International Energy Agency

Perspectives for the Clean Energy Transition

The Critical Role of Buildings

April
2019

Abstract

This report explores the critical role buildings can play in meeting climate change ambitions, using a portfolio of clean energy solutions that exist today. It considers the investment needs and strategies to enable the buildings sector transition, and the multiple benefits that transformation would deliver, including improving the quality and affordability of energy services in buildings for billions of people. Importantly, it sets out what policy makers can do to overcome the economic and non-economic barriers to accelerate investment in low-carbon, energy-efficient solutions in the buildings sector. This ranges from traditional, yet highly effective policy tools to ambitious, innovative market-based approaches that can increase the speed and scale of investment for a sustainable buildings sector. This is the third report in a series. In 2017, the International Energy Agency (IEA) explored how a very ambitious and rapid energy transition to address climate change might look, in support of the German presidency of the G20. In 2018, the IEA provided further insights into the fundamentally important role of energy efficiency to achieve that energy transition.

Highlights

- The pace and scale of the global clean energy transition is not in line with climate targets. Energy-related carbon dioxide (CO_2) emissions rose again in 2018 by 1.7%. The buildings sector represented 28% of those emissions, two-thirds from rapidly growing electricity use. In fact, since 2000, the rate of electricity demand in buildings increased five-times faster than improvements in the carbon intensity of the power sector.
- CO_2 emissions need to peak around 2020 and enter a steep decline thereafter. In the Faster Transition Scenario, energy-related emissions drop 75% by 2050. The carbon intensity of the power sector falls by more than 90% and the end-use sectors see a 65% drop, thanks to energy efficiency, renewable energy technologies and shifts to low-carbon electricity. The buildings sector sees the fastest CO_2 reduction, falling by an average of 6% per year to one-eighth of current levels by 2050.
- Technology can reduce CO_2 emissions from buildings while improving comfort and services. In the Faster Transition Scenario, near-zero energy construction and deep energy renovations reduce the sector's energy needs by nearly 30% to 2050, despite a doubling of global floor area. Energy use is cut further by a doubling in air conditioner efficiency, even as 1.5 billion households gain access to cooling comfort. Heat pumps cut typical energy use for heating by a factor of four or more, while solar thermal delivers carbon-free heat to nearly 3 billion people.
- A surge in clean energy investment will ultimately bring savings across the global economy and cut in half the proportion of household income spent on energy. Realising sustainable buildings requires annual capital flows to increase by an average of USD 27 billion (United Sates dollars) over the next decade – a relatively small addition to the USD 4.9 trillion dollars already invested each year in buildings globally. Yet, cumulative household energy spending to 2050 is around USD 5 trillion lower in the Faster Transition Scenario, leading to net savings for consumers, with the average share of household income spent on energy falling from 5% today to around 2.5% by 2050.
- Government effort is critical to make sustainable buildings a reality. Immediate action is needed to expand and strengthen mandatory energy policies everywhere, and governments can work together to transfer knowledge and share best practices. Clear policy support for innovation will enable economies of scale and learning rates for industry to deliver solutions with little increase in cost. Policy intervention can also improve access to finance, de-risk clean energy investment and enable market-based instruments that lower the cost of the clean energy transition.
- Delaying assertive policy action has major economic implications. Globally, the scale of new buildings likely to be built by 2050 under inadequate energy policies is equivalent to 2.5-times the current building stock in the People's Republic of China ("China"). Waiting another ten years to act on high-performance buildings construction and renovations would result in more than 2 gigatonnes of additional CO_2 emissions from 3 500 million tonnes of oil equivalent of unnecessary energy demand to 2050, increasing global spending on heating and cooling by USD 2.5 trillion.

Acknowledgements

This report was produced by the International Energy Agency (IEA), with support and funding from the German Federal Ministry for Economic Affairs and Energy (BMWi). The report was prepared under the leadership of Mechthild Wörsdörfer, Director of the Directorate of Sustainability, Technology and Outlooks, and Timur Gül, Head of the Energy Technology Policy Division. The report was led by John Dulac and written by Thibaut Abergel, Chiara Delmastro, Peter Janoska, Kevin Lane and Andrew Prag.

The report benefited from valuable inputs and comments from other experts within the IEA, including, Stéphanie Bouckaert, Laura Cozzi, Brian Dean, Kathleen Gaffney, Jessica Glicker, Timothy Goodson, Luca Lo Re, Francesco Mattion, Jad Mouawad, Brian Motherway, Uwe Remme, Sasha Scheffer, and David Turk. Thanks also go to Astrid Dumond, Katie Lazaro and Therese Walsh of the IEA Communications and Digital Office for their help in producing this publication.

