energy and buildings sector actors to adjust their investment behaviours. Regulatory instruments could also simply forbid investments in emissions intensive technologies such as a full ban on the installation of new gas boilers in building codes Box 7: Banning new installations of fossil fuel equipment for heating.

Because public funds are often limited, and public funds alone cannot finance the transition to net zero emissions in the buildings sector, it is important that policy instruments trigger private sector investments and not substitute them (Bertoldi *et al.*, 2019). We take such aspects into consideration when reviewing existing policy instruments.

Table 5: Overview of policy instruments and the challenges they address. Source: Authors.

| Policy | Policy effect | | | | | |
|---|---|---|---|---|---|---|
| | Reduce upfront costs | Spread upfront costs over time | Increase access to finance | Shorten payback periods | Reduce perceived risk | Redirect investments |
| **Grants and debt instruments** | | | | | | |
| Grants | ✓ | | | ✓ | | ✓ |
| Subsidised loans | | ✓ | ✓ | ✓ | Possibly | |
| Credit risk guarantee | | | ✓ | Possibly | ✓ | |
| Performance-based debt-relief | | | | ✓ | ✓ | |
| Blended finance | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Tax instruments** | | | | | | |
| VAT reduction | ✓ | | | ✓ | | ✓ |
| Tax credits | ✓ * | | | ✓ | | ✓ |
| Accelerated depreciation | ✓ * | | | | | ✓ |
| Energy / carbon taxes | | | | | | ✓ |
| Lien-based energy efficiency financing | | ✓ | ✓ | | | |
| Energy efficiency adjusted property taxation | | | | ✓ | ✓ | ✓ |
| **Regulatory instruments** | | | | | | |
| Energy efficiency obligations | | | | | | ✓ |

* *Although subject to a time delay*

## Grants and debt instruments

Financial incentives either diminish upfront costs or reduce payback periods, thus increasing the financial viability of zero carbon buildings. Governments can make use of an array of finance and policy options to support investments in Zero carbon buildings and energy retrofits. Financial instruments can come in the form of 1) incentives that render the construction and purchase of Zero carbon buildings and (deep) energy retrofits economically attractive or 2) financial support schemes that grant a larger share of the population, companies and public entities access to financing options when their own funds are insufficient.

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**Grants** are a form of direct funding by governments to overcome high costs and are especially relevant to support activities where a financial return is not directly anticipated, such as energy audits and/or assessments of decarbonisation options in buildings. Grants enable a temporary shift in the market with the aim to have a lasting effect (Bertoldi et al., 2019; GlobalABC/IEA/UNEP, 2020).

**Advantage:** Grants are useful instruments to incentive first-movers' investments and drive down the cost of emerging products. Access to grants may also improve a project's cash flow and thus enable access to debt financing (Bertoldi *et al.*, 2019).

**Disadvantage:** This type of financial instrument is directly sourced from national budgets and therefore it is constrained by limited financial resources. Countries with limited budget are likely not able to offer this type of policy instrument. As a result, the provision of grants and subsidies should be limited in time, for example when a new technology reaches cost parity.

**Examples**: Since 2019, South Korea has offered a 10 % refund for the purchase of home appliances with the highest efficiency rating on the market, including air conditioners (IEA, 2020d). The Free Energy Upgrade Scheme in Ireland provides grant finance for better insulation and renewable heating systems to low-income homeowners. The grant includes a mandatory Building Energy Rating (BER) after the retrofit work is carried out (SEAI, 2021).

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Governments can offer **subsidised loans**, also referred to as soft loans or concessional loans. Subsidised loans are available at below market interest rates and can include extended payback periods and/or payback grace periods. Governments can directly provide subsidised loans through public banks, or engage in public-private partnerships with financial institutions so that commercial loans are available at more attractive terms (Bertoldi et al., 2021) (Element Four — A multitude of actors). The aim of providing subsidised loans is essentially twofold: incentivise actors to invest in high upfront costs by spreading these costs over time at no, or minimal, cost and to provide access to debt financing to more actors.

**Advantage**: Subsidising loans puts a lower financial burden on public resources, because borrowers repay received capital and are therefore a financially sustainable way to support investments that are likely to produce a return. Furthermore, governments take the risk of financing early-stage technologies and services until these become commercially viable, at which point governments can retract concessional loans to allow financial institutions to finance such measures at market rates.

**Disadvantage**: The provision of affordable, easily accessible loans may result in indebtedness of households and companies, as seen in the 2008 financial crisis, and accrue already high levels of indebtedness of low-income countries. However, generously subsidised loans with long grace periods increase the burden on public budgets. Furthermore, subsidised loans can lead to the crowding out of capital, competing for financial profits with private sector actors. For that reason, it is important to regularly reassess the necessity of subsidised loans once commercial viability and financial feasibility of technologies and services are reached.

**Example:** Australia Clean Energy Finance Corporation (CEFC), an independently operated government institution, lends capital below market rates, at "risk-adjusted terms". The government of Australia allocated USD 1.52 billion to the CEFC to be disbursed between 2013 and 2018. Among other priorities, the CEFC specifically targets the funding of zero carbon buildings and energy retrofits for public buildings and social housing (Clean Energy Finance Corporation, 2019). Many more examples of governments providing debt solution below market rate exist (Bertoldi *et al.*, 2021) (see Element 4 – A multitude of actors).

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A (generally partial) credit risk **guarantee** and/or a performance risk guarantee allows the government to assume some of the risk of default that would otherwise have been assumed by the lender. Loan guarantees counteract banks' perceived higher risks of energy efficiency investments and enable the access to debt to clients with lower creditworthiness (Aditya, 2018).

**Advantage**: When entering public-private partnerships with financial institutions, governments often bear most of the default risk, so that financial institutions are more willing to provide (affordable) debt. The provision of loan **guarantees** enables financial institutions to venture in and build adequate capacities in new markets without taking more risk.

**Disadvantage**: The government takes on the risk of defaults, for which public resources need to be available. Financial institutions may also lower their due diligence processes as they do not bear the risk of default themselves, allowing the funding of low-quality projects, for example where energy savings may not be guaranteed. Furthermore, the provision of loan guarantees is only useful in countries with a fairly well-developed financial market "in terms of liquidity, competition, interest rates" and in which financial institutions are willing to venture in new funding areas (Aditya, 2018)

**Examples**: The US Department for Agriculture provides 'Single Family Home Loan Guarantees' to enable low- and moderate-income households to buy or retrofit a building. The government guarantee is available to approved lenders and is only applicable for borrowers with lower than average income and that are not able to access commercial debt (U.S. Department of Agriculture, 2020). The Bulgarian Energy Efficiency Fund (BgEEF), a public-private entity established in 2004, provides loan guarantees to ESCOs carrying out EPCs and thus enables them to access commercial debt to finance their activities. BgEEF also provides ESCOs with portfolio guarantees, applicable to the company's entire activities rather than a single loan. In case of payment delays from clients, the ESCO is guaranteed to receive up to 5% of total payments from BgEEF, minimising the risk that ESCOs default on their debt payments (Bullier and Milin, 2013).

A mix of finance instruments and public and private capital, often referred to as **blended finance** in the context of development aid, can help to support higher upfront investments. The principle of blended finance is that public financial resources are scarce and should leverage private finance for targeted purposes (Pereira, 2017). The blending of grant capital to a commercial loan reduces the overall capital to be repaid and the blending of subsidised debt at below market rates reduces the cost of the loan. Blended finance is especially relevant in the context of larger endeavours such as the construction of zero carbon buildings.

An additional relevant financial instrument to be integrated in blended finance is **performance-based debt-relief.** Borrowers can apply for partial debt cancellation in case the investments led to the forecasted energy savings. Debt relief is a form of grant financing since it is a direct cash inflow from the government's budget to borrowers. Performance-based debt-relief incentivises the borrower to ensure that investments result in energy savings and thus influence occupancy behaviour.

**Advantage:** Blended finance helps with reducing the total capital that needs to be made available by public sources and can potentially avoid crowding out private capital: in contrast to subsidised loans, that risk crowding out private funds[9], blended finance specifically targets the crowding-in of private finance by cooperating with commercial banks and non-public financial institutions. By blending financials instruments and public and private, the borrower is offered one single financial support package and does not need to make use of different funding avenues for one same project. Further, blended finance can also help get the financial sector accustomed to the type of projects to be financed in the long run, reducing some of the perceived performance risk.

**Disadvantage:** Commercial banks and financial institutions act as intermediaries between the borrower and government funds, which requires that banks build internal know-how and capacities to offer such financial packages.

**Example:** Germany's development bank KfW proposes a combination of finance instruments to finance decarbonisation measures, available at any commercial bank and in combination with commercial debt. Households and companies can access grant financing, for example for passive house construction planning or an energy efficient heat pump (KfW, 2021a).

[9] In the case that public banks provide subsidised loans below market rates they may compete with, and may displace, financial services by commercial banks. The crowding out of commercial debt counteracts capacity-building and mainstreaming of financial services for the targeted technologies, products or services to be financed.

## Tax instruments

Fiscal instruments can render the construction and purchase of zero carbon buildings and (deep) energy retrofits economically attractive. Fiscal instruments can be especially impactful in instances of high taxes, as is often the case for building / property owners and can thus incentivise investments even in the case that the owner rents out their property. At the same time, fiscal instruments can also discourage investments in emissions intensive technologies for example by increasing taxes on emissions intensive technologies or fuels.

Any carbon price on heating fuel should be carefully implemented to ensure that it does not increase the likelihood of people falling into fuel poverty. Carbon pricing should not be implemented as a single instrument but as part of a package of instruments that also protects the more vulnerable and ensures that comfortable homes are affordable for all.

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Tax reductions and exemptions are a widely used fiscal instrument to incentivise investments in higher risk and more expensive services and technologies. Tax reductions and exemptions generally apply to any tax, the most prominent ones are the value added tax (VAT) and the income tax.

Governments can apply a **VAT reduction** which translates in direct funding from the government to reduce or eliminate taxes for sustainable products and services (GlobalABC/IEA/UNEP, 2020). VAT reduction can target end-consumers for example by applying the VAT reduction to air conditioners or target actors in buildings' supply chain, for example by reducing the VAT on energy efficient building materials purchased by building developers.

**Advantage**: Governments can target certain services/technologies and reduce their tax burden to incentivise investments. The reduction of the VAT is particularly relevant for innovative services or products that come at a higher cost in comparison to their energy intensive counterparts. In case a service/technology reaches cost parity with more energy intensive alternatives by reducing or exempting the VAT, this fiscal instrument can be simpler to put in place than the provision of grants.

**Disadvantage**: A reduced VAT is lost revenue for governments. Similar to grants and subsidies, reduced VATs should be limited in time, for example when a new technology reaches cost parity.

**Example**: The UK government lowered the VAT for certain energy-saving products from 20 to 5% as early as 1998. Suppliers sell products at reduced VAT directly and additionally the installation of the product in buildings also benefits from the reduced VAT. The reduced rate is only applicable when sourcing energy services from professional contractors (Government of the United Kingdom, no date). In 2019, the government made significant changes to the support scheme, reverting the VAT of heat pumps and insulation material to 20% (Harvey, 2021).

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Similarly, governments can provide **tax credits**, whereby a percentage of the investment cost of approved technologies can be deducted from companies' or individuals' income taxes. Tax credits thus act similarly to grants and subsidies, but are administered via income tax declarations

**Advantage**: Tax credits are often designed with a specific technology focus, which mean that they are designed to stimulate investments in specific technologies and services rather than set overall energy performance criteria. Tax credits can have a positive impact early stage technologies and services: frequent updates of the eligible measures list can facilitate the introduction and uptake of new technologies and services to the market (Bertoldi *et al.*, 2019).

**Disadvantage**: The main beneficiaries of tax credits are high taxpayers, who may deduct several measures from their income tax. Companies or individuals paying lower taxes may not be able to take advantage of tax credits to the same extent, particularly as tax credits would apply at the end of a fiscal year. For example, low-income households may not find tax credits attractive and may not be able to pay for the upfront costs. Furthermore, governments often redirect income tax budget towards social welfare programmes, which would be diminished by such tax credit schemes. Finally, the tax benefit will only kick in at the end of a fiscal year which can be up to 12 months after the investment occurs. The delayed policy impact is likely to have a lower effect due to the time preference factor.

**Examples**: The city of Baltimore in the US offers tax credits for all new residential buildings that qualify for the minimum LEED Silver certification or better (Siva, Hoppe and Jain, 2017). Products and/or building components and refurbishments are also available in some European countries. For example, France and Italy have established tax credits as a policy to promote energy efficiency measures (Bertoldi *et al.*, 2019)

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Allowing for **accelerated depreciation** enables reporting of higher expenses in the first years after the purchase of an asset, reflecting the burden of high upfront costs. The reporting of higher costs reduces the tax burden in those first years.

**Advantage**: This fiscal instrument lowers the tax burden of eligible assets in the first years and may reduce the pay-back period of related investments (Nadel and Farley, 2013).

**Disadvantage**: Using accelerated depreciation for assets is complicated and its tax effect is minimal (Nadel and Farley, 2013). Furthermore, accelerated depreciation only applies to companies and not to individuals.

**Example**: In the US, smart meter equipment benefits from an accelerated depreciation, allowing taxpayers to recover the cost of the property over a 10-year period instead of the 20-year general recovery period for this type of property (U.S.Code, 1954; U.S. Department of Energy, 2007).

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**Energy taxes** are applied on energy carriers, the likes of natural gas or electricity. Energy taxes often reflect the emissions intensity of certain energy carriers and are thus also referred to as carbon taxes (OECD, 2019). Increasing energy taxes can create a larger incentive for efficient construction and energy retrofits.

**Advantage**: Energy taxes are simple and cost-effective and can have a longer-term impact as they are not bound by limited public resources. On the contrary, energy taxes can generate income for public budgets. Adjusting tax levels to the emissions intensity of energy carriers can help to reach a level playing field and internalise the cost of emissions in energy prices. Energy taxes incentivise energy efficiency equipment and low carbon energy production, such as a switch to electric equipment or solar PV.

**Disadvantage:** Past experience has shown that setting proper energy taxation is politically challenging, which has resulted in low energy taxes thus far (OECD, 2019). Further, energy taxes result in higher energy prices, which can disproportionately burden low-income households. More generally, energy taxes only affect the operational lifetime of a building, thus they are unlikely to affect energy-related decisions made by building developers who aim to keep construction costs as low as possible and will not be affected by energy prices.

**Example**: The Dutch government differentiates taxes by energy source, thus reducing electricity use taxes and increasing gas taxes in households to incentivise a switch away from gas (Vos, 2017).

In a **lien-based energy efficiency financing** scheme, governments or municipalities raise funds on capital markets through bonds and use these funds to provide loans to homeowners and commercial property owners to perform energy retrofits by professional contractors. Loan recipients repay borrowed capital over a certain time period (typically 15 or 20 years) through their property tax bills (Bertoldi *et al.*, 2019).

**Advantage**: Governments play an enabling role to finance and incentivise energy retrofits. They transfer national and municipal governments' typical affordable access to capital to property owners that may otherwise not have access to (affordable) debt for energy retrofits. This scheme requires little effort from property owners. The government acts as an intermediary between borrowers (property owners), contractors and capital markets. The scheme imposes limited costs to governments and facilitates the process of energy retrofit contracting and financing.

**Disadvantage**: A poorly designed property taxation billing scheme may lead to indebted clients, especially among homeowners. The lack of information available to owners and the absence of third-party verification and certification schemes may result in drastic increases of property tax bills that homeowners cannot afford. Clients that cannot afford to pay increased property taxes are eventually forced to sell their homes through public auctions because they are indebted to the state (Bloomberg Green, 2021; Energy News Network, 2021).

**Example**: In the US, a number of states have proposed such property tax bill schemes, called property assessed clean energy (PACE) programmes, for over two decades. In 2019, the US federal government started a nation-wide PACE scheme (Bertoldi *et al.*, 2019). The lack of liability from involved parties has left numerous property owners unable to repay borrowed capital, often due to misinformation on the part of contractors (Bloomberg Green, 2021; Energy News Network, 2021). In case of default, municipalities and the government have priority access to the property, whilst investors of PACE bonds have no certainty to recover their capital. Notably, the U.S. mortgage authorities, Freddie Mac and Fannie Mae, refused to finance mortgages with an affiliation to the PACE programme (Nicholas Groom, 2015). As a response to lenders' concerns, the State of California recently established the loss reserve program to refund lenders in case of mortgage defaults associated to the PACE programme (California State Treasurer, 2021).

**Energy efficiency adjusted property taxation** is a fiscal scheme that links the taxation level of a property to the building's energy efficiency level. It is essentially a form of tax exemption but is linked to the energy performance of a building. Higher energy efficiency levels result in a lowered property tax. The energy efficiency adjustment can be applied to 'recurrent immovable property taxes', for example due on a yearly basis, as well as to the 'capital gains tax', when a property is sold/purchased. Bertoldi *et al.* (2019) suggest that buyers of a new property may be given a grace period before such a tax applies, so that they could invest in energy retrofit measures and improve the building's energy performance in that period.

**Advantage**: Through this fiscal scheme, governments incentivise property owners to invest in energy retrofits so to reduce their tax burden. This scheme could have limited impact on public budgets, in the case that tax levels are increased for inefficient buildings and decreased for efficient ones.

**Disadvantage**: Property taxation is often an important source of income for municipalities so that reducing it may lead to lowered public budgets. Further, the property tax can reflect more than a simple tax on land but also public services and land use policies (Blöchliger and Kim, 2016). A reduction in property taxes and transaction taxes can also have limited impact in regions where such taxes are already low. Recurrent immovable property tax levels widely vary between countries. For example, it is around 0.3% in Mexico and over 4% in the UK (OECD, 2021).

**Examples**: The region of Flanders, Belgium, adjusts the recurrent property tax level based on the property's energy performance level since 2013. The tax on energy efficient buildings is part of a long-term plan to decarbonise all buildings by 2030. It can be reduced by 20 to 100% for a period of five to ten years. The share of zero carbon buildings in the region increased from 10% to over 50% of all new buildings between 2013 and 2016 (Verbeeck, 2019; Jankovic *et al.*, 2022). In France, certified low energy buildings are partially or wholly exempt from the property tax for a certain period of time. Similarly, Mexico City offers real estate tax reductions for certified sustainable buildings (KPMG, 2017)

## Regulatory instruments

Governments can further incentivise investments in Zero Carbon Building and energy retrofits by mandating energy efficiency investments. The most straight-forward policy instrument to ensure that investments are redirected to energy efficient buildings and technologies are building energy codes and MEPS (see Element Two — Minimum Energy Performance Standards). Because such regulatory instruments are reviewed in a separate section, we only scope out energy efficiency obligations, which directly mandate investments into energy efficiency measures.

**Energy efficiency obligations** require energy utilities to meet energy savings targets through investments in eligible end-use energy-efficiency measures. Market participants need to pay financial penalties if they do not reach the mandated energy savings (Novikova et al., 2017; Bertoldi et al., 2021).

The introduction of certification of project-based savings and the possibility to trade certificates (referred to as white certificates) is an additional policy option related to the implementation of energy saving obligations. The savings related to the implementation of energy efficiency projects are verified by an independent party (either ex-ante or ex-post) and certified by means of white certificates. In the EU, Italy and France are the only countries where the policy portfolio includes energy savings obligations in combination with fully tradable white certificates.

**Advantage**: Implementing an obligation on energy utilities does not burden public funds, apart from some administrative costs in setting up such a scheme and monitoring the achievement of energy savings. This policy instrument mandates energy utilities, rather than end-consumers, to invest and perform energy retrofits. Energy utilities are affected by the transformation towards electrified zero carbon buildings (see Box 9: Implications for energy utilities) so that they can be an entry point for public interventions.

**Disadvantage**: Energy efficiency obligations are large-scale schemes, as a result they are very sensitive to projected energy savings, which have been difficult to accurately predict and report (Bertoldi *et al.*, 2021). Energy utilities do not benefit from the measures they implement – on the contrary the measures result in income loss – so that the scheme may not incentivise deep energy retrofits. Instead, it is likely that energy utilities focus their investments on low-hanging fruits that are economically more attractive. Furthermore, such schemes require a strong regulatory and governance framework (Novikova *et al.*, 2017).

**Examples**: Energy efficiency obligations schemes are in place in several European countries including Denmark, Belgium (the region of Flanders), France, Italy, and the United Kingdom. Since the introduction of the EU Energy Efficiency Directive (EED), that include energy efficiency obligation schemes, 16 schemes existed in 2017. France and Italy have also introduced white certificates, allowing the trading of energy savings (Bertoldi *et al.*, 2021).

## Case studies

Of the diverse set of funding options and policy instruments that enable a shift of investments to decarbonise the buildings sector, we scope three case studies. We use these examples to highlight where and how discussed funding options and policy instruments have been (successfully) implemented. For each case study we assess the transformational impact along guiding questions as set in Table 6 and consider the enabling factors behind each case study.

Table 6: Considerations of transformational impact and related guiding questions used to scope and assess good practice case studies.

| Consideration | Guiding question |
|---|---|
| **Mitigation potential /impact** | What is the emissions mitigation potential and impact of the case study? |
| **Challenges addressed** | What challenges were overcome in the case study?<br>▶ Inability to pay for upfront costs<br>▶ Fluctuating energy prices<br>▶ Lack of access to (affordable) funding options<br>▶ Perceived risk of energy efficiency investments<br>▶ Time preference<br>▶ Lack of awareness of funding options<br>▶ Split incentive |
| **Replicability / Scalability** | How easy is the action to replicate under other conditions, such as climate or governance context, and to scale up? |
| **Equity considerations** | It is important that a transition to a decarbonised buildings sector doesn't exacerbate existing global and national social inequalities. How were equity considerations included (or not) in the case study? |

## Case Study 6: Germany's KfW's financial support scheme linked to voluntary building energy codes

Germany's development bank, the KfW, provides a mix of public financial instruments to incentivise the construction of and retrofitting to highly energy efficient buildings. The mix of finance instruments composed of grants, subsidised loans, loan guarantees and performance-based debt-relief results in a financial support package that is offered and disbursed by commercial banks. These financial support packages are linked to building standards that go beyond minimum energy standards and thereby can support the setting of more ambitious building energy codes.

### Mitigation impact

Financial incentives are performance based: the amount of financial support is directly linked to the energy levels of the constructed or retrofitted building. The scheme incentivises the uptake of additional debt to reach higher efficiency levels (Diefenbach *et al.*, 2019). A more recent type of grant that was added to the financial support package is 'performance-based debt-relief'. Building owners can diminish their debt levels upon proof that their building consumes a certain (low) level of energy (KfW, 2021d, 2021b). Therefore, building owners have an additional incentive to ensure that the measures lead to reduced energy consumption and may influence building occupants' behaviour.

Germany's mandatory building energy code for new builds was updated in 2021 and left no room for more ambition that would require financial incentives. Public funds were thus redirected to the retrofitting of existing buildings. Due to the lack of a long-term vision for the building sector and a clearly communicated phased approach of financial support the ending of the scheme for new builds in 2022 faced immense backlash from the construction industry (Tagesschau, 2022). The support scheme will be linked to avoided $CO_2$ emissions in the future with the aim to link financial support more closely to the mitigation impact of measures.

### Challenges addressed

The financial support packages combine several financial instruments and thus encourage investments in mitigation measures by reducing and spreading upfront costs over a longer period. Because the financial support package is distributed by commercial banks, the public support scheme grants a higher share of 'investors' access to affordable debt. In such a scheme, commercial banks bear the responsibility to inform clients of public financial support available to them, which may increase the awareness of public funding options of building owners and enhance know-how in the banking industry. The scheme is based on a list of approved banks and energy service contractors so that the scheme can also alleviate challenges related to a perceived risk of energy efficiency investments and lack of trust in service providers.

### Replicability / scalability

- Climate: The financial support package is not linked to single technologies and thus it can be replicated to all climates.
- Governance: The scheme heavily relies on commercial banks to play an intermediary role between public funds and investors. Therefore, a robust governance structure of commercial banks is required. Moreover, the scheme requires a well-developed finance sector so that the scheme may not be fully replicable in countries where banks focus their services at deposit options and lack capacity to offer other financial products, such as debt.
- Building type: The financial support package is available for the construction and retrofitting of residential, commercial, and public buildings (municipalities can apply for financial support).
- Track record: The scheme has been in place since 2005 in Germany and has developed since. In 2017, the scheme supported close to 40% of all newly constructed dwellings. These close to 120 000 dwellings reached higher energy efficiency levels than set by the national building energy code (Diefenbach et al., 2019).

## Equity considerations

The scheme only targets the additional investments required to construct buildings beyond mandatory MEPS. Although it can be combined with other support schemes, it may not be applicable to a large share of the population that cannot afford to buy their own property.

## Enabling factors

The ease of access to public finance and the support provided by funders to investors facilitates the uptake of debt to cover higher upfront costs of zero carbon buildings and (deep) energy retrofits. Moreover, the government backs loans for the construction of, and retrofitting to, zero carbon buildings and therefore reduces funders' perception that such investments are risky. Another enabling factor is the fact that governments can transfer their access to debt at lower lending rates to investors. For that reason, this scheme is an entry point for development aid between countries with access to low interest rates to countries with higher lending rates.

## Case Study 7: Netherlands - Energiesprong's standardised EPCs for affordable, quick, and deep energy retrofits

Energiesprong (energy leap) is an energy service company (ESCO) providing energy performance contracts (EPC) to households to perform deep energy retrofits. The retrofits are standardised solutions that can be rolled out to many similar buildings. The economies of scale allow for affordable and quick interventions in up to ten days. The energy retrofits consist of new pre-fabricated façades, the installation of smart heating and cooling systems, such as heat pumps, and the insulation of rooftops with integrated solar photovoltaic panels (Energiesprong, 2022). The intervention is financed through energy savings so that monthly costs remain the same for 30 years, after which no more costs occur to the customers. The EPC also include a 30-year warranty.

Stylised energy performance contract (EPC)
**The example of the energy service company Energiesprong** (The Netherlands)

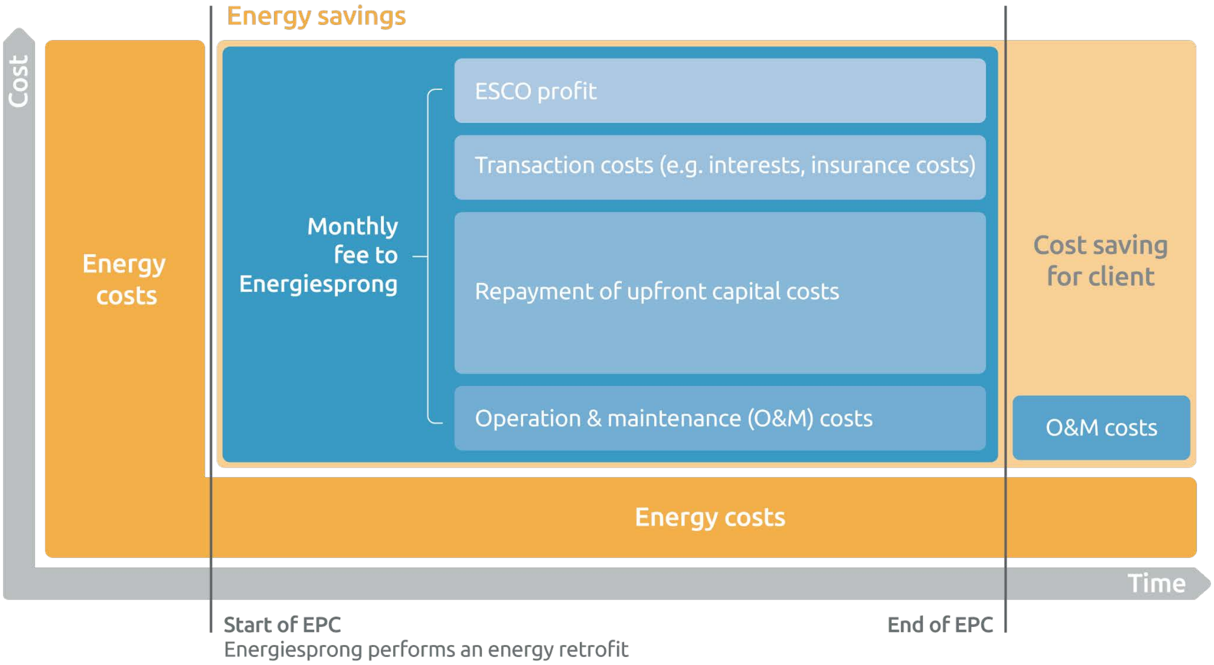



Figure 21: Stylised energy performance contract (EPC) with Energiesprong. Source: Authors.

### Mitigation impact

Energiesprong enabled deep energy retrofits through an "all-in-one" approach that addresses several components at once to reach a net zero energy building standard. The mitigation potential is therefore especially high in countries with a large existing building stock.

### Challenges addressed

From the perspective of building owners and occupants, Energiesprong addresses all challenges identified in this report, reflecting its transformative potential in the buildings sector. Energiesprong removes the burden of high upfront costs and long payback periods since the customer 'only' continues to pay fixed or reduced energy bills over a set period of time, after which the installed equipment belongs to the customer at no additional cost. The payment of fixed monthly fees also removes the challenges linked to volatile and/or uncertain future energy prices.

Because Energiesprong finances and implements the energy retrofit, it further removes the barriers concerning access to capital of individual owners, lack of awareness of finance options, perceived risk that energy savings may not pay out the original investment, and lack of incentive due to the time preference phenomenon. The 30-year warranty provides additional security to customers and alleviates the potential mistrust in energy contractors.

Other non-financial challenges addressed are the invasive, time intensive, inconvenient aspects of energy retrofits, since the intervention only last up to ten days and building occupants may not need to leave the building. Additionally, provision of the retrofits and finance being provided through a single entity simplifies the process from the perspective of the building occupants and / or owners.

## Replicability / scalability

Energiesprong has a promising replicability and scalability potential, as was intended from the outset of the concept and demonstrated through initial projects in several countries. The scalability of the model may be more difficult in countries with weaker regulatory frameworks, however the lack of experiences in such countries renders the assessment difficult.

- Climate: The energy retrofits are designed around better insulation, rooftop solar PV and heat pumps. Air conditioners, which cost less, could replace heat pumps in warmer climates where buildings do not require heat. The model of combining building envelope components, energy efficient heating and/ cooling systems and solar PV is likely replicable to other climates with appropriate modifications.
- Governance: EPC and warranties need a sound regulatory environment to properly overcome challenges. Further, Energiesprong reports that legislation needs to be amended to allow the conversion of monthly energy bills into monthly energy service fees in the context of housing associations (Energiesprong, 2022).
- Building type: The model is particularly scalable for apartment and office buildings because these buildings are often relatively standardised compared to single houses or public buildings. The model is, however, also replicable to individual houses given enough demand for a similar type of single houses is available. For that reason, this model is particularly suitable for social housing, which often comes in the form of apartment buildings or standardised single houses.
- Track record: The Energiesprong model has expanded from the Netherlands to neighbouring countries: France, Germany, Italy, and the United Kingdom. The project also expanded from residential to public buildings. A similar model has been replicated in the US through the initiatives ‘Casa pasiva’ and ‘REALIZE’ in New York City and California (RMI, no date; Sisson, 2020). The model of standardised and prefabricated solutions was successfully replicated to buildings in the US, including old houses in New York City, despite different technical requirements as compared to European buildings.

## Equity considerations

Customers need only switch contracts from energy utilities to energy service companies, so that the intervention poses no additional financial burden on households. The ESCO model can also provide more predictable energy costs that are less sensitive to fuel price fluctuations than existing models.

Furthermore, the use of standardised and prefabricated solutions results in affordable solutions. For example, Energiesprong has been implemented in several social housing projects, notably in the UK. On the other hand, households without stable income may be trapped in an EPC they cannot afford to reliably pay on a monthly basis.

## Enabling factors

Governments have played a key role in providing the enabling conditions for the kick-off and upscaling of the Energiesprong initiative.

- Financial support: Energiesprong is a public-private partnership. It has received public support in all countries it has expanded into. Governments could further reduce the VAT on EPCs to make the service more attractive to investors. Governments can also provide financial support to ESCOs to facilitate their access to capital.
- Regulatory support: Government can adapt legislation to accommodate the conversion of monthly energy bills into a monthly energy service fee and enhance trust in EPCs by backing such schemes.
- Role model: Governments can act as front-runners by making use of the Energiesprong model for social housing operated by public entities and government buildings, as done in the UK.

## Lessons learned

Large scale and timely investments in the order of USD 440bn per year are needed to decarbonise the global buildings sector by 2050 – this represents less than 15% of current capital spent in the construction of new buildings.

Around 40% of capital flows in the buildings sector are spent on energy use, mostly from fossil fuels. These finance flows need to be redirected towards measures to decarbonise space heating and cooling: a shift of finance flows is required. Such a shift of investment would globally reduce household spending on energy bills from 5% today to 2.5% in 2050.

Costs are coming down and, in some situations, the costs of zero carbon new builds are comparable with conventional builds, as seen in California. Unfortunately, the overall costs of low carbon options are not always cost-competitive, even when long-term energy savings are taken into account, and financial support is needed to ensure these low carbon options are taken up.

Policies so far, sometimes in place for several decades, have not been able to trigger a transformation wave: the transition in the residential sector is particularly slow. This can, in part, be explained by other financial challenges and barriers that hinder the uptake of zero carbon building construction and retrofits, such as a fragmented actor landscape, unclear time periods on return of investments, lack of access to low-cost debt, perceived investment risks, and lack of awareness of available options.

Energy prices have a direct impact on the cost-competitiveness of energy efficiency measures and the electrification of heating, particularly through payback periods. Energy or carbon taxes can be used to discourage the construction of energy intensive buildings, or the purchase of fossil fuel-based space heating and cooling equipment, but should be used with care to avoid exacerbating energy poverty and social inequalities.

Availability of funds and ability to access funds varies greatly between and within countries. In almost all countries a non-negligible share of the population is subject to energy poverty. Debt is the most common funding option to construct, and sometimes also to retrofit, buildings, but green bonds and contract financing for the retrofitting of existing buildings have emerged as alternative funding streams.

### Recommended interventions

- If not yet established, utilise **grants** to get nascent industries and technologies off the ground until cost parity is reached and a skilled workforce established.
- Support compliance with building codes by making compliance more affordable through improving access to **low-interest loans** or grants. Supportive actions include the development of comprehensive financial support packages offered through private banks (e.g. the KfW scheme in Germany) and the establishment of green banks (see also Green and development banks).
- Such financial support schemes can also be an entry point for governments of high-income countries to transfer their access to affordable debt to governments of low-income countries subject to higher lending rates (concessional debt).
- When switching from fossil-based to electric heating, **carbon taxes on fossil fuels** can be used to improve the cost-competitiveness of low-carbon technologies and make low carbon options cost-competitive in the long-term. Carbon taxes could be implemented alongside policies that ensure low-income households can afford appropriate retrofits or rents in retrofitted buildings and therefore also benefit from the energy and cost savings of switching to zero-carbon heating / cooling. Options could include using carbon tax revenues for supporting retrofitting in low-income households through grants, or paying back the revenues to the population, favouring low-income households.
- Modify **regulations** to allow for innovative financing models, such as monthly energy service billing, that improve the accessibility and ease of attaining low-cost finance, while decreasing the risks.

Many of these options are not new, although some are becoming more common. Each of them can provide a key component in a broad strategy to scale up zero carbon construction but are generally not sufficient when utilised as single instruments. They can, however, enhance compliance with building codes (Element Two — Minimum Energy Performance Standards) and enable various actors (Element Four — A multitude of actors) to make a shift.

# Element Four — A multitude of actors

Of all the economic sectors needing to be decarbonised, the buildings sector has a uniquely complex path to this end goal. The number and variety of stakeholders that need to be engaged to achieve buildings decarbonisation far outnumbers those of any other sector, with a global building stock in excess of 240 billion $m^2$ and given the multi-faceted approach needed to reduce emissions (IEA, 2020e).

To expedite buildings decarbonisation, finding novel ways to engage the various key stakeholders, incentivise them to take the measures necessary, and facilitate new forms of cooperation will be key. Building decarbonisation can be subdivided into two distinct challenges, ensuring new builds are zero carbon, and renovating the existing building stock to a sufficient level of energy efficiency. The first of these challenges involves far fewer actors than the second given the lack of individual owner-occupiers and renters, but nonetheless entails a wide array from various sectors.

This chapter will first describe the landscape of actors across the various facets of the buildings sector, underscoring the multitude of relationships and roles they play. Special focus is given to the nature of the landlord-tenant relationship and how the 'split incentive' dilemma can be resolved. Several case studies are provided that illustrate novel ways that the many key actors within the buildings sector have been effectively engaged in countries from around the world. Finally, a summary of key lessons learned is provided to conclude the chapter.

## State of Play

Buildings sector actors can be broadly split into the sub-categories outlined in Figure 22: institutional, financial, and built environment. These overarching categories of buildings sector actors will be explored individually in the following sections with examples provided for clarity. Good practice examples relating to the engagement with, and cooperation of, the multitude of buildings sector actors are covered later in the chapter.