Several experts from outside the IEA provided input, commented on the underlying analytical work and reviewed the report. Their contributions were of great value. Those people include: Luca De Giovanetti (World Business Council for Sustainable Development [WBCSD]), Cristina Gamboa (World Green Buildings Council [WorldGBC]), Dolf Gielen (International Renewable Energy Agency), Toni Glaser (BMWi), Siyue Guo (Tsinghua University Building Energy Research Center [BERC]), Nicolas Howarth (King Abdullah Petroleum Studies and Research Center), Roland Hunziker (WBCSD), Marc LaFrance (United States Department of Energy), Jennifer Layke (World Resources Institute), Régis Meyer (French Ministry of Ecological and Inclusive Transition), Natacha Nass (United Nations Environment Programme [UN Environment]), Emmanuel Normant (Saint Gobain), Thomas Nowak (European Heat Pump Association), Oliver Rapf (Buildings Performance Institute Europe), Nora Steurer (UN Environment), Sandra Tacke (BMWi), Paul Voss (Euroheat & Power [EHP]), Detlef van Vuuren (Netherlands Environmental Assessment Agency), Ingo Wagner (EHP), Terri Wills (WorldGBC) and Da Yan (BERC).

Executive summary

The global energy sector is not on track for a low-carbon transition

The world's energy supply is almost as carbon intensive as it was two decades ago. Energy-related carbon dioxide (CO_2) emissions rose by 1.7% in 2018, following an increase of 1.6% in 2017. This comes after three years of emissions staying flat and is due to a variety of factors, including economic growth, extreme weather and a slowdown in efficiency improvements.

The buildings sector accounted for about 28% of total energy-related CO_2 emissions, two-thirds of which is attributable to emissions from electricity generation for use in buildings. The sector's energy intensity per square metre improved, but its emissions increased more than 25% since 2000. This reflects a 65% increase in floor area since then, growing demand for energy services and rising electricity consumption. Electricity use in buildings grew five-times faster than improvements in the carbon intensity of power generation since 2000, and rising demand for equipment such as air conditioners is putting pressure on electricity systems.

A clean energy world will look significantly different than today

In contrast to current trends, the Faster Transition Scenario sets out a vision for an extremely ambitious transformation of the energy sector. Energy-related emissions peak around 2020 and drop 75% to around 10 gigatonnes of CO_2 ($GtCO_2$) per year by 2050. The carbon intensity of the power sector falls by more than 90% and the end-use sectors see a 65% drop, thanks to energy efficiency, uptake of renewable energy technologies and shifts to low-carbon electricity.

Electrification plays a major role in the transition, combined with clean power generation. Electricity's share in final energy reaches about 35% by 2050, compared to less than 20% today. That growth is mainly due to adoption of heat pumps in buildings and industry, as well as a swift evolution in transport. Efficiency improvements keep electricity demand for other end uses, such as lighting and cooling, relatively stable, while access to electricity improves worldwide.

Buildings will play a central role in the clean energy transition

Among the sectors, buildings undergo the most abrupt CO_2 emissions reductions in the Faster Transition Scenario. Emissions from fuel combusted directly in buildings fall nearly 75% by 2050. This dramatic drop is achieved by almost total elimination of coal from use in buildings, 85% reduction in oil consumption and 50% drop in overall natural gas demand relative to today.

The significance of buildings is further highlighted when direct emissions are combined with indirect CO_2 emissions from electricity use. The share of electricity in energy use in buildings jumps from 33% in 2017 to nearly 55% in 2050. Yet, major efficiency improvements mean electricity demand is around 300 million tonnes of oil equivalent (Mtoe) lower in 2050 than it would have been otherwise. Paired with clean electricity, this means buildings-related emissions fall by around 6% per year to reach 1.2 $GtCO_2$ by 2050 – one-eighth of current levels.

Technology and design are at the heart of a sustainable buildings sector

Multiple cost-effective technologies unleash average energy savings of 500 Mtoe per year in the buildings sector worldwide between 2020 and 2050. High-performance buildings construction and energy renovations reduce the sector's energy use by nearly 30% to 2050, even as floor area doubles globally. A doubling in air conditioner performance reduces energy demand further, as 1.5 billion households gain access to cooling comfort. Heat pumps cut typical energy use for heating by four, and solar thermal delivers carbon-free heat to nearly 3 billion people by 2050.

Efficiency gains in lighting and appliances deliver around 110 Mtoe of energy savings over the period to 2050, while allowing access to and improved quality of energy services everywhere. Digitalisation and smart demand-side management further reduce energy use in buildings by as much as 10%. Demand-side response for 1 billion households and 11 billion smart appliances allows shifts of peak electricity demand to off-peak hours, supporting clean power generation in a synergistic combination with increasing electricity consumption in the buildings sector.