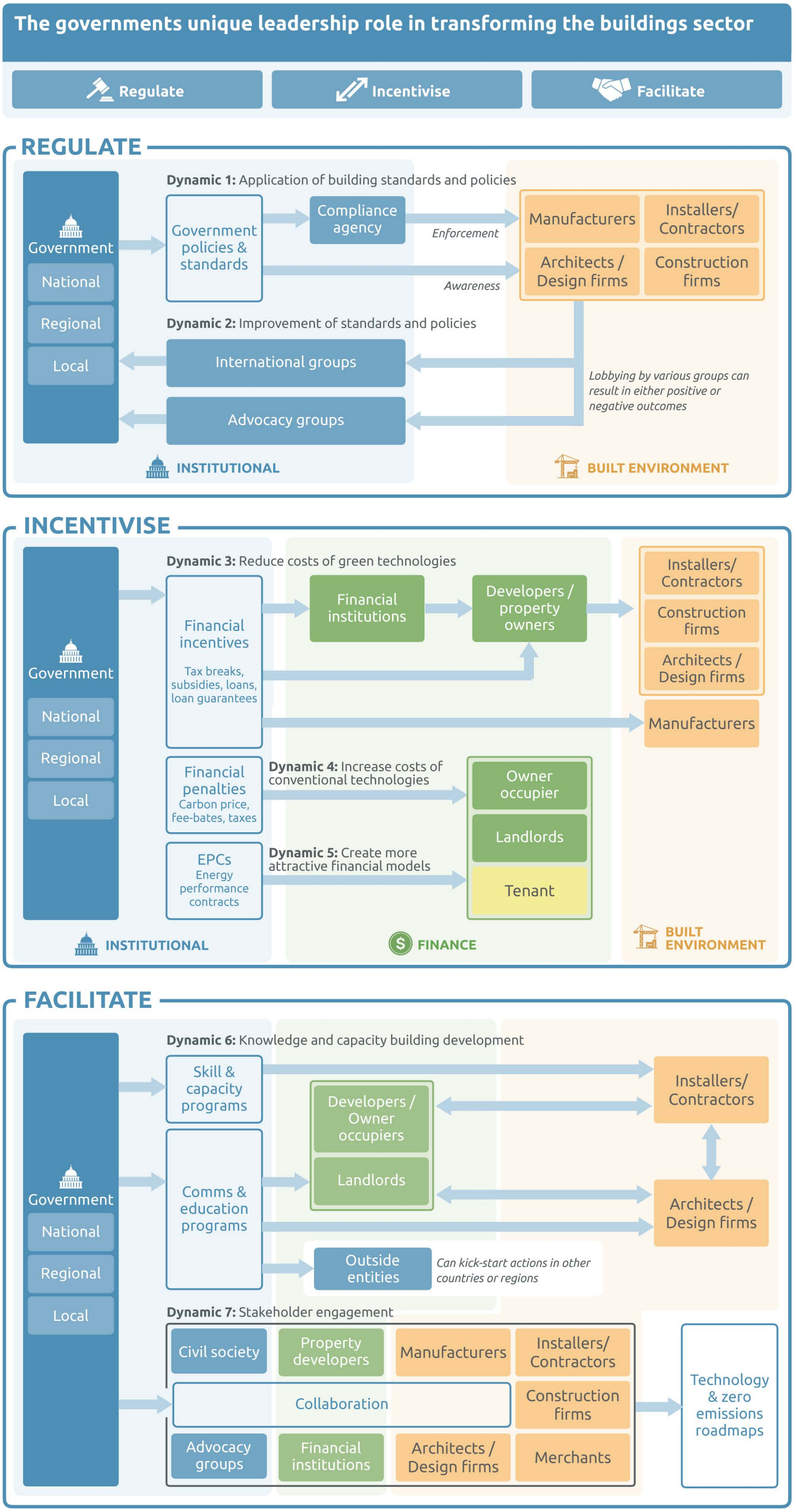



Figure 22: Key actors in the buildings sector that need to work together to decarbonise all buildings.

## Institutional Actors

Aside from the set of actors involved in financing, designing, and constructing energy efficient buildings or retrofits, a wide variety of actors play advocative, educational, or facilitative roles across the buildings sector. The nature, scale of operation, and relative impact of these actors varies substantially.

Several associations composed of built environment actors exist to advocate on their behalf, or to bring together actors seeking to proactively instigate a transformation in the buildings sector. These exist at both the national and international level, but until now, have had limited impact on catalysing wholesale change. Governments, however, play an outsized role among institutional actors in buildings decarbonisation efforts given their unique ability to effect change through numerous channels.

### Government

At all levels of governance, national, regional, and local, governments have a unique ability to impact actions across a wide variety of domains and by a diverse set of actors. By stating an intention to achieve a particular outcome, governments perform a leadership role that directs attention and resources to that end. The types of actions governments can take to create such impacts can be broadly delineated into three categories. These three types of actions, and the nature and directionality of relationships between key actors are outlined in Figure 23.

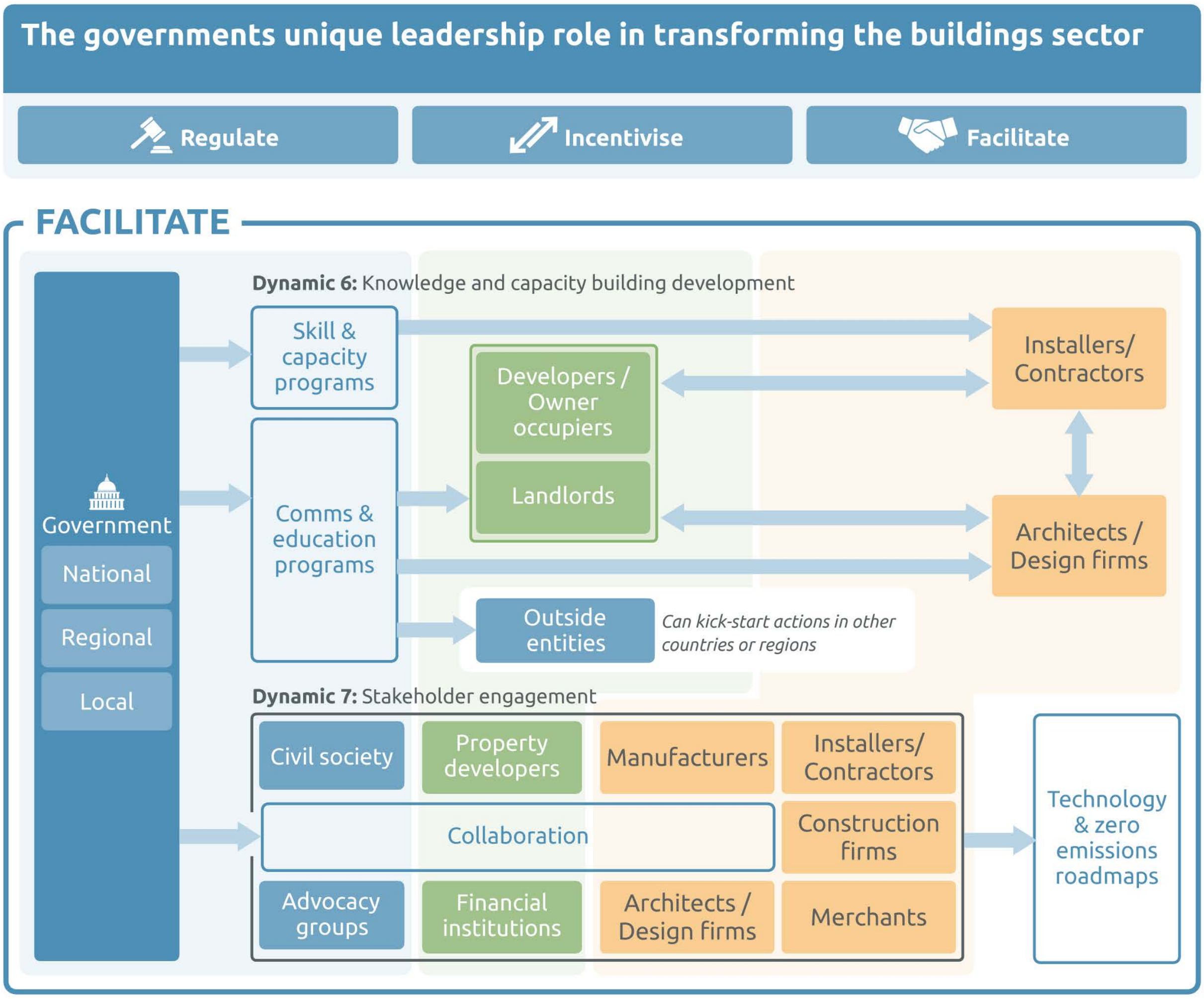



Figure 23: Governments' unique leadership role in transforming the buildings sector

Key capabilities and opportunities stemming from each overarching category of actions from Figure 22. are explored below.

### Regulate

- National or regional climate change targets set the overall framework in which sectoral activities are conducted.
- Legislative ability of governments is a uniquely powerful tool for effecting change
  - See Element Two — Minimum Energy Performance Standards
- Urban planning to maximise housing density, establish district heating/cooling (Box 10: Urban Planning)
- Targeted regulation prohibiting specific technologies, developing appliance energy efficiency standards, or banning gas connections to new buildings provides certainty of expected emission savings compared to reliance on compliance of developers and property owners with MEPS
- Specific regulations on, for example, HFCs, can be used to ensure that all emissions sources are covered and compliance with international agreements.

### Incentivise

- Combining incentivising measures like subsidies, tax breaks, debt guarantees, and low interest loans with MEPS can increase the likelihood of compliance from developers and installers
- Broad fiscal capacity enables strong incentivisation of key financial and built environment actors
  - Bringing key technologies to price parity disincentivises actors to ignore MEPS and catalyses faster adoption
- Complex approaches that leverage fiscal capacity like green banks or instruments that provide low interest finance or loan guarantees creates the ability to engage with a broad set of actors, including those in the 'Financial Actors' section of this chapter
- Creating disincentives to guide behaviour is key and is the domain of governments (e.g. buildings sector carbon price, taxes on inefficient appliances)

### Facilitate

- Broad number and variety of interfaces between governments and other actors reflects unique capacity to establish collaborative initiatives
  - Such fora can help broaden understanding of sub-sector-specific issues and formulate coordinated strategies to move whole sector forward
  - e.g. Fossil Free Sweden – Heating roadmap, EU BUILD UPON initiative
- Ensuring maximum participation minimises risk of unintended consequences stemming from devised strategies, enables key issues facing various actors for which there is currently no viable solution to be highlighted, potentially leading to a commitment of further study (e.g. Fossil Free Sweden initiative – see 'Case Studies' section of this chapter)
  - UK Clean Homes Grant highlights the potential for dysfunction due to lack of consultation with key actors (see Technologies section)
- Availability of measures to support the improvement of building energy efficiency and the importance of such measures for climate change mitigation must be widely known to maximise uptake
- Governments can invest heavily to promote these measures due to absence of profit-making imperative
- Government-funded or –subsidised training opportunities are an important supply-side approach to facilitate the future increase in demand for skilled installers
  - A study of EU Member State National Energy Efficiency Action Plans concluded that the provision of such training opportunities is lacking in more than half of Member States (Rivas, Cuniberti and Bertoldi, 2016).
- Commissioning research to better understand key barriers to progress can better inform government policy, correct potential misconceptions held by buildings sector actors, and incentivise them to voluntarily adopt more sustainable practices and materials.

## Box 10: Urban Planning

A key competency of governments, particularly at the subnational level, is ensuring urban areas are laid out in a manner that maximises quality of life for its inhabitants and economic potential, without creating unexpected social or environmental consequences. Forward thinking urban planning can make a significant contribution to buildings sector decarbonisation in several ways (Figure 24).

1. **Increasing overall housing density**

   In countries with low-density urban areas such as the US and Australia, changing zoning laws to allow and encourage greater housing density can help to improve overall energy efficiency. High density residential urban areas with lower surface-to-volume ratios generally exhibit lower energy service demands, and projections of future global building energy demand show increasing housing density can achieve even greater energy savings as efficiency measures by 2050 (Ürge-Vorsatz, Petrichenko, *et al.*, 2012; Güneralp *et al.*, 2017).

2. **Heat resilient urban design and infrastructure**

   Urban environments retain heat to a greater degree than their surrounding areas due to a higher proportion of dark surfaces like roads, roofs, and sidewalks. To mitigate these 'urban heat islands', urban planners implement three key categories of actions (UNEP, 2021b). The first is to reduce the amount of sunlight such surfaces absorb through 'green' roofs and walls, by increasing urban vegetation, especially trees, or by painting common surfaces like roads and roofs white. Second, shifting transport away from single occupancy vehicles and switching the rest to electric can reduce the overall heat production in cities. Lastly, planning streets and designing buildings to maximise ventilation and maximising green spaces will help to dissipate heat.

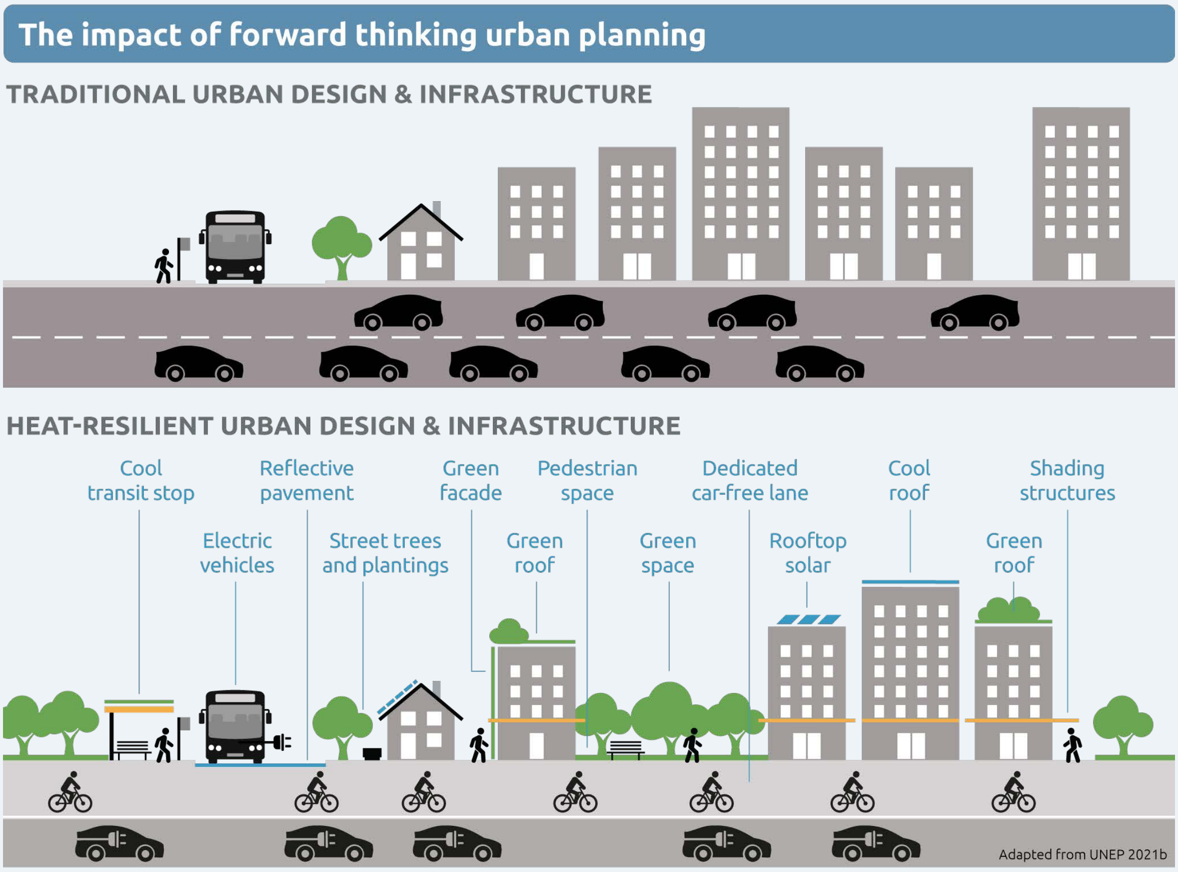



Figure 24: Conventional (top) versus heat-resilient (bottom) urban areas

*Source: UNEP, 2021b*

3. **District heating/cooling**

   Establishing a district heating or cooling network is a way to centralise the heating or cooling requirements of a large number of buildings in one area, leading to higher overall energy efficiency than alternatives that service individual buildings or dwellings. To construct a district heating/cooling network requires considerable planning and investment of resources and the coordination of several groups of stakeholders (Box 5: Role of district heating and cooling).

### Advocacy Groups

A wide variety of groups have been established for the purpose of advocating for either the interests of specific buildings sector actors, or for the transition to a sustainable buildings sector. These include building industry associations, national and international NGOs with a specific climate or sustainable buildings sector focus, and philanthropic organisations.

Built environment advocacy groups exist to promote the interests of their members, which can consist of manufacturers and installers of particular building components or technologies, or of a broad collection of buildings sector actors. The interests of buildings sector associations represent a far broader spectrum than climate considerations, and therefore are often not a key focus of their advocacy efforts, limiting their impact on buildings decarbonisation. Evidence suggests they are more likely to instead respond to signals on climate action in the buildings sector from government (Hurlimann, Warren-Myers and Brown, 2019).

In contrast, industry associations for individual technologies like heat pumps provide a clear voice advocating for an expedited transition to near zero energy buildings. In instances where national governments are falling short in the ambition of their building decarbonisation measures and targets, such technology-specific industry associations can play a role in increasing pressure on these governments to act via marketing campaigns or partnerships with relevant not-for-profit organisations. Conversely, industry associations representing fossil fuel-based technologies like the American Boiler Manufacturers Association and the American Gas Association provide pushback against regulations that would affect their viability (Pontecorvo, 2021).

The European Heat Pump Association (EHPA) is an example of a prominent industry group that has done both. It has partnered with the Energy Efficiency in Industrial Processes platform for the purpose of "promoting awareness and proper deployment of heat pump technology in the European market for residential, commercial, and industrial applications", and ran an award-winning communications campaign promoting heat pumps to the general public (EHPA, 2019; EEIP, 2021).

International organisations like the EHPA can play a variety of roles; the case of the EHPA is unique in that it operates in a supranational jurisdiction, where it is able to advocate at the EU level. The sphere of influence of other international organisations is often less clear-cut, but their broad approach to advocacy and knowledge sharing can make unique contributions to global buildings decarbonisation efforts.

## Box 11: What role for international organisations?

The varied roles of international organisations focused on expediting decarbonisation of the buildings sector can be broadly divided into three categories:

- Advocacy or lobbying key stakeholders
  - e.g. World Business Council for Sustainable Development (WBCSD), Zero Carbon Buildings for All, World Green Building Council
- Knowledge creation and sharing
  - e.g. Architecture 2030, Global Alliance for Building and Construction, IEA Technology Collaboration Programme on Heat Pumping Technologies (HP TCP)
- Attraction or leveraging of finance, or direct funding
  - e.g. Clean Cooling Collaboration, UNEP Finance Initiative: Responsible Property Investment Initiative, Renewable Energy and Energy Efficiency Partnership (REEEP)

Numerous key international organisations engage in more than one of these important activities, with many of them boasting an influential set of partners or member organisations. These include national and subnational governments and government institutions, other international organisations, private sector companies, and industry groups. With the comprehensive number and reach of such organisations, a focus on strengthening those that exist should be prioritised over the establishment of new ones.

Engaging with governments in international fora to advocate for a greater focus on buildings decarbonisation is an important role, and every avenue available to pressure policymakers to act should be utilised. Similarly, providing a source of reliable and relevant information to countries or subnational stakeholders that have not yet derived such information themselves can be impactful. Such knowledge transfer is particularly relevant for developing countries that may lack the mature industries to produce it domestically. The impact of organisations providing or leveraging finance can be especially pronounced in developing countries which may lack necessary resources.

Just as commitments to overall global climate finance are so far insufficient to enable 1.5°C-compatible development in developing countries, greater funding and assistance through knowledge transfer to expedite decarbonisation of buildings in these countries is critical.

In developed countries, however, international organisations are but one piece in a multi-faceted process that relies largely on government intent and action to bring the necessary actors together and commit sufficient resources to spur progress.

## Financial Actors

Financial capital is a key ingredient to expedite the transition to a decarbonised buildings sector. The key challenges are finding ways to direct money where it is most effective, and finding ways to maximise the overall financial contribution to this goal.

To a large extent, government funding will be required in the form of subsidies, tax breaks, and direct investment in social housing construction and upgrades. However, governments cannot do all the heavy lifting; leveraging government funding with private sector investments can be a powerful tool to achieve emissions reductions.

Figure 25 underscores the key role governments play in both the direct funding of creating zero carbon buildings, and the incentivisation of financial actors to invest.

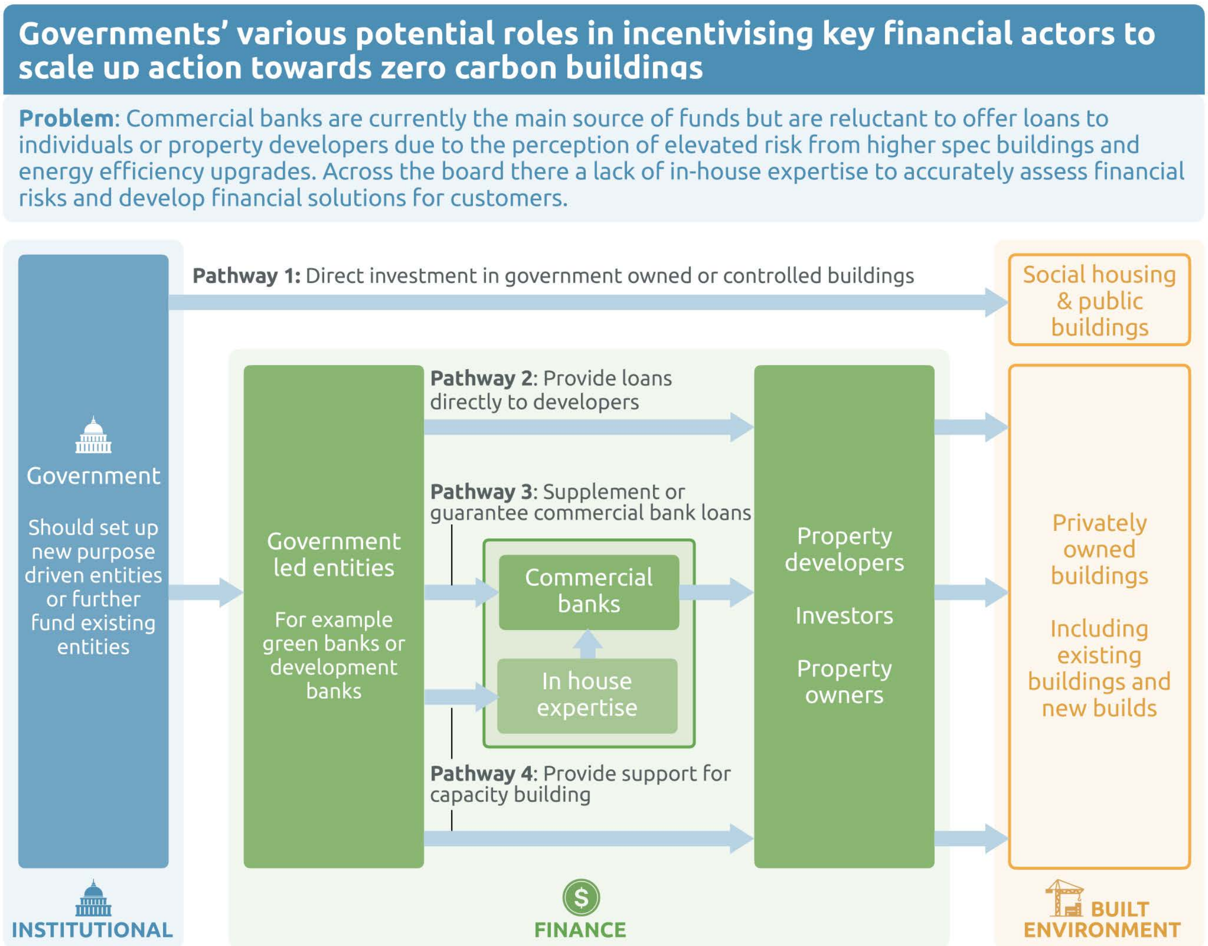



Figure 25: Governments' role in incentivising key financial actors

### Green and development banks

A well-tested and versatile approach to leveraging public funds is the creation of 'green banks', publicly capitalised entities set up to catalyse private sector investment in emissions reduction projects. These can be established at the national level, as seen in the UK, Australia, Japan, New Zealand, and Malaysia, or at lower levels of government like the state level green banks widely established in the US (Green Bank Network, 2020).

Development banks, publicly capitalised entities with a broader mandate and geographical scope, can also be directed to finance climate-related initiatives. Germany's development bank KfW has done just that by adopting sustainable promotion as its primary objective. Of its EUR 106bn total loan commitments in 2020, energy efficient construction and refurbishment in the housing sector constituted roughly a quarter of this total volume, rising 140% year-on-year (KfW, 2021c). Given the diluted climate mandate of development banks compared to climate-focused green banks, a priority should be given to establishing green banks in instances where neither yet exists.

Green banks and development banks have the unique ability to collaborate across a wide variety of key financial actors that must be engaged to ensure the wide-scale progress needed across the buildings sector. They can provide low-cost finance where otherwise it may have been prohibitively expensive from commercial banks, and incentivise investments from other financial actors such as property developers.

An obligation to finance profitable projects domestically that provide a return on the investment of public funds can make these banks more politically palatable than direct expenditure that adds to national debt levels. For development banks that also operate in developing countries, ensuring a timely drawdown of financing activities for energy efficiency projects is crucial to enable a local financial sector to develop.

The 'Actors case studies' section (Case studies, p. 97) highlights a number of green bank initiatives from Australia's Clean Energy Finance Corporation. These initiatives show three distinct avenues for non-commercial banks to channel public funds to achieve emissions reductions in the buildings sector, while engaging various stakeholders and stimulating private sector investment. The security of funding and government guarantee also fosters a greater creative potential, meaning that innovative solutions that may have been considered too risky by existing stakeholders can be explored.

### Other government-backed financial institutions

Some commercial banks already offer financing for energy efficiency retrofits, but many are hesitant due to a perception of such projects representing an elevated level of risk. In addition, commercial banks generally lack expertise related to energy efficiency upgrades, creating a perceived barrier to financing them (PF4EE, 2019). One approach that has been shown to overcome this barrier is the establishment of a government-backed financial instrument that can simultaneously guarantee commercial loans and provide expertise on energy efficiency projects such as the EU's Private Finance for Energy Efficiency instrument (Case studies, p. 97).

### Energy service companies (ESCO)

Some companies have stepped into this vacuum of commercial energy efficiency financing by establishing an alternative business model that provides 'energy-as-a-service', a type of contract financing (Element Three – Financing, p. 51). These companies eliminate the need for commercial banks to directly finance energy efficiency upgrades by liaising directly with property owners to offer efficient technologies at zero upfront cost and charging a recurring fee that is lower than the calculated savings generated by the project. ESCOs also have expertise that both commercial banks and property owners may lack, further helping to incentivise the uptake of energy efficiency projects. The financial risk contained in some forms of energy-as-a-service contracts are borne by consumers, meaning that ESCOs do not always fulfil this intermediary role.

## Built Environment Actors

While institutional and financial actors play a role in establishing enabling conditions for energy efficiency and decarbonisation policies in the buildings sector, other actors that are more involved in on-the-ground management and facilitation of building design and building materials play a key role in executing policies enacted by institutional and financial actors further upstream. At the highest levels like property developers (actors that span both financial and built environment categorisation), they are key decision makers and have a direct impact on demand for specific technologies and building approaches.

In addition to investors and property developers, built environment actors include manufacturers, merchants, designers and architects, as well as installers and contractors. Here we will outline the complex interactions among built environment actors when using energy efficient technologies in the building construction process by using case studies from the UK and Sweden.

The relationships among these actors are not necessarily simple or linear, despite the building construction process often being seen as a linear downstream relationship beginning with the architects or designers of buildings and plans being communicated downward along the chain of command to contractors and installers. Many parallel or feedback loop relationships also exist among these built environment actors.

Dynamics of interactions between key built environment actors and others are outlined in this section, along with important factors that impact on their ability to effect change in the sector. There are a plethora of actors and relationships between them in the buildings sector; this section does not seek to give a comprehensive overview of them, but rather to highlight important relationships between key actors.

### Merchants, Manufacturers & Installers: leveraging multi-directional relationships

One example of the aforementioned non-linear relationships among built environment actors is the relationship formed among merchants, manufacturers, and installers/contractors through training programs and accreditation schemes that are offered by many merchants and manufacturers to train contractors in the use and installation of their products. These types of training programs complement those offered at government run, sponsored, or regulated institutions which are crucial for ensuring a sufficient supply of qualified and accredited installers for heat pumps and other energy efficient technologies.

Installers or contractors also play an important role in the effective use of energy efficient technologies, as energy efficiency is only achieved when technologies are installed and fitted properly within the context of the individual building envelope. Research indicates that these are often-underrepresented actors when considering the network effects of different stakeholders on the use of energy efficient technologies in both new and retrofitted buildings (Killip, Owen and Topouzi, 2020). Their impact is underappreciated given, not only their ability to influence the choice of technology used in retrofits, but the fact that an insufficient number of skilled contractors to accommodate an increase in demand is a limiting factor for any stimulatory measure.

Installers play an important role in surveying building sites and communicating specifications of the construction site to developers and property owners, while being responsible for adapting a factory-made element to fit the needs of the construction site, or vice versa. In this way, installers and contractors can ultimately influence the types and specifications of products purchased for projects (Killip, Owen and Topouzi, 2020).

The impact the actors involved in propagating and participating in skill and capacity building programs have on the creation of zero ready homes is outlined in Figure 26 below.

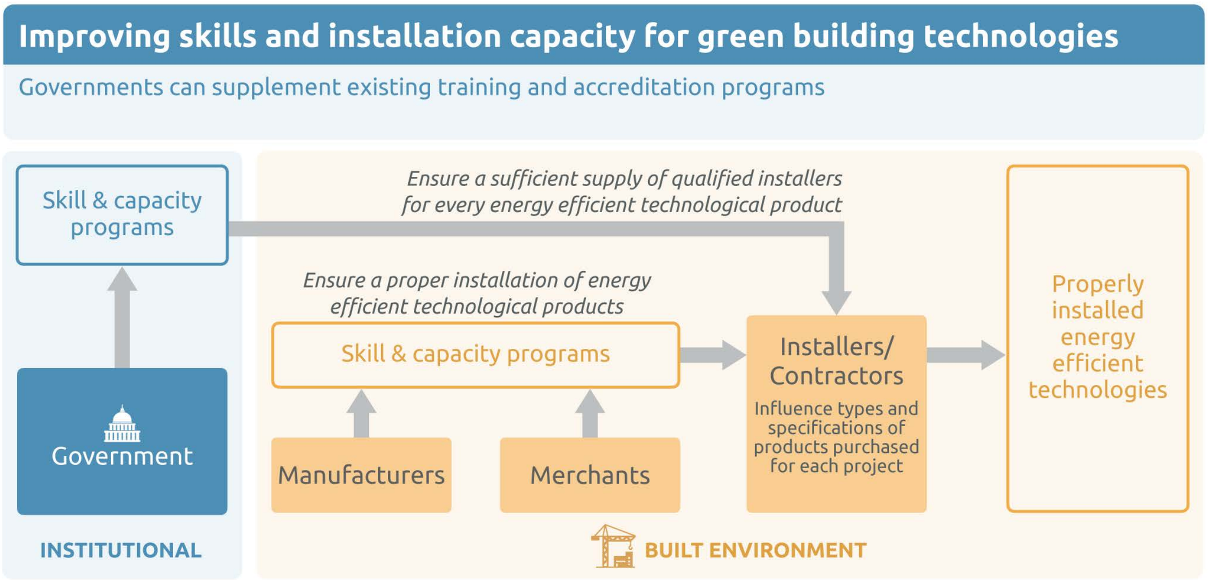



Figure 26: Improving skills and installation capacity for green building technologies

Leveraging these interactive, multi-directional networks among manufacturers, merchants and contractors/installers could play an important role in increasing uptake of energy efficient technologies. Iterative processes that incorporate the experiences of contractors and installers with energy efficient or emission reducing technologies at building sites may provide useful information for how to design more efficient or less emitting building elements.

### Construction firms & contractors: perceived powerlessness of downstream actors

A key challenge identified in research interviewing actors along the value chain of buildings is the lack of clear responsibility for operational emissions from buildings and how energy efficient technology choices may mitigate these (Du *et al.*, 2014; Dadzie *et al.*, 2018; Killip, Owen and Topouzi, 2020).

In interviews undertaken in the UK, both merchants and manufacturers of energy efficient technologies felt a greater sense of responsibility towards emissions reductions relating to processing, production or the end-of-life disposal stage of the product lifecycle. Conversely, both merchants and manufacturers felt they had little influence or responsibility towards emissions and energy efficiency during a buildings operational stage (Killip, Owen and Topouzi, 2020). However, researchers noted an exception to this trend in cases where merchants or manufacturers were serving specialized firms or clients where energy performance or environmental outcomes were highly prioritized within the expectations of the project.

A similar finding was demonstrated in interviews with actors within the Chinese buildings sector regarding where each actor directly involved in the construction process tended to place the responsibility for employing energy efficiency practices and technologies on the adjacent, upstream actor organization (Du et al. 2014). Interviews with architects and project managers on Chinese construction projects indicated that these two sets of actors felt they had little power to influence the degree to which energy efficiency or emissions reduction measures were implemented in new or retrofitted building projects, as they are bound by the expectations of the developers and clients who submit the requirements to them.

This sense of 'powerlessness' was echoed further down the value chain as, in the same set of interviews from Du et al. (2014), employees of construction firms who were interviewed placed the responsibility for incorporation of energy efficiency measures on the actor most directly upstream from them, architecture and design firms. The ultimate decisions on such measures will be made by developers or owners, though, with architects only able to propose them.

This transfer of responsibility for promoting and mainstreaming energy efficiency may indicate the need to more thoroughly enforce priorities for energy efficiency and emissions reductions into building design and codes. If clearer mandates and incentives for proper installation and use of energy efficient technologies are given already from the building design phase, this may encourage a greater sense of responsibility and agency for emissions from the operational stage of a building's life cycle. It also highlights opportunities for education and a cultural shift for developers and owners to increase demand for efficient, low-carbon options.

### Architects, developers & owners: knowledge gaps and the importance of accurate payback period calculations

The projected payback period of investing in energy efficiency technologies, whether they are for new or retrofitted buildings, has been shown in research to play a substantial role in the decision of developers, architects and project managers when designing the blueprints and the ultimate energy efficiency priorities for the building design (Palm and Reindl, 2018). In interviews conducted with developers and project managers of a design firm in Sweden, payback times of as little as 6 years were used as the maximum payback time considered acceptable by developers when implementing energy efficiency measures.

Developers and project managers used a self-developed formula to determine payback, which many participants interviewed stated was likely "too pessimistic" (Palm and Reindl, 2018). In China, a payback time of 3-5 years for installing a ground source heat pump was already considered to be too long of a payback period to warrant the high initial investment (Du et al. 2014). Resistance to even relatively short payback periods and high initial investments for energy efficient technologies was also cited as a barrier by architects and designers when giving feedback to developers. As a result, efforts to include them in initial proposals and planning are often not made to avoid conflict (Dadzie *et al.*, 2018).

Based on this evidence from several case studies in different national contexts, **a key barrier to effective adoptions of energy efficient technologies in the built environment sector is the payback time of an investment in such technologies, whether it has been calculated accurately or not**. This is compounded by the lack of standardized national or regional formula for calculating payback times.

This points to the urgent need for improved policy measures to lessen the length of payback periods on energy efficiency investments in buildings, as well as greater research and standardization on average payback periods for investment in different technologies to boost confidence of investors. As shown previously, there is a lack of clear responsibility in the chain of actors regarding who should promote and champion energy efficient technologies. Most of the actors tend to push the responsibility backwards up the interaction chain, landing on the investors and developers as those primarily responsible for prioritizing and mandating energy efficiency measures into projects.

**Developers and property owners therefore currently act as a barrier or "blocker" to the adoption of energy efficiency measures, as they hold the most decision-making power among built environment actors.** Figure 27 outlines the key factors that influence the decisions made by these actors.

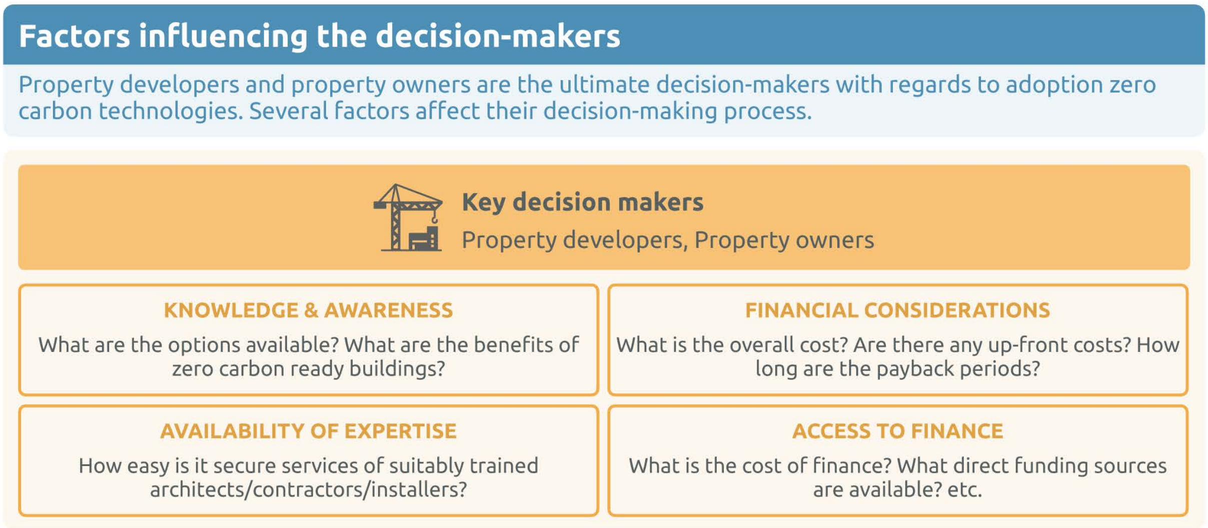



Figure 27: Factors influencing ultimate decision-makers with regards to adoption of zero carbon technologies

Implementing and enforcing MEPS can counteract this power by compelling compliance. Ensuring built environment actors lower down the decision-making chain have sufficient knowledge to promote low carbon options that may also compete on cost alone can also help address this issue. Government support to ensure such options are cost-competitive will often be necessary for some time, but together, this could help to shift demand to the best available low-carbon technologies. Governments can also develop standardised tools for calculating payback periods that can avoid decisions made on incorrect assumptions of non-competitiveness of key technologies.

## The Landlord-Tenant Dilemma

Getting incentive structures right is fundamental to catalysing rapid change in the behaviour of a set of diverse actors, and in the absence of a forcing mechanism like regulation. In the buildings sector, a fundamental obstacle to realising deep emissions reductions is the misaligned incentive structure created by property owners leasing to tenants.

Achieving energy efficiency improvements in a leased property is made difficult by the fact that landlords do not reap the benefits of lower utility bills resulting from building upgrades (Figure 28). To account for this, innovative approaches are needed that incentivise landlords to act. Such approaches exist and have been introduced in various contexts to overcome these misaligned incentives.