Enabling the clean energy future requires ramping up investment

Reaching the goals of the Faster Transition Scenario requires a rapid reallocation of capital. Fossil fuel supply investments decline sharply, but that is almost entirely offset by a doubling of investment in low-carbon power generation. Overall energy investment, driven by the end-use sectors, increases by about 65% from today's level, but this leads to considerable energy reductions that translate into major cost savings for households and businesses.

Realising sustainable buildings requires capital flow to increase by an average of USD 270 billion (United States dollars) a year over the next decade. This is a small addition to the USD 4.9 trillion already invested each year in the sector, and ultimately leads to USD 4.8 trillion in global savings to 2050. As a result, the share of household income spent on energy in the Faster Transition Scenario is cut in half by 2050. Delaying action ten years on high-performance construction and renovation would result in 3 500 Mtoe of unnecessary energy use to 2050, increasing cumulative spending on energy in buildings by USD 2.5 trillion.

Comprehensive policy packages foster market-based solutions

Immediate action is needed to put in place mandatory energy policy that addresses rapid buildings growth in emerging economies with limited or no policy coverage. As much as 2.5-times the current floor area of the People's Republic of China ("China") will be built in those countries over the next 30 years. Governments can co-operate to expand and strengthen building energy codes as well as performance standards for end-use equipment, building upon decades of successful experience.

Buildings are not homogenous and require solutions tailored to their specific conditions. Clear policy signals on energy and CO2 emissions performance levels are necessary to push and pull markets to identify appropriate solutions. Government support for technology innovation and new business models will enable economies of scale as well as improved learning rates to deliver solutions with little increase in manufacturing cost or consumer prices.

The buildings energy transition will deliver long-term returns on investment, but upfront financing remains a challenge. Governments can affect this through policy intervention to improve access to finance, de-risk clean energy investment and broaden availability of market-based instruments that lower the barriers for a clean energy transition.

Governments can reap benefits of international co-operation. Countries can share knowledge, enable best practices and deliver better solutions through multiple initiatives such as the IEA Technology Collaboration Programmes (TCPs), the IEA Global Exchange for Energy Efficiency and the Global Alliance for Buildings and Construction.

1. Energy transition progress and outlook to 2050

- The pace and scale of the clean energy transition is not in line with climate change targets. Energy-related carbon dioxide (CO_2) emissions are on the rise again, with emissions from both advanced and emerging economies increasing in 2017 and 2018, despite energy efficiency and decarbonisation efforts. Renewables are playing a bigger role, but fossil fuels still met around 70% of primary energy demand growth in 2018.
- Recent investment in the energy sector falls short of the level needed for the clean energy transition. Total investment in energy worldwide fell by 1.7% in 2017 – the third successive year of decline. In addition, the share invested in clean energy tampered off to less than a third of global energy investment in 2017.
- Despite some progress, deployment of most clean energy technologies is not on track. Comprehensive analysis of the clean energy transition shows that only 4 of 38 technologies are on course to meet long-term climate goals. Significant effort is needed to expand and ramp up deployment to achieve the rapid transformation of the global energy system.
- A clean energy sector will look fundamentally different to today's energy system. The Faster Transition Scenario sets out a vision for an extremely ambitious transformation of the energy sector, well in line the objectives of the Paris Agreement. Achieving that vision would require an immediate step-change in policy ambition and in technology deployment, across all aspects of energy supply and demand.
- CO_2 emissions need to peak around 2020 and enter a steep decline thereafter to meet the goals of the Paris Agreement. Energy-related emissions in the Faster Transition Scenario drop by 75% to around 10 gigatonnes of CO_2 ($GtCO_2$) per year by 2050. The carbon intensity of the power sector falls by more than 90%, and the end-use sectors see on average a 65% drop, thanks to energy efficiency, renewables and shifts to clean electricity.
- A surge in clean energy investment will ultimately bring savings across the global economy and cut household spending on energy in half. The Faster Transition Scenario calls for a increase or around 65% in average annual investment relative to today. The vast majority of the increase is on the demand side, in particular for end-use energy efficiency. This leads to savings in fuel costs for consumers and businesses, with the share of household income spent on energy falling from 5% today to around 2.5% by 2050. On the supply side, overall investment increases modestly, but with a substantial shift in capital allocation. Clean energy accounts for almost 75% of investment in the coming decade, while fossil fuel supply investment falls sharply.
- The buildings sector accounts for 28% of energy-related CO_2 emissions today including emissions from electricity use. Direct emissions from fossil fuel use in buildings drop by 75% by 2050 in the Faster Transition Scenario, a steeper percentage reduction than most other sectors. Energy efficiency and demand-side flexibility are equally essential to relieve pressure on the power sector, given the significant share of electricity demand in buildings.