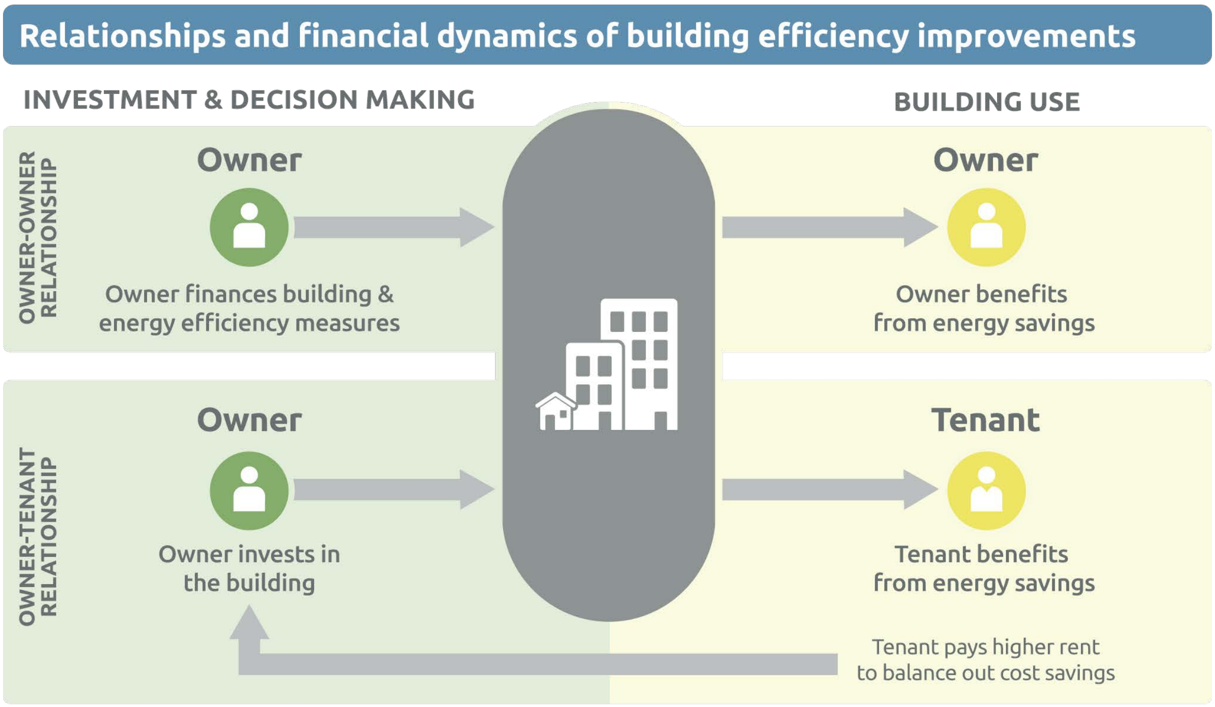



Figure 28: Financial relationship between investors and building occupants: the owner-owner and owner-tenant case.

## Incentivising Landlords

One widely used approach is employed by companies that offer energy performance contracts (EPCs); installing energy efficient technologies and turning the resultant savings into a profitable revenue stream. There is no disincentive for landlords to implement such a contract given the lack of upfront costs, and the improved energy efficiency of the property may justify an increase in rent. An alternative potential top-down approach could involve implementing a buildings sector carbon price alongside measures that incentivise landlords.

### Energy Performance Contracts (EPCs)

Potential savings from building energy efficiency upgrades are increasing in magnitude as the prices of key technologies continue to fall. This is increasingly incentivising private sector actors to enter the 'energy-as-a-service' market. Subscription fees charged by companies that install energy efficient technologies are set at a rate below the overall savings generated for the customer from lower energy bills, guaranteeing an overall cost reduction to tenants with no upfront expenditure (see 'Contract financing' in Current funding streams to support investments and the case study 'Standardised EPCs for affordable, quick and deep energy retrofits: Energiesprong' under Element Three – Financing) (U.S. Department of Energy, 2021a).

Landlords are incentivised by the removal of the barriers of upfront and maintenance costs for installations, and the prospect of eventual ownership of installations and an increase in property value generated by an improved energy efficiency rating. In addition, the promise of lower total energy costs may incentivise tenants to seek out EPC providers.

### Novel rental contracts and a targeted buildings sector carbon price

Carbon pricing is a commonly discussed approach to incentivising economy-wide emissions reductions and has been adopted in many jurisdictions around the world. Many carbon pricing schemes cover only a limited number of sectors, often the power and industry sectors, but a whole-of-economy level of coverage is usually the intended end goal. Including the buildings sector, however, in any carbon pricing scheme without first devising an approach to ensure landlords are impacted would unfairly burden tenants who do not have significant agency to improve the energy efficiency of their residences.

One such approach has been implemented in Sweden where rental contracts are all-inclusive, meaning landlords are required to pay for all utilities. This arrangement, combined with an aggressive carbon tax that is currently at a rate of EUR 114/t$CO_2$, has created a strong incentive for landlords to implement energy efficiency measures in their leased properties and has resulted in a steep reduction in buildings sector emissions since 2000 (Agora Energiewende and Universität Kassel, 2021). Figure 29 shows direct $CO_2$ emissions from Swedish buildings declined by 83% between 1990 and 2019.

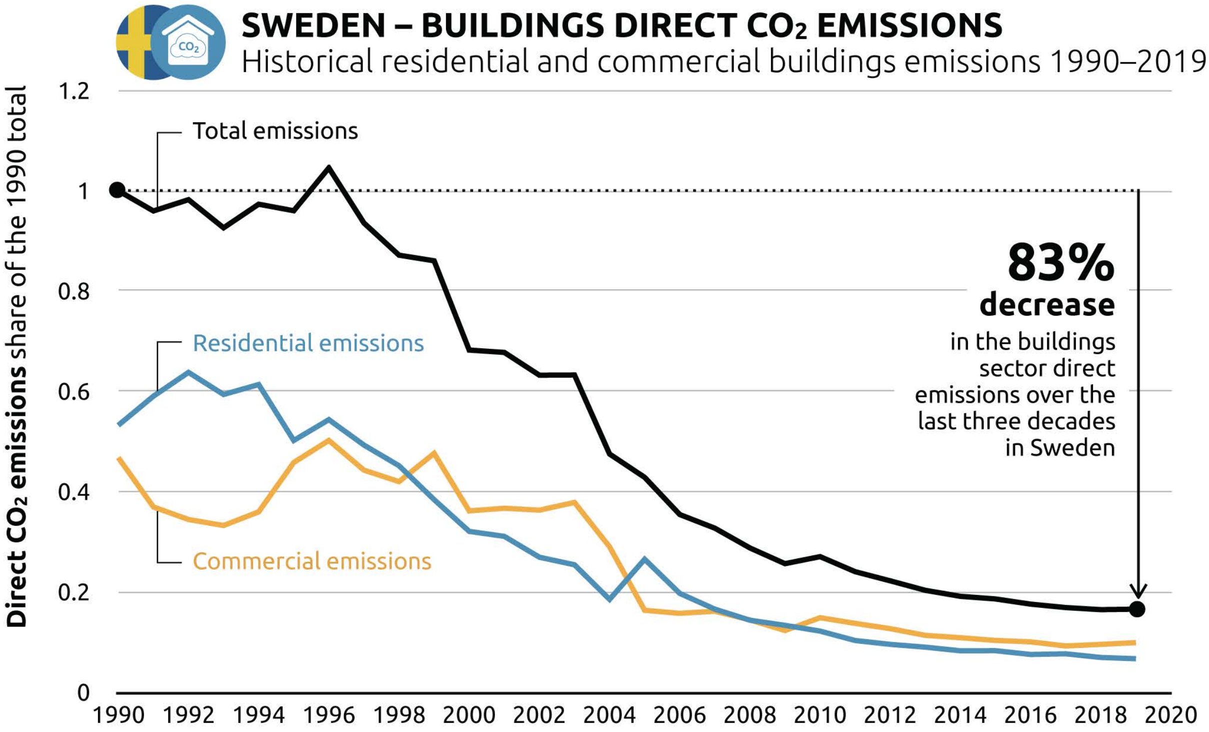



Figure 29: $CO_2$ emissions reductions in Sweden's buildings sector

*Source: (IEA, 2021f)*

Adjusting incentive structures is a 'soft' approach to achieving a desired behaviour change, but mandating such changes is an alternative that can yield more immediate impacts. Where altered incentive structures have failed to produce the desired rate or scale of change, or where immediate results are required, governments can wield their legislative powers to ensure compliance.

A legislative approach to solving the landlord-tenant dilemma could involve a requirement that all rental properties meet a minimum energy efficiency standard (see Element Two — Minimum Energy Performance Standards). In Boulder, Colorado, minimum energy performance standards for rentals (MEPSR) have been in place since 2010, one of the longest-standing examples of such regulation (Petersen and Lalit, 2018). Under this "SmartRegs" scheme, all rentals were required to meet the specified energy efficiency rating within eight years of its adoption.

As in many localities, all long-term rental properties in Boulder require a rental licence before it can be leased. To achieve compliance with the SmartRegs scheme, obtaining or maintaining a rental licence in Boulder was made conditional on meeting set energy efficiency requirements. Leasing a property without a licence incurs increasingly stringent financial penalties. To assist landlords in meeting the SmartRegs specifications, the City of Boulder offers technical and logistical support, lowering the barriers faced to achieve compliance.

By 2018, only 14% of rentals in Boulder were deemed non-compliant, a steep fall from 37% after the initial round of inspections. Upon reaching full compliance, the upgrades resulting from the SmartRegs scheme are expected to result in annual savings of 4.2 GWh in energy consumption, USD 1.1 million and 8,300 tonnes of $CO_2$ (Petersen and Lalit, 2018).

Another approach to mandating the improvement of rental property energy efficiency can be found in the UK, where since 2018 it has been unlawful to lease properties with an Energy Performance

Certificate (EPC) below an 'E' rating. Owners of residential properties are not required to spend more than GBP 3,500 per dwelling on upgrades to reach this minimum standard, limiting the potential required outlay to within reasonable bounds. Owners of commercial buildings are limited to those measures that result in a payback period of seven years or less.

## Case studies

We explore various best practice measures from around the world that address the difficulties of engaging with actors from each of the three key categories: financial, built environment, and institutional. The intention is to provide examples demonstrating their potential replicability for establishment in other jurisdictions, and that such measures are possible.

| Consideration | Guiding question |
|---|---|
| **Challenges addressed** | What challenges were overcome in the case study?<br>▶ Fragmented buildings sector with many diverse actors and lacking in avenues for collaboration<br>▶ Lack of investment and engagement from the private sector<br>▶ Skills deficit for rolling out key technologies<br>▶ Setting targets and devising strategies that have sufficient buy-in from these diverse actors |
| **Replicability / Scalability** | How easy is the action to replicate in other conditions, such as climate or governance context, and to scale up? |
| **Just transition** | In a transition to net zero emissions buildings, it is important to also reduce global and national social inequalities. How were equity considerations included (or not) in the case study? |

## Case Study 8: Australia's Clean Energy Finance Corporation

Australia's government-sponsored Clean Energy Finance Corporation (CEFC) operates a USD 7 billion fund with the purpose of accelerating Australia's transition to net zero emissions. The CEFC has devised several means to channel investments into buildings decarbonisation efforts. These include investing in energy efficiency upgrades, improving the design of proposed developments, and creating a 'green home loan' to spur construction of energy efficient new housing.

### Office building upgrades

The CEFC contributed USD 18 million to the High-Income Sustainable Office Trust managed by real estate fund manager EG Funds Management (CEFC, 2020). These funds have enabled the purchase of four office buildings where a suite of upgrades is being implemented to reduce energy use and improve their overall sustainability ratings.

The upgrades are expected to raise the overall value of the buildings, with the Green Building Council of Australia demonstrating that green buildings generate a 4.3% premium while also increasing net income by over 13% (GBCA, 2020). Generally, EG Funds Management has found that investing in properties that require near term upgrades can lead to an increase in asset value if they are upgraded to a higher energy rating due to improved environmental and operational performance, reduced operational expenditure and increased net revenue.

The cornerstone investment from the CEFC has helped to attract additional investments from the private sector, and university and church investment funds. This demonstrates the potential for state-sponsored financial institutions to guide capital towards upgrading the existing commercial building stock.

### Improving commercial building design

Another example of a CEFC investment in buildings decarbonisation is the USD 49 million in debt finance towards an USD 87 million commercial property redevelopment in Geelong, Australia, shown in Figure 30 (CEFC, 2016). This investment enabled a 25% reduction in the total projected GHG emissions compared to the original design.


Figure 30: Commercial property in Geelong, Australia, the design of which was improved to increase energy efficiency. Source: CEFC, 2016

## Improving residential buildings

In the residential sector, the CEFC has devised a green home loan in conjunction with Bank Australia to finance the construction of energy efficient housing. This USD 65 million investment covers both new builds and upgrades to existing homes, and is limited to mortgages below USD 1.1 million. The funds are provided to Bank Australia who distribute the green home loans to individual property owners or builders who qualify for a discounted interest rate providing they commit to building efficient designs or undertake energy efficiency upgrades on their existing home.

In addition to financing green home loans, the CEFC is providing up to USD 190 million in debt financing to construct 720 social and affordable homes. The average additional cost to achieve an increase in efficiency rating compared to the minimum compliant home was USD 3,500-4,300 per dwelling, resulting in an average 40 per cent saving on heating and cooling energy demand. The higher rating is estimated to generate an average annual saving for tenants of USD 360 per year.

## Challenges Addressed

A lack of action from key financial actors like developers, real estate fund managers, commercial banks on improving building energy efficiency is being overcome through the development of novel financing arrangements using public funds. A government mandated organisation equipped with substantial capital can engage with several of these key financial actors simultaneously to catalyse investments.

The example of the CEFC shows how public funds can be leveraged in various contexts, and to incentivise a range of actors. Whether it be to fund the purchase and upgrade of existing commercial buildings, the improvement of an existing building design, to catalyse commercial bank activity in the residential market, or to boost the energy efficiency of social housing. The CEFC's mandate leads it to establish relationships with investors, developers, and commercial banks that then result in investments in zero carbon buildings and retrofits that wouldn't have otherwise occurred.

## Replicability

Creating a green bank such as the CEFC is possible for any national government but is also possible at the city level. There are several examples around the world of green banks operating at various jurisdictional levels including national level banks in Malaysia, and previously the UK, several state-level green banks across the US, and city level banks in London and New York City.

In countries with financial systems less developed than those in the global North, it may be challenging to establish such institutions. However, green banks established with international funds, or by a collection of wealthier countries can act as an entry point for the distribution of aid for climate mitigation measures including those for buildings decarbonisation.

## Equity considerations

Green banks such as the CEFC can greatly assist in ensuring a just transition to near zero energy buildings through the choices of where to direct funding and low-interest loans. Two examples of CEFC activity targeting residential building upgrades demonstrates this fact.

The development of a low-cost home loan to encourage the construction of energy efficiency homes or to upgrade existing homes, while limiting this to loans of USD 1.1 million and below, lowers the barrier of achieving energy efficient homes for middle income individuals and families. Investing in the construction of energy efficient social housing ensures that lower income individuals and families with less agency to invest in upgrades are still able to live in energy efficient homes.

## Case Study 9: EU - Private Finance for Energy Efficiency Instrument

The Private Finance for Energy Efficiency (PF4EE) instrument is a joint initiative between the European Investment Bank (EIB) and the European Commission that seeks to overcome barriers to greater participation from commercial banks in financing energy efficiency upgrades.

The key barriers identified that led to the establishment of PF4EE, are a lack of adequate and affordable financing for energy efficiency investments, a continued perception of risk from commercial banks regarding potential losses, and a lack of commercial bank expertise in the energy efficiency market (PF4EE, 2019).

In response to these perceived barriers, PF4EE guarantees up 80% of any potential losses from commercial loans up to an agreed amount and provides consultancy services to "improve partner banks' understanding of the energy efficiency market, to support them in the development of loan pipelines, and to ease the appraisal of PF4EE financing requests" (PF4EE, 2019). The EIB may also directly finance these commercial banks to provide loans for the purpose of energy efficiency investments.

Through partnerships with PF4EE, commercial banks in ten EU countries offer finance for such energy efficiency investments. In total, almost half a billion euros in funding has been allocated towards energy efficiency improvements.

As part of its consultancy role that PF4EE undertakes with its partner banks, it has created a tool that can be used by companies to check whether their proposed project meets the necessary criteria to obtain preferential financing. Currently this tool is available in five partner countries, and also can be used by interested parties that do not yet have a concrete proposal to formulate project ideas. Another tool developed by PF4EE and available to the general public gives an estimate of the potential savings of different energy efficiency measures across all 27 EU countries and the UK (PF4EE, 2021).

These tools are a neat representation of a channel of engagement that brings together multiple key stakeholders. Development of these tools by PF4EE connects business owners and individuals to commercial banks that can offer discounted loans, while providing the tools to understand how profitable potential projects are.

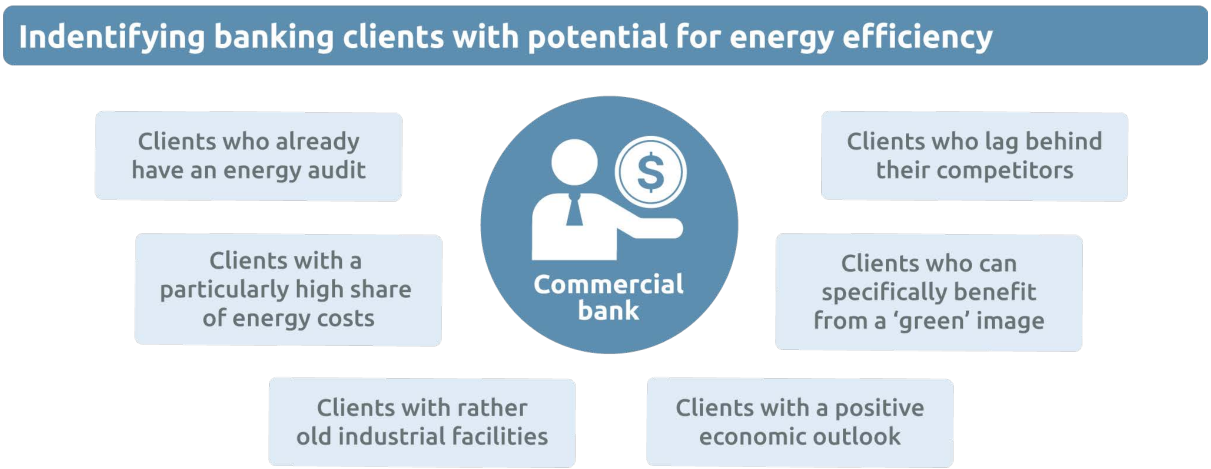



Figure 31: Examples of potential commercial bank clients that could be identified with the assistance of PF4EE

*Source: PF4EE, 2019*

Consultancy services from PF4EE to commercial banks can also help them proactively identify potential clients, encouraging an active role for banks. This facilitates a bi-directional flow of engagement that includes bank-to-client in addition to client-to-bank engagements. Maximising both of these channels of engagement can help boost the overall uptake of energy efficiency retrofits. Figure 31 demonstrates the variety of potential clients that could be proactively engaged by commercial banks.

## Challenges Addressed

Commercial banks across the world are so far mostly failing to take the initiative to offer and promote finance for energy efficient homes or upgrades. This limits the options available to those that are motivated to improve the efficiency of their home, but do not have the resources to cover the upfront costs of upgrades. In addition, those that are seeking to build a new home, but are motivated purely by financial factors are less likely to improve the energy efficiency of the design if it results in substantially higher upfront costs.

Incentivising commercial banks to offer finance for energy efficiency upgrades and provide low-cost home loans for new construction eliminates this barrier and could incentivise others that were not already contemplating making such investments to do so. In addition, assisting banks to improve their knowledge on energy efficiency matters may incentivise them to offer these products without government incentives in the future. The creation of an online platform that links building owners with contractors and banks to finance retrofits creates avenues to establish relationships between these actors and catalyse project development.

## Replicability

To replicate the structure and competencies of PF4EE would require a minimum level of sectoral expertise in buildings energy efficiency to assist banks in devising financial products and provide consultancy services. Skills to design and populate the portal that hosts relevant information for individuals and businesses would also be needed.

Beyond this, governments would simply require the fiscal capacity to guarantee home loans and offer consultancy services as needed.

## Equity considerations

In addition to businesses and middle- to high-income individuals that would benefit from a greater availability of finance options and information to invest in energy efficiency upgrades, lower income individuals and families that would like to upgrade their home, but do not have sufficient resources to pay the upfront costs would have access to low-cost loans to do so. Creating a platform with key information relating to building energy efficiency and embarking on upgrade projects results in an equitable availability of this content to everyone in society.

## Case Study 10: The US - Ithaca's multi-level governance approach

So far, examples of national and international (EU) governance have been highlighted, but often a multi-level governance approach can be optimal. In Ithaca, a city of 32,000 people in upstate New York, such an approach is being undertaken with the aim to decarbonise all 6,000 buildings across the city.

This ambitious program was conceived as the first plan of the Green New Deal adopted by the City of Ithaca in 2019. It aims to use a USD 10 million state government-backed loan loss reserve to guarantee loans obtained from private equity and has attracted USD 100 million in commitments to the program so far.

The New York State Energy Research and Development Authority (NYSERDA) has been actively seeking applications for support from the New York State loan loss reserve to catalyse the financing of energy improvements to various building types since mid-2020. The availability of these funds spurred the City of Ithaca to devise the program that promised lenders low risk investments that would deliver substantial returns through zero- to low-cost energy performance lending and operating leasing programs.

The program's goals would be transformational if achieved, with an aim to create around 1,000 jobs by 2030 in addition to the targeted wholesale emissions reductions (de Socio, 2021). Money will be offered to building owners as low- or no-cost loans that will be repaid through savings on energy bills. As the loans are backed by the City, low-income residents with credit ratings that may disqualify them from commercial loans will still have access. This is a critical piece of the plan; by ensuring that participation is open to everyone, it is possible to aim for universal adoption and the deep decarbonisation that this can achieve.

An approach that combines stewardship from local government with the greater resources available to regional or national governments has large potential synergies, as it ensures projects are undertaken by actors with the local knowledge and relationships often necessary for success. Public trust is also often higher for lower levels of government than at the federal level, increasing the chances for wider public buy-in (Brenan, 2021).

Campaigns to raise the profile of initiatives like Ithaca's Energy Efficiency Retrofitting and Thermal Load Electrification Program enacted at the local level may also have a greater chance of attracting the attention of local residents. Locally-run campaigns will usually have the benefit of understanding the local media landscape, and can engage local news and other media outlets that may reach a greater proportion of local residents than state or national outlets.

The superior ability of state and local governments to reach, work with, and garner the trust of local populations is a highly valuable advantage that should be considered in the design of buildings decarbonisation schemes.

### Challenges Addressed

Local governments are those with the greatest knowledge of local conditions, limitations, and available skills, and with more developed relationships with the various stakeholders in the local community. They are often limited, however, in the scale of projects they can undertake by their own fiscal capacity and the skill base of their employees. They are also the level of government that usually grants approvals for building upgrades and construction.

By partnering with a state or federal government, their greater resources and skills to fund and support a comprehensive approach to buildings decarbonisation within a particular locale are made available. Leveraging state or federal funding to guarantee loans provided by private equity widens the potential pool of funding available to achieve the project's objectives greatly.

## Replicability

Most countries have subnational governments that could partner with a higher level of government to take advantage of their superior resources and capacities. Achieving consensus between different levels of government, however, on the scope or cost of the scheme, may prove challenging, particularly if opposing political parties are in place at these different levels.

Some countries may not have the fiscal capacity to support such ambitious actions at a local level, but this could potentially be overcome by seeking international climate finance from bodies like the Green Climate Fund.

The municipally owned utility enables the repayments to be achieved through power bill savings, which is a relatively unique situation. Whether these savings exist depends to a large extent on the local gas and power prices and whether increasing power usage offsets the savings from reduced gas demand.

## Equity considerations

The design of the City of Ithaca's scheme explicitly targets universal adoption, ensuring access to those with what would otherwise be a disqualifying credit score. This is what justifies the lofty goal of full decarbonisation of the city's building stock of 6,000. Ensuring other such schemes are designed to facilitate participation from low-income individuals and families is crucial if widespread decarbonisation is to be achieved.

## Case Study 11: EU/Spain - BUILD UP Skills Initiative/Contruye 2020

As noted in our analysis of built environment actors, having a well-trained and knowledgeable workforce in the construction and installation sector is key to properly execute energy efficiency measures and ensure that installed technologies operate at their true potential. The BUILD UP Skills Initiative is an EU funded project that aims to "increase the number of qualified workers across Europe to deliver retrofits offering a high energy performance as well as new, nearly zero-energy buildings" (Build Up Skills, 2016). The project has made considerable impacts in this regard, notably the accreditation of 17 training centres, mobilisation of more than EUR 40 million in training schemes to train more than 120 trainers, which conducted 2,000 training sessions for some 10,000 workers (European Commission, 2017).

The initiative involves EU Member States developing 'status quo analyses' and 'national roadmaps' to determine how to achieve an upskilling of each national workforce. Training courses were developed to cater to each country's unique circumstances. By the end of the initiative in 2018, the objectives of the initiative were deemed to have been met, with all countries developing, upgrading, or piloting new qualifications and training schemes based on their national roadmaps (Trinomics, 2018). A reboot of this initiative is now underway, with a call for proposals to update the status quo analyses and national roadmaps to align with the EU 2030 energy targets closing in January 2022.

An example of a BUILD UP Skills initiative is Construye 2020, a project that began in 2016 in Spain and aims to promote professional training and accreditation to construction professionals in energy efficiency, renewable energy and net zero energy buildings.

In fact, the project has already been highlighted as a best practice in the field of construction by the World Economic Forum. Construye 2020+ offers "green courses" for construction professionals on energy efficient technologies such as geothermal systems, insulation, biomass systems, heating and hot water systems and even on the profitability of energy efficiency in buildings (Construye 2020+, 2020).

### Challenges Addressed

As previously discussed in the examination of built environment actors, contractors and installers are often some of the most overlooked actors when considering how to improve the adoption and proper use of energy efficiency measures (Du *et al.*, 2014; Dadzie *et al.*, 2018; Palm and Reindl, 2018). Most studies on barriers to energy efficiency adoption among built environment actors focusing on investors, developers, architects and designers as being primarily responsible. However, contractors and installers can make or break the effectiveness of energy efficiency technology, as they can only reach their full potential in mitigating energy use and emissions when properly executed and when adapted to the unique character of the building site. Ensuring there are sufficient numbers of skilled contractors to accommodate additional demand resulting from measures that stimulate demand is fundamental to ensuring their success.

Providing comprehensive and targeted training to these built environment actors can help improve knowledge on energy efficiency measures in the construction industry and improve communication on this topic among designers, contractors and installers. Particularly interesting is Construye 2020's offer of education on the profitability of energy efficiency, an often-missing aspect which can help to overcome hesitance towards energy efficiency measures.

### Replicability

While replicating Construye 2020's efforts does not require any specific technology or a high degree of innovation, it does require strong coordination of efforts among government offices and accreditation bodies in the construction sector to ensure the training and certification received are properly executed and recognized. Construye 2020 is funded by the EU Horizon 2020 Programme, which means that to apply the idea at the national or regional level would require specialized funding and budgeting to ensure that construction professionals are not deterred from the training by high costs.

## Equity considerations

Platforms using the model of Construye 2020+ have the potential to contribute to a just transition by building skills in energy efficiency to form a more climate-friendly and sustainability-minded workforce. This can not only contribute to local, regional and national climate targets towards overall emission reductions and decarbonization of the buildings sector, but also provide greater economic opportunities to workers acting in various capacities within the construction industry through upskilling.

Building a knowledge base on energy efficiency measures with those workers on the frontlines of construction can help to solve the traditional "top-down" chain of command seen among built-environment actors and create a more even dialogue coming from both directions along this chain (Du *et al.*, 2014; Dadzie *et al.*, 2018; Palm and Reindl, 2018).

Retraining contractors in modern technologies also ensures they are not left behind once the market shifts sufficiently to where there is very low demand for current technologies such as oil and gas boilers.

## Case Study 12: Sweden - Fossil Free Sweden's stakeholder engagement process

Engaging with the broadest range of stakeholders possible is an important element of improving communications among actors in the buildings sectors and creating synergies among financial, institutional and built environment actors. Fossil Free Sweden, an initiative of the Swedish government established in 2015, provides an example of comprehensive stakeholder engagement in the buildings sector. Fossil Free Sweden requires each sector in the Swedish economy to set out a roadmap for removing fossil fuels from its energy supply. The heating sector has its own roadmap and represents a particularly important industry for decarbonisation in Sweden, as the heating sector makes up a large part of the Swedish energy market at 100 Twh per year (Fossil Free Sweden). Sweden's heating sector roadmap has set the commitment to become fossil fuel free by 2030 and to become a carbon sink for the Swedish economy by 2045.


Sweden's heating sector roadmap has widespread buy-in from a wide variety of actors, including companies from district heating, heat pump, biofuels, property owners, builders and municipal governments. In this regard, it represents a unique approach by incorporating as many actors as possible heavily integrating institutional and built environment actors.

### Challenges Addressed

This approach to stakeholder engagement helps to address the problem of responsibility-uncertainty mentioned in the exploration on built environment actors, where if energy efficiency is not clearly set as a priority in mandate at the top of the chain of command by investors and developers, all actors downstream on the chain feel powerless to promote the use of energy efficiency in the building's development. By bringing all of these actors together alongside governments which standards for energy efficiency, priorities and mandates can coordinated and communicated clearly to all building actors from the beginning. Creating an open forum for a broad range of actors in the buildings sector around strong, quantitative targets can also improve investor confidence in energy efficiency measures and create more pressure on investors to include emissions and energy usage in their risk assessments.

### Replicability

Perhaps the greatest power of Sweden's approach to improving stakeholder engagement in its buildings sector lies in its simplicity. The practice of creating platforms that can bring various stakeholders involved in an industry or concern is not a new concept. However, involving them from the beginning of the target setting process of the roadmap, rather than establishing targets within a roadmap and only asking for feedback afterwards, is powerful. This practice would be easily replicable in many national contexts.

### Equity considerations

The stakeholder engagement approach used in Fossil Free Sweden's heating sector roadmap provides an enabling environment for a just transition by ensuring that as many voices as possible are brought to the discussion table. Involving government, developers, installers and private industry together can create a conversation around the full chain of production and implementation for energy efficiency measures. However, a key piece of information missing from the roadmap is the extent to which additional actors representing civil society interests are involved in the dialogue.

## Lessons Learned

We have seen how the buildings sector is unique in the number and diversity of actors that need to be engaged to achieve a rapid decarbonisation. This engagement can take many forms, from designing schemes to (dis)incentivise specific actions or educate one or more groups of actors, lobbying governments to take action, or simply mandating compliance with government regulations.

Each group of actors outlined in this chapter plays a crucial role in the drive to decarbonise the buildings sector, and to achieve the required pace of change, all must be effectively engaged simultaneously. One actor wields an outsize degree of power to effect change and engage across all other groups of actors, namely governments of various levels. Governments' ability to enact and enforce legislation, deploy funds, and bring other actors together make them the primary driving force and agent of change, above all others.

### Primacy of Governments

The proven effectiveness of compulsory measures underscores the central role that governments have to play in the buildings sector decarbonisation effort. Not only are governments the only actor with the authority to adopt energy performance standards for buildings and appliances, and subsequently enforce them, but their broad regulatory capacity reflects a great potential to devise creative solutions.

Some such solutions have been outlined in this chapter, including the creation and directing of green banks and development banks or institutions that partner with and incentivise commercial banks to more readily invest in building energy efficiency projects.

Governments can incentivise action from other key stakeholders in numerous ways. The various methods of providing financial incentives for commercial and residential building upgrades covered in the finance chapter spur an increase in retrofitting rates, and maximise the early adoption of crucial, but prohibitively expensive technologies.

Governments are uniquely able to bring diverse sets of actors to the table and facilitate collaboration between them. By signalling intent to achieve a broad outcome like buildings decarbonisation that would require significant investment, create extensive commercial opportunities, and achieve the public good of reducing emissions, actors are incentivised to respond to government requests for participation. The Fossil Free Sweden initiative demonstrates the potential for widespread sectoral collaboration resulting from government leadership.

When the success of an initiative is dependent on the participation of such a wide number and variety of stakeholders, investment in awareness raising and education can be crucial. Whether it be informing the public of the availability of a funding scheme, upskilling a subset of the workforce, or fostering a whole new industry, governments play a central role in the dissemination of the information necessary to achieve these ends.

The EU's BUILD UP Skills initiative is an example of a government-coordinated initiative that achieved an increase in the education and training of construction workers and installers, and boosted the overall number of qualified workers (Trinomics, 2018). A key finding from the second phase of this initiative was that the majority of projects funded in member states would not have occurred without it. The initiative also led to the creation of national level networks of experts that generated follow-up projects.

### Improving engagement with built-environment actors

Existing research has underscored the importance of investors, developers, and building owners as decision makers, and the feelings of powerlessness common in downstream actors like architects and contractors as a result. Research has also highlighted the reluctance of investors and developers to implement technologies and approaches with even moderately longer payback periods than conventional alternatives (Du *et al.*, 2014; Dadzie *et al.*, 2018; Palm and Reindl, 2018).

This suggests governments should target measures at overcoming the reluctance of these actors to invest in key technologies to achieve near zero energy buildings. Such a comprehensive approach would include compelling them with MEPS, correcting misconceptions on the payback period of these technologies, and lowering or removing the cost premium on them through financial incentives.

The importance of downstream actors should not be discounted, and here, engagement should be improved. Ensuring sufficient resources are allocated to make training widely available to installers and promoting participation in such training will be key to ensuring there is capacity to facilitate an increase in demand for key technologies.

### Solving the Landlord-Tenant Dilemma

The large proportion of the global building stock occupied by tenants makes finding approaches to achieve wholesale emission reductions from these buildings critical. Tenants cannot be expected to invest in energy efficiency upgrades themselves, so incentivising or compelling landlords to make these investments is necessary.

Sweden provides a compelling example of how to achieve large emissions reductions in rental properties without mandating such actions. The combination of all-inclusive rental agreements, whereby heating costs are covered by monthly rent payments, and a stringent carbon price that currently sits at EUR 114/t$CO_2$ have helped to almost eliminate residential buildings sector emissions (Agora Energiewende and Universität Kassel, 2021).

Adjusting rental contracts in this way would require government intervention to create a financial incentive structure that encompasses landlords, rather than mandating specific upgrades. Examples of mandated energy efficiency upgrades to rental properties also exist, with the UK implementing such regulations in 2018. In Boulder, Colorado, the local government in 2010 linked the award or maintenance of a rental licence to the achievement of a minimum energy efficiency level.

### One-stop-shops to address the multi-actor problem

Given the large number and variety of actors in the buildings sector, we have seen that a fundamental challenge inherent in achieving its decarbonisation is finding ways to effectively engage these disparate actors. Establishing so-called ‘one-stop-shops', which can offer information and services to both renovators and built environment actors is a proven approach to achieve this.

These platforms play an important role in boosting retrofit rates. It is where prospective renovators may have access to technical and financial assistance, or learn about the potential benefits of various retrofitting options, or where contractors and installers can enrol and participate in training courses. They have been shown to unify a fragmented energy retrofit market, and act as agents of change by integrating home retrofitting processes in a single point of contact (Biere-Arenas *et al.*, 2021).

In this way, these platforms can play an intermediary role, bringing together contractors, architects, financial institutions, and individuals in one place. Limiting participation to certified and accredited built environment actors can help individuals ensure the quality of work and equipment employed for retrofitting or construction work.

Most existing one-stop-shops are public initiatives or public private partnerships, demonstrating another key role for governments, which can establish such platforms without the need for it to be profitable. Biere-Arenas et al (2021) have developed a list of initiatives from across Europe that includes public initiatives like HomeGrade (Belgium), ProjectZero (Denmark), and KredEx (Estonia).

These platforms can also host and accept applications to government grant schemes that may already be in place, streamlining this process and providing an additional avenue to raise awareness of their existence. Governments can also use these platforms to host and promote a standardised approach for calculating the projected payback period for energy efficiency upgrades. Providing such a standardised approach may overcome a key barrier voiced by investors, developers, and project managers that have been shown to calculate overly pessimistic payback periods.

# What would it take to transform the buildings sector?

## State of play across the four elements

The urgency of addressing emissions from buildings is clear. Despite the rapidly diminishing carbon budget and need for decarbonisation from all sectors, buildings have largely been a consistently high source of emissions. Where progress is lifting off in some sectors – power, light-duty vehicles – the buildings sector has been stubbornly slow moving. Why is progress not happening, and what would it take to initiate transformative change?

Technological solutions are not the main challenge (Element One — Technologies). Various technologically mature, low-carbon options are available to decarbonise heating and cooling, including heat pumps, district heating or cooling, and energy efficiency measures. However, despite well-known lock-in effects, new buildings are still constructed with low energy efficiency and are commonly reliant on fossil fuels, particularly gas, for thermal comfort.
Although zero carbon technologies are available, the most appropriate technological strategy at the local level depends on the climatic conditions, building purpose, and existing infrastructure. This calls for tailor-made approaches considering national and even local circumstances, drawing from the diverse set of available options. In many cases, heat pumps are the best option, but district heating or cooling will likely have a role to play in densely populated areas (Box 5: Role of district heating and cooling) and hydrogen and biomass contributing elsewhere (IEA, 2021h). Solar thermal heating for hot water is well-established and can be expanded widely.

Regulation through Minimum Energy Performance Standards (MEPS) has been recognised by many as fundamental to transforming the sector (Element 2 – Minimum Energy Performance Standards; Economidou *et al.*, 2020; Nadel and Hinge, 2020). One third of nations have some type of energy efficiency requirement in building codes, but many do not have regulations in place for existing buildings and very few are stringent enough to ensure Paris Agreement compliance. Enforcement of those existing codes and standards can be weak and limit their effectiveness. Improving the stringency, extent, and enforcement of building codes and standards is a necessary key component of a building decarbonisation strategy.

However, regulation alone is unlikely to be sufficient without supporting policies to facilitate and incentivise appropriate actions, and to ensure that any existing inequalities are not exacerbated. The myriad of actors involved in the buildings sector (Element Four — A multitude of actors) all make decisions that can impact whether a building will become zero carbon. Crucially, these choices are strongly influenced by cost considerations.

In some cases, new or retrofitted zero carbon buildings are cheaper than the higher carbon alternatives, at least when considered over the lifetime of the building. In these cases, easy access to finance can reduce the perceived risk of high up-front costs and overcome financial barriers.

However, where gas and oil remain cheap relative to the cost of electricity, improvements to reduce emissions may not pay for themselves and instead come at a real cost to the investor. Alternative financial support arrangements are required to change the market through improving the cost-competitiveness of low carbon investments and reducing financial risks (Element Three – Financing). Where present, carbon pricing has proven to be an effective instrument in reducing buildings sector emissions (Case Study 13: How Sweden has cut carbon intensity by two thirds). Ensuring that any carbon pricing scheme is revenue neutral, and that money collected is redistributed such that it does not exacerbate social inequalities, is crucial for ensuring its long-term viability.

## Why is the buildings sector particularly challenging to decarbonise?

The buildings sector is complex. Each building requires a unique, multi-faceted approach to decarbonisation that's appropriate for the local climate and needs to meet the safety requirements, purpose, and budget of the building. Each building also has a different set of independent actors making decisions and providing relevant knowledge. These multiple independent situations means that for all buildings to be zero carbon, many decisionmakers must get multiple decisions right. The challenge is ensuring that all these actors are sufficiently well informed and motivated to take the zero-carbon options, and that the necessary skills are locally available to execute them.

Technology improvements and associated cost reductions alone are unlikely to be sufficient to shift the sector onto a transformational pathway. Although there will be long-term cost savings across the sector, that may not be true for every individual building and high up-front costs still present a financial barrier that needs to be overcome. Even where zero carbon is the lower cost option, education, awareness, skills, and trust need to be built up to engage more people in opting to prioritise zero-carbon buildings.

## The key role of governments in decarbonising the buildings sector

As a complex challenge, reducing emissions in the buildings sector requires a comprehensive strategy to address the multiple facets. Governments are in a unique position to effect change, as they can influence many of the wide range of actors and set the overall direction of the economy towards decarbonisation.

The buildings sector is unlikely to 'tip' with just a few initiatives from private sector. Instead, it will require a wide range of actors to work together towards a Paris Agreement compatible sector – governments can create those connections and implement effective frameworks for efficiency and low-carbon buildings.

Of the varied government responses to the challenge of buildings sector decarbonisation, there is one country that has enacted a comprehensive and long-standing campaign to bring emissions down. Sweden's government has been investing and regulating this sector for over forty years in an attempt to decarbonise its building stock, and has achieved impressive results, with total buildings sector emissions falling by roughly two thirds between 1990 and 2019. An exploration of the various measures enacted by Sweden over the previous four decades is included in Appendix II.

Three major steps are required from national, regional, and local governments (Figure 32):

1. Set out clear climate targets for the sector.
2. Make a detailed plan and strategy for decarbonisation at the national, regional, or local level.
3. Implement the plan with a broad set of policies that regulate, facilitate, and incentivise the transition.

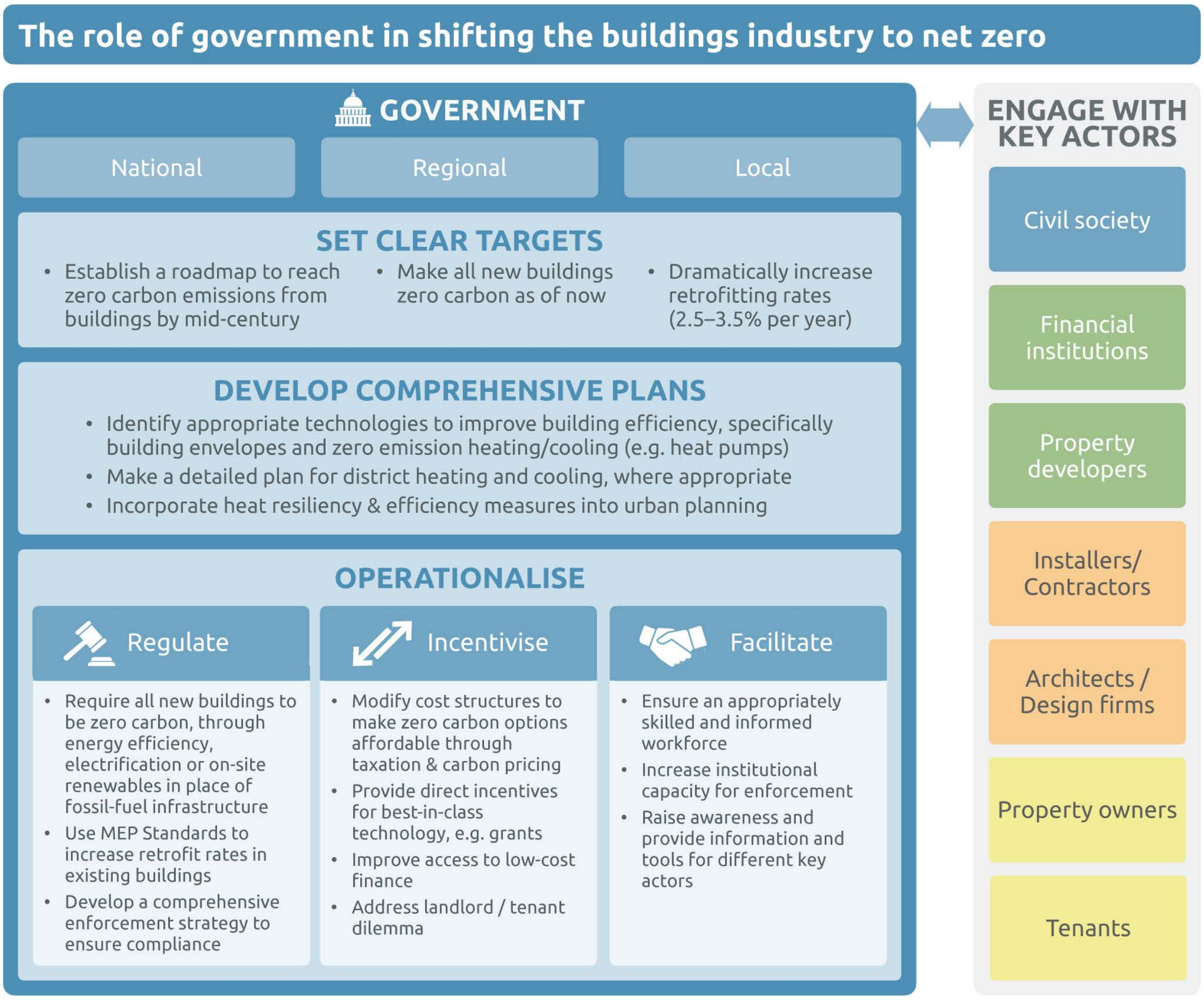



Figure 32: Role of governments in providing incentives for other actors to take appropriate actions to decarbonise the buildings sector.

## Set clear targets

All countries are expected to set national emissions reduction targets in line with the Paris Agreement and elaborate them in long-term decarbonisation strategies. The buildings sector should be explicitly included in those strategies with a timeframe for reaching zero operational emissions.

With the potentially long lifetime of buildings, back casting from the point of zero emissions is particularly important, usually meaning that all new buildings should be zero carbon from now on and requiring very high retrofitting rates (2.5-3.5% of buildings per year).

Clear targets send a signal to all regarding the direction of travel and are a necessary first step.

## Make a plan

All targets need a detailed plan on how to reach it. Plans for buildings sector decarbonisation should include the key decarbonisation measures, a timeline, and the broad policy strategies.

In terms of decarbonisation measures, governments need to establish priorities based on national or local circumstances. The current building stock and existing heating and cooling strategies in place are the starting point, but how best can these develop? What's the local climate, and how is it expected to change over the coming decades? Is there a role for district heating and cooling, and to what extent? Should retrofits be prioritised, or are new buildings going up quickly? How much on-site renewables are feasible and / or needed? What materials and energy sources are available locally? How can existing policies and institutions be developed and built upon?

Plans should be developed in collaboration with key stakeholders, both to ensure feasibility and to develop engagement and buy-in from those who will enact the plans. This collaboration should not only cover the technical details, but also the policies that will be implemented to operationalise the plans.

The focus of this paper is on operational emissions from heating and cooling, but a buildings sector plan should incorporate all emissions and provide a co-ordinated strategy across the sector. Embodied emissions in buildings are a major contributor to global emissions and national plans for retrofitting and new builds should take these into account. Where possible, retrofitting should be prioritised over demolishing and rebuilding (Power, 2008).

Other building operations – including cooking, water heating, lighting and appliances – should also be covered in a coherent manner. For example, a shift away from natural gas for heating implies a commensurate electrification of cooking.

## Operationalise the plan - regulate, incentivise, facilitate

Governments also play a fundamental role in the details of implementing decarbonisation plans. National and sub-national governments have multiple possible intervention points to instigate change. Our analysis indicates that many of these intervention points need to be utilised in a co-ordinated manner and that no single action will suffice alone.

Government interventions can be considered along three dimensions – regulate, incentivise, and facilitate. Each dimension has its own role, and all are necessary; the measures catalyse each other. In all case studies considered in this report, those with most success took a multi-pronged approach whereas those that were not backed up with sufficient supporting policies did not fare well.

Finally, governments can also ensure that implemented policies are supportive of other priorities, including ensuring protection for the most vulnerable. Any new policies that aim to reduce emissions need to ensure protection of low-income households so that they are neither faced with higher costs nor trapped in low-standard housing.

These three types of policy instrument need to be utilised in concert with each other and updated through time. If effective, building codes and accompanying incentives should lead to a scale-up of the market and help to reduce the costs of zero carbon options. The stringency of building codes should increase over time, ideally according to a pre-announced roadmap, and incentives can be shifted to support only those options that are not cost-competitive.

The table below outlines the main interventions that a government can support, and highlights some of the more successful examples to date. Governments and policy makers can use this table as an overview to check that their plans and policies are sufficiently comprehensive in that they address all the potential challenges and provide a combination of both regulatory and supportive approaches. The case studies indicated here are elaborated in the main report and provide concrete examples from which others can learn and, in some cases, replicate.

## Operationalise the vision

Countries or jurisdictions' vision should inform the creation of a comprehensive policy package consisting of policies to regulate, incentivise and facilitate the transformation towards decarbonised space heating and cooling. This table provides an overview of available interventions that governments can choose from. Governments should ensure a broad selection of different intervention types and the more options taken, the higher the likelihood that the transition will be fast enough to meet the Paris Agreement goals.

Table 7: Summary of key interventions and policies

## Key interventions and policies for governments to operationalise a successful zero carbon buildings vision

| REGULATE | INCENTIVISE | FACILITATE |
|---|---|---|

Governments should back up a zero carbon buildings vision by building a comprehensive policy package of the many available interventions towards decarbonising space heating and cooling. The more options taken, the higher the likelihood that the transition will be fast enough to meet the Paris Agreement goals.

## REGULATE

### INTRODUCE ZERO CARBON STANDARDS FOR ALL NEW BUILDINGS

- Introduce and strengthen building codes to aim for high energy efficiency. Include prescriptive energy efficiency requirements adapted to local climate conditions.
  - *Case Study 4: US - A voluntary framework for local mandatory codes*
  - *Zero Code*

### INCREASE RETROFIT RATES THROUGH MINIMUM ENERGY PERFORMANCE STANDARDS

- Mandate energy performance certificates for all buildings and require energy upgrades at clear trigger point, such as a specified time period or change of hands.
  - *Case Study 5: New York - Building energy code for existing buildings*
  - *Box 6: EU Energy Performance Buildings Directive for existing buildings*

### MANDATE THE USE OF RENEWABLE ENERGY WITH STANDARDS

- Either as part of building codes with minimum thresholds or as separate regulations, require installation of on-site renewable energy systems and/or green electricity procurement
  - *Box 6: EU Energy* Performance Buildings Directive for existing buildings

### STRENGTHEN HEATING AND COOLING EQUIPMENT STANDARDS

- Use MEPS to shift average market toward best available efficiency standards.
- Regulate high GWP HFCs in heat pumps and AC's in line with Kigali Amendment.

### PHASE-OUT FOSSIL-BASED HEATING TECHNOLOGIES

- **Step 1**: Stop new gas connections or fossil fuel boilers in new builds.
  - *Box 7 with the Netherlands, Ireland, France and more*
- **Step 2**: Stop new oil and gas boilers in all buildings.

### ENSURE COMPLIANCE THROUGH A COMPREHENSIVE ENFORCEMENT STRATEGY

- Establish a public entity responsible for the monitoring and evaluation of buildings' compliance, including penalties for non-compliance.
  - *Case Study 3: China - A coordinated top-down policy package and a comprehensive enforcement strategy*

### TAKE A LEAD BY UPGRADING PUBLIC BUILDINGS

- Mandate energy efficiency improvements to government-owned and rented buildings and invest in upgrades to social housing to kick-start local markets.

## INCENTIVISE

### ADJUST TAX STRUCTURES

- Adjust energy taxes to reflect emissions intensity, adjust VAT for low-carbon products and/or introduce a carbon price, adjust property taxes for energy efficiency levels.
  - *Case Study 13: How Sweden has cut carbon intensity by two thirdsCase Study 13: How Sweden has cut carbon intensity by two thirds*
  - *Belgium: Flanders's energy-efficiency adjusted property taxes*
  - *Netherlands: VAT linked to energy sources*
- Couple tax increases with support schemes for low-income households.

### ADDRESS THE LANDLORD TENANT DILEMMA

- Incentivise landlords to perform energy upgrades. Options include enforcing energy codes and amending rental contracts to ensure utility bills are passed on to landlords.
  - *Sweden's rental agreements linked to energy efficiency levels*

### DEVELOP ALL-IN-ONE FINANCIAL SUPPORT PACKAGES

- Consisting of grants, credit risk guarantees, low-cost debt, energy saving dependent partial debt cancellation, whereby the level of support is linked to the expected energy savings.
  - *Case Study 6: Germany's KfW's financial support scheme linked to voluntary building energy codes*

### DIRECTLY INCENTIVISE PURCHASE OF BEST-IN-CLASS TECHNOLOGIES

- Provide grants and subsidies to kick-start the market, such as direct refunds or feed-in-tariffs for rooftop solar panels.
  - *South Korea: A 10 % refund for best-in-class ACs*

### PROVIDE CREDIT RISK GUARANTEES

- Reduce the risks for financial providers, including ESCO's and private banks, by guaranteeing loans and credit.
  - *Case Study 10: The US - Ithaca's multi-level governance approach*
  - *Bulgaria: Bulgarian Energy Efficiency Fund (BgEEF)*

### INCREASE ACCESS TO LOW-COST DEBT

- Either directly through public banks or through commercial banks.

### SUPPORT INNOVATIVE FINANCE MODELS TO OVERCOME HIGH UPFRONT COSTS

- Incentivise the uptake of Energy Performance Contracts (EPCs), pay-as-you-go services and/or other models until they reach market maturity.
  - *Case Study 7: Netherlands - Energiesprong's standardised EPCs for affordable, quick, and deep energy retrofits*

### ESTABLISH AND FUND A GREEN BANK

- Backed by government funds to specifically leverage investments from the private sector.
  - *Case Study 8: Australia's Clean Energy Finance Corporation*

## FACILITATE

### ENSURE AN APPROPRIATELY SKILLED AND INFORMED WORKFORCE

- Support the creation and ongoing operation of training programs that impart relevant knowledge and skills on installers/contractors.
  - *Case Study 11: EU/Spain - BUILD UP Skills Initiative/Contruye 2020*

### INCREASE INSTITUTIONAL CAPACITY FOR ENFORCEMENT OF CODES AND STANDARDS

- Develop capacity-building programs to increase the number of qualified third-party certifiers.

### RAISE AWARENESS AND PROVIDE INFORMATION

- Fund communication campaigns showcasing available funding schemes or outlining benefits of energy efficiency upgrades.

### ENGAGE KEY STAKEHOLDERS IN PLANNING PROCESSES

- Consult with, and facilitate exchange between, actors of the buildings sector to develop and revise decarbonisation roadmaps with widespread sectoral buy-in.
  - *Case Study 12: Sweden - Fossil Free Sweden's stakeholder engagement process*

### USE A MULTI-LEVEL GOVERNANCE APPROACH

- Where possible and prudent, leverage the natural advantages of different levels of government to maximise potential impact of policies.
  - *Case Study 10: The US - Ithaca's multi-level governance approach*

### SUPPORT THE ESTABLISHMENT OF ENERGY SERVICE COMPANIES (ESCOS)

- Make appropriate adjustments to regulation of energy services.
- Provide training for installers and contractors to shift to ESCOs.

### TRACK PROGRESS TOWARDS ZERO EMISSIONS

- Collect and share data to track and communicate progress amongst actors.
  - *France: Publicly supported nationwide network of one stop shops in the making*

### STREAMLINE PROCESSES AND PROVIDE GUIDANCE THROUGH ONE-STOP-SHOPS

- Reduce complexity and improve access to trusted information on technological, finance, and contracting options.

**Regulations** and their effective enforcement can push efficiency and decrease the carbon intensity of new buildings and retrofits. Regulations establish a floor of efficiency requirements. Clear regulations help to communicate the seriousness with which the government intends to achieve its goal and, if communicated clearly and early enough, can help to steer the market to align with those regulations early.

Setting energy codes and standards for both new and existing buildings is a fundamental component of any building policy portfolio. Energy codes need to be expanded to all countries and need to be strengthened where they already exist. Ensuring that all new buildings are zero carbon will prevent the need for deep retrofits in the future and have lower costs over the lifetime of the building. In countries where most of the building stock has already been constructed, the priority for governments should be in adapting codes to ensure an increase in the rate of energy retrofits, particularly for the worst rated buildings.

Additional regulations to be considered include efficiency standards for heating and cooling appliances, a phase-out of HFCs in equipment in line with the Kigali Amendment (Box 2: Refrigerants with low global warming potential) and bans of new installations of fossil fuel-based equipment, such as gas or oil boilers (Box 7: Banning new installations of fossil fuel equipment for heating).

**Incentives** are needed to promote compliance with any regulations. Most incentive options available to governments are financial incentives.

Governments can use financial incentives to improve the cost-competitiveness of zero carbon options, including the provision of grants, of low-cost loans, or by adjusting tax levels such as products' VAT, property taxes, or energy / carbon taxes (Element Three – Financing). The most appropriate policy, or set of policies, will depend on existing policies and other government priorities. Increasing the uptake of zero carbon buildings can boost the associated knowledge, skills, awareness, and reduce costs as economies of scale are achieved, thereby catalysing additional uptake.

The relative cost of gas or oil and electricity can provide a barrier to zero carbon buildings. Where the costs of electricity are high, the financial incentives to electrify heating are low. A carbon price can be one way to make the costs more comparable, provided there is a substantial share of renewable energy in the grid. Alternatively, support for on-site renewables in combination with a carbon price could provide sufficient financial incentives to electrify heating.

Governments can use additional policy actions and instruments to facilitate compliance with regulations. Facilitative roles governments can play include those that ease the logistics of compliance, that inform, support, and engage relevant actors. Of the options to facilitate change, it's not so easy to single out one or two as fundamentally necessary. Rather, it's important that governments leverage multiple, or all, options available to increase the speed with which a transformation can be achieved.

Easing the logistics of compliance could be achieved by ensuring that regulations are well-formulated, appropriate, and easy to follow. Regulations should be updated to ensure that new building materials can be used or that innovative approaches to retrofitting can be applied.

Regulation may also need to be introduced or adjusted to enable or encourage the establishment of energy service companies and agreements. Implementation and enforcement of these regulations requires sufficient institutional capacities that also need to be enhanced by governments. Getting the transition right will require detailed policy work.

All those involved in the construction and retrofitting of buildings need to have the relevant knowledge and skills. Government supported education and training schemes can promote zero carbon strategies, ensure the necessary skills are available, and help contractors to adapt to new requirements.

One-stop-shops (see Element Four — A multitude of actors) have high potential for promoting zero carbon buildings among key decisions makers. They can ease the access to information regarding appropriate technological and financial options and establish connections to trusted contractors.

Perhaps most importantly, facilitating transformative change requires the engagement of all relevant stakeholders. Governments can work with relevant stakeholders at all stages – target setting, planning and in the detailed policy implementation – to get the details right for the specific local situation.

### Box 12: Social housing and other publicly- owned buildings

One way that governments can kickstart or expedite the transformation of a building stock to reach zero carbon is the targeting of those buildings directly under their control. For many governments, the largest proportion of such buildings will be made up of social housing; government-owned residential buildings offered to low-income individuals and families that are otherwise priced out of the housing market.

Ownership of such a large and diverse set of residential buildings provides an ideal opportunity to achieve progress on decarbonisation of the total building stock within a government's jurisdiction. Targeting social housing upgrades has several merits, and benefits from the avoidance of various potential pitfalls of schemes targeting the private sector. These include:

- Removing risks of scheme failure due to poor uptake of grant funding or scheme design;
- Complete oversight over quality of work and achievement of efficiency outcomes;
- Improving the quality of life of low-income individuals and families, reducing inequality in society;
- Provision of certainty as to the longevity and scope of the scheme, which can kickstart investments from firms in expansion and training needed to accommodate greater future demand;
- The diversity of building types and sizes within an overall social housing stock provides opportunities to understand the myriad potential challenges resulting from this diversity, helping to inform the design of future schemes targeting the private sector.

In addition to social housing, other government-owned buildings are similarly excellent targets as an early intervention and for an investment of government resources. Large government offices and other facilities are often similar to various commercial buildings. All of the advantages listed above apply to retrofitting these buildings, bar the reduction of societal inequality.

Investments in retrofits and construction of zero carbon government buildings of all types is a highly effective tool for generating early momentum towards the end goal of full buildings sector decarbonisation.

## Why should governments act?

Governments clearly have the agency and tools to effect substantial change in the buildings sector, but it can be a challenging issue politically. The topic is complex, and large-scale impacts can take a long time to materialise. Addressing climate change also needs to be combined with concerns regarding the safety, affordability, and availability of housing and other buildings. Prioritising buildings in lower-income economies can be particularly challenging where there are other pressing issues to address, including the COVID-19 pandemic.

To be serious about addressing climate change, energy efficiency improvements in the buildings sector are essential. Securing energy supply is a fundamental role of government and energy efficiency must be a major strategy for doing so. Reducing energy demand is fundamental for a decarbonised world with electrification of end-use services and a shift to renewable energy supplies. If efficiency does not improve, then there are major risks to energy services and the challenge of fully decarbonising power supply becomes even greater. Improvements in energy efficiency are fundamental to meeting net zero emissions by 2050 (IEA, 2021c).

In addition to the need for governments to adhere to their commitments under the Paris Agreement, addressing emissions from heating and cooling buildings can have multiple other benefits when done well.

As with mitigation efforts in other sectors, shifting toward electrification and decarbonising the power grid reduces reliance on fossil fuel imports and increases energy independence, eliminating a source of energy price volatility. The recent natural gas crisis in Europe highlights the major risk of gas fuel price volatility in nations dependent on gas for heating.

Further benefits of ambitious mitigation policies include cost-savings, employment, health, productivity, and comfort for occupants (UNEP, 2019).

## Pressure through advocacy – entry points for non-governmental stakeholders

While governments are key to transforming the buildings sector, other actors also have tools at their disposal to accelerate and push this transformation (see Box 11: What role for international organisations?).

One critical role is holding governments accountable for their promises and highlighting gaps in action. This is particularly relevant for developed countries' governments, that have the capacity and responsibility to implement action in line with the Paris Agreement.

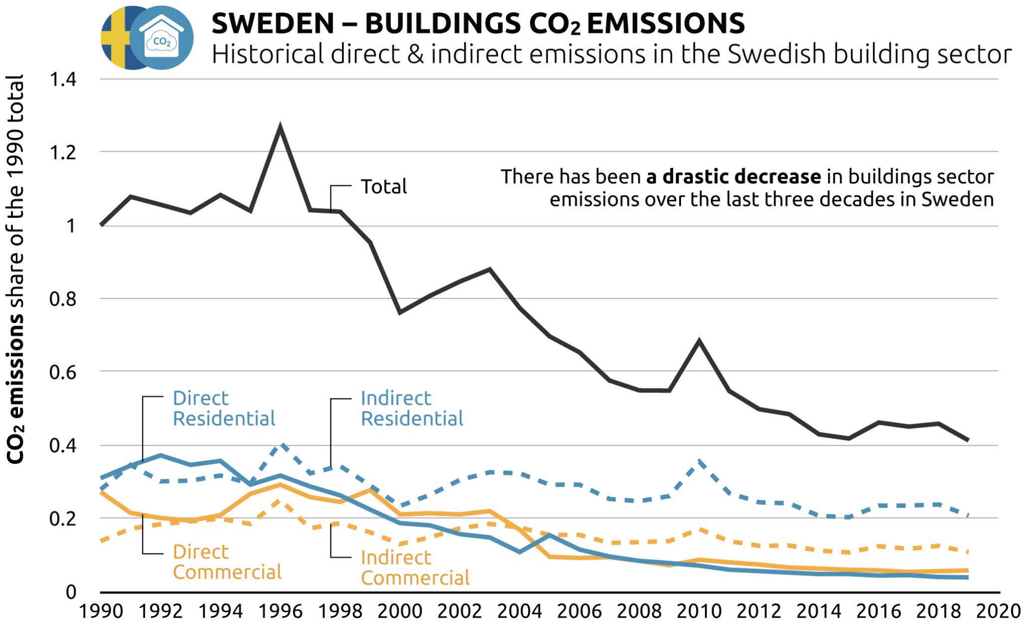
Non-government stakeholders already monitor the activities and commitments of companies, decarbonisation strategies, including net-zero emissions targets. These targets can be monitored for transparency, integrity, ambition, and importantly, scope. Company decarbonisation targets need to include the decarbonisation of buildings owned or rented by the company, including construction or retrofitting. Some companies are more directly engaged in the buildings sector and should look toward aligning their services with a net zero pathway. For example, ensuring sufficient training for a switch to installing zero carbon heating equipment, designing zero carbon buildings, or ensuring there are no HFCs in manufactured cooling products.

Developing country governments are often more limited in their reach, and other actors could provide some of the facilitative roles such as information and knowledge sharing around low-carbon buildings. For example, in those developing countries where cooling needs are growing quickly, non-government stakeholders could support sharing information around (1) skills for designing and constructing passive cooling in buildings, and (2) regulating energy performance standards of cooling equipment.

# Annex I National Case Study: Sweden

## Case Study 13: How Sweden has cut carbon intensity by two thirds

One country that has seen a drastic decrease in buildings sector emissions over the last three decades is Sweden. While maintaining fairly steady energy use, Sweden's $CO_2$ emissions for the buildings sector have decreased, particularly direct emissions. Sweden is not alone but is one of very few that has achieved this. The strong supply-side focus to buildings sector decarbonisation taken by Sweden means that there is still great potential to realise energy efficiency gains in its building stock. This case study illustrates the package of measures that have regulated, incentivised, and facilitated change in Sweden.



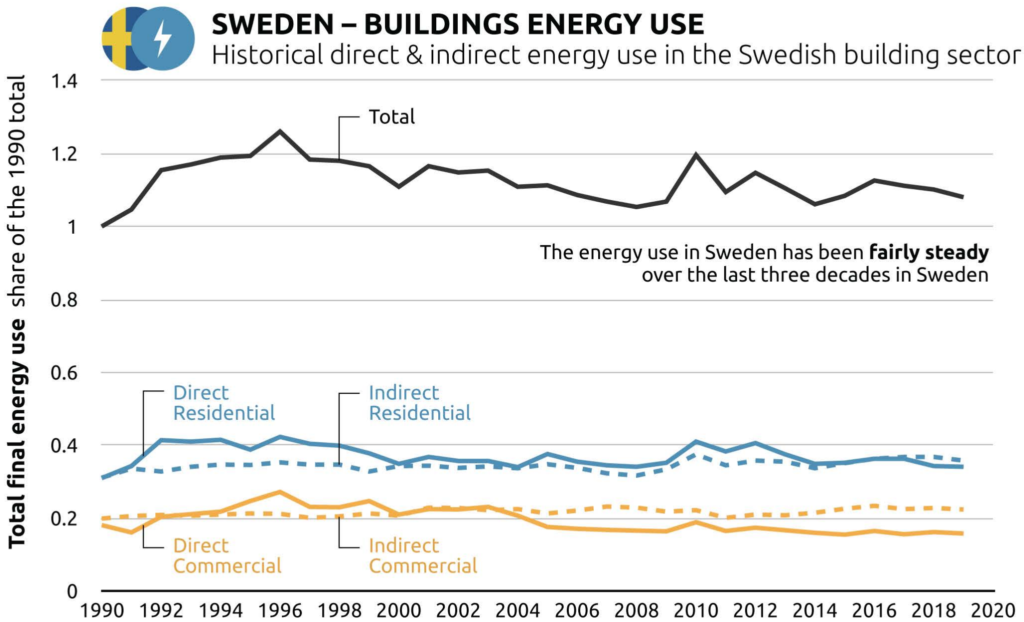




Figure 33: Trends in buildings sector emissions and energy use over the last three decades. Direct emissions have decreased substantially since 1990 while overall energy use has remained fairly constant. Source: (IEA, 2021f, 2021j)

## Sweden's low-carbon buildings sector: A brief history

The steep and continual decline in direct buildings sector emissions in Sweden is the result of a confluence of factors, many of which are the result of targeted government interventions. The introduction of a carbon tax in 1991 represents one of the earliest implementations of such a scheme, and the price of carbon in Sweden has risen over time to be the highest in the world (World Bank Group, 2020).

The inclusion of the buildings sector in the scheme's coverage has provided a strong **incentive** to minimise fossil fuel use in homes and commercial buildings. Addressing the tenant-landlord dilemma through devising novel rental agreements that extended this incentive to renters was a critically important step. Sweden's relatively cheap electricity also meant that switching to electric space and water heating, and cooking has been financially viable for many. Many multi-family dwellings also benefit from district heating that has seen a reduction of more than 75% in the emissions intensity of energy produced since the introduction of Sweden's carbon tax in 1991 (Werner, 2017a). District heating benefited from consistent investments that began in response to the energy crisis of the 1970s, and now constitutes almost a fifth of household heating demand (Government of Sweden, 2020).

A high level of renewable and nuclear electricity generation in Sweden's power sector has ensured Sweden has the lowest emissions intensity of electricity in Europe (EEA, 2021). Such low emissions intensity of power generation means that a switch to electric space and water heating via heat pumps has an especially pronounced impact on total emissions, and explains why a steep decline in direct building emissions has not led to an increase in indirect emissions. This highlights the importance of an expedited decarbonisation of the power sector for achieving a rapid decline in buildings sector emissions.

A shift from prescription-based to performance-based building **regulations** in 1988 created the conditions for a more efficient and flexible achievement of targeted energy efficiency gains, and was well ahead of the EU's shift to this approach in the Energy Performance of Building Directive (EPBD) of 2002 (Neij and McCormick, 2009; Economidou *et al.*, 2020). The adoption of Sweden's National Programme for Energy Efficiency and Energy Smart Construction in 2006 set a goal of phasing out fossil fuel use and reducing energy use in the buildings sector by 20% below 1995 levels by 2020 and 50% by 2050. This coincided with the establishment of an industry rating system for windows in the same year.

While overall energy use in the Swedish buildings sector did not decline by the targeted 20% by 2020, the fossil fuel phase out has mostly been realised and greater than 20% reduction was achieved in energy for space and water heating by 2017 (Government of Sweden, 2020). This coincided with the elimination of oil for heating, that made up approximately a quarter of total demand in 1995.

Sweden has largely achieved buildings decarbonisation from the supply-side, with fuel-switching from oil to very low-carbon electricity through the adoption of heat pumps having an outsized impact, but large reductions in heating demand are still possible. Savvidou & Nykvist (2020) show a 61% reduction by 2050 below 1995 is possible if measures are implemented addressing technological, structural, and behavioural drivers of demand. Addressing just technological drivers of demand alone is shown to almost lead to the achievement of Sweden's 2050 target of a 50% demand reduction, due to large improvements in single-family dwellings.

Sweden's continued government support in establishing and **facilitating** a local heat pump manufacturing industry in the form of purchase subsidies and funding for research and development has also helped to ensure the necessary skills exist to build, install and maintain an extensive number of heat pumps.

## What can be learned from Sweden's experience?

**Build a strong foundation and accelerate efforts when windows of opportunities open**

Early and concerted efforts by the Swedish Government have helped to lay the groundwork for achieving a low-carbon buildings sector. In responding to the energy crisis of the 1970s through investments in heat pump research and development, and fostering a local production capacity, a strong foundation was formed to build upon in later decades.

A parallel can be drawn with the current gas supply crisis in Europe, with high and volatile prices for natural gas, the primary heating fuel for many European countries, providing a strong impetus to invest in alternative heating technologies. The emergence of such a crisis provides an opportunity for governments to demonstrate that they are taking action to address it and insulate their constituents from future crises. Investing in public building upgrades and subsidising heat pumps and building envelope upgrades for businesses and households can be enacted relatively quickly in response to such a crisis. These investments can then be built on to continue the momentum generated by them.

The long-standing support for heat pump technology development and adoption has led the Swedish public to become more familiar with it over time. It is possible that this increased familiarity has contributed to Sweden's far higher rate of heat pump adoption than neighbouring Finland which has similar climate, culture, and infrastructure. It has been suggested that these continued investments in research and development have led to a propensity to adopt such locally developed technology over imported alternatives (Bayer *et al.*, 2012).

Establishing a system of zero-carbon district heating networks would enable a centralised approach to achieve largescale decarbonisation of existing building heating demand in cities. Replicating Sweden's success with district heating, however, which provides 17% of total household heating demand and has helped to all but eliminate waste being sent to landfill, would require substantial planning and foresight. Sweden began its efforts to establish a district heating system in the 1950s.

**Carefully design standards and improve them over time**

Improving poorly designed or lax MEPS should be a priority for governments given the outsized impact MEPS have on generating large emission reductions. Sweden's decision to switch from prescriptive to performance-based building regulations all the way back in 1988 was followed in turn by EU-wide regulations more than a decade later, vindicating this decision and underscoring its importance.

Consulting built environment actors in the process of devising or amending MEPS can help to ensure greater adherence and superior outcomes. In developing its third strategy for energy efficient retrofits, the Swedish government ensured the process involved consultation with a wide range of relevant stakeholders including the construction industry, property owners, and researchers (Government of Sweden, 2020).

Implementing such carefully designed standards is crucial, but they are only successful if they are complied with. This requires effective enforcement, often the most challenging ingredient for success.

**Create a comprehensive and effective set of (dis)incentives**

Sweden has long provided financial incentives to encourage the adoption of key low emission technologies like heat pumps. But there are numerous examples of the Swedish government introducing impactful incentives and disincentives to guide actions by the various key buildings sector actors. Including the buildings sector under Sweden's stringent carbon tax has helped drive uptake of government subsidies for energy efficient technologies from individuals and businesses.

In addition, tax breaks and low interest loans for energy efficiency upgrades and technologies create a suite of incentivising measures reaching a broad swathe of key actors like property and business owners, and developers. Incentivising tenants is equally important, and Sweden's all-inclusive rental contracts provide a proven template for doing so.

**Promote actions taken**

Sufficiently publicising measures taken towards decarbonising the buildings sector is key to ensuring their success. Sweden has shown its competence in producing effective communications outputs, with its waste-to-heat information campaign going viral (Karolyte, 2017). Communicating the design of Sweden's carbon tax that was implemented in 1991 was crucial to ensure the public understood it would not disproportionately impact low-income households. This campaign was run in conjunction with the release of subsidies for home improvement projects, helping to alleviate potential negative connotations with the policy.

**Assemble a multitude of actors**

Given the uniquely large and diverse set of stakeholders that affect the trajectory of the buildings sector, devising means to engage them in a constructive process is crucial. The Swedish government's 'Fossil Free Sweden' initiative is a broad engagement strategy tackling all climate-relevant sectors of the economy. For each sector covered, including heating for buildings, a roadmap is developed with the input of a large number and type of sector-specific actors.

This approach both incorporates the relevant knowledge of this broad set of actors, but achieves buy-in from these actors to meet the agreed targets and action. These include a complete phase out of fossil fuel use in building heating by 2030 and a commitment to become a net carbon sink by 2045, and sub-sector specific commitments from heat pump manufacturers, property owners and builders, and municipalities, among others (Fossil Free Sweden, 2019). The heating sector 'roadmap' demonstrates that it is both possible and beneficial to bring buildings sector actors to the table in a collaborative process.

## Take-aways from the case study

The example of Sweden shows how change can happen as a result of consistent and concerted efforts. Multiple motivators initiated and sustained these efforts over time in Sweden, starting with energy security during the oil crisis in the 70s and the need to mitigate climate change more recently. The actions taken by the government have been diverse and tackled different areas that together enable the decarbonisation of buildings. The actions have in common that they target the goal of minimising the use of fossil fuels in buildings. Such a common goal and sense of direction is essential, particularly in a heterogeneous environment as the buildings sector.

The case study shows that building on performance-based energy standards is key, however their verification is more difficult and requires greater resources. District heating fuelled by biomass has been an important route for decarbonising energy supply for buildings in Sweden – enabled by conditions that many other governments will not find. Even Sweden can still improve their buildings sector further to get closer to zero emissions and push energy consumption down.

Shifting the buildings sector is complex. The changes in carbon intensity in Sweden happened mainly over two decades, with a foundation in energy efficiency measures already existing for decades before. Looking forward, many other countries significantly need to step up their efforts to consolidate and intensify action in this sector, to move towards a Paris-compatible pathway. Countries can learn from what Sweden has done, and implement measures that will shift the sector both further and faster.

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## The Consortium

NewClimate Institute is a non-profit institute established in 2014. NewClimate Institute supports research and implementation of action against climate change around the globe, covering the topics international climate negotiations, tracking climate action, climate and development, climate finance and carbon market mechanisms. NewClimate Institute aims at connecting up-to-date research with the real world decision making processes.

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Climate Analytics is a non-profit climate science and policy institute based in Berlin, Germany with offices in New York, USA, Lomé, Togo and Perth, Australia, which brings together interdisciplinary expertise in the scientific and policy aspects of climate change. Climate Analytics aims to synthesise and advance scientific knowledge in the area of climate, and by linking scientific and policy analysis provide state-of-the-art solutions to global and national climate change policy challenges.

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