Introduction

Energy forms the backbone of modern economies and is fundamental to economic development and prosperity. At the same time, the energy sector – still largely dominated by fossil fuel use in energy production, transformation and use – is responsible for two-thirds of global greenhouse gas (GHG) emissions and nearly 90% of CO_2 emissions. Consequently, it is central to any serious efforts to tackle climate change. The energy sector is also the dominant source of air pollution worldwide and is therefore pivotal to achieve sustainable development ambitions to reduce the serious health impacts being felt increasingly all around the world.

The global energy system is changing, with a fundamental shift in the geography of energy demand, shake-ups in conventional energy supply, increasing presence of digital tools and technologies, and the convergence of low-cost renewable energy with rising electrification of energy end uses. This evolution is happening across all branches of the energy sector, at different scales and speeds, and supported by various policy-based incentives. The ongoing transition is significant but it does not imply that the needed transformation of the energy sector will occur without further efforts, nor does it suggest the world is on track to meet its sustainable development targets. New and enforced policy frameworks put in place by public authorities will be central to achieve an accelerated, long-term and least-cost clean energy transition.

The energy sector is so complex and so pervasive across almost all segments of the economy that identifying how key energy trends and their drivers will affect climate outcomes is particularly challenging. Understanding the role and influence of a particular part is difficult to isolate given the complex interactions between the numerous elements of the energy sector. The buildings sector, the main focus of this report, well illustrates such complex interactions. CO_2 emissions are generated directly through fuels combusted in buildings as well as through indirect emissions from electricity use. Buildings also act effectively to reduce overall emissions through a host of efficiency-related technologies, as well as through building-integrated renewables. The construction of buildings also has a carbon footprint that can vary substantially depending on methods and materials used.

Understanding whether the current pace of transition is fast enough, and which policies can accelerate and redirect that transition, is no easy task. In this report, a very fast global energy transition is represented by the Faster Transition Scenario, which represents a low-carbon transition of exceptional scope, depth and speed. The scenario was first introduced by the International Energy Agency (IEA) following a request by the German government, in support of its 2017 presidency of the G20, for the IEA and the International Renewable Energy Agency to investigate the scale and scope of investments necessary to achieve deep and rapid decarbonisation (IEA-IRENA, 2017). The scenario, which was then known as the "66% 2°C scenario",[1] was further developed with a focus on energy efficiency for the Berlin Energy Transition Dialogue in 2017 (IEA, 2018a).

The Faster Transition Scenario incorporates ambitious assumptions about technology deployment and energy efficiency improvements across the energy spectrum. The result is a global CO_2 trajectory that peaks in the very near term and enters a steep decline towards net

[1] For more information on the relationship between the Faster Transition Scenario and long-term temperature outcomes, see Box 1.2.

zero global CO_2 emissions in the coming three decades. The scenario is well in line with the long-term temperature objectives of the Paris Agreement, but its compatibility with other Sustainable Development Goals, such as energy access and air pollution, has not been assessed explicitly in this analysis (Box 1.1).

In this analysis, the Faster Transition Scenario is compared with the New Policies Scenario, the main scenario in the IEA *World Energy Outlook* that aims to provide insights of where today's policy ambitions seem likely to take the energy sector based on existing policies and announced plans (IEA, 2018b). These include the climate pledges made by countries, known as the Nationally Determined Contributions (NDCs), which are the building blocks of the Paris Agreement. The New Policies Scenario cannot be taken as a "given", since to achieve its outcomes requires not only that all policies and measures already in place achieve their intended outcomes, but also that the targets and intentions that have been announced make their way into legislation and are successfully implemented. Nevertheless, the New Policies Scenario serves as a useful benchmark of expectations, allowing measurement of the scale of change required for a rapid energy transition, as in the Faster Transition Scenario.

Box 1. 1. Clean energy transition and the United Nations Sustainable Development Goals

The Faster Transition Scenario depicts an extremely ambitious, fast transition to a low-carbon energy sector, requiring very rapid changes in energy policy and technology deployment. The scenario does not focus on achieving other development goals related to energy. For example, access to modern energy services – both electricity and clean cooking facilities – is a fundamental prerequisite for social and economic development in countries where people still lack access. Reducing the health impacts of air pollution, of which the energy sector is the main source globally, is another key development concern.

The 17 Sustainable Development Goals (SDGs), agreed by 193 countries through the United Nations, provide a comprehensive framework for measuring progress towards sustainable development. The SDGs integrate multiple policy objectives, for example, recognising that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs, while also tackling climate change and strengthening environmental protection.

Energy underpins many of the SDGs and is fundamental for three goals in particular. This includes: SDG 7 concerning access to affordable, reliable, sustainable and modern energy; SDG 3 on health, specifically target 3.9 on reducing number of deaths and illnesses from air pollution; and SDG 13, which aims to take urgent action to combat climate change and its impacts.

While much attention has focused on action to tackle climate change, it is just one of many policy priorities related to energy, and many countries frame their climate contributions in the context of other policy goals, including ending poverty and reducing air pollution.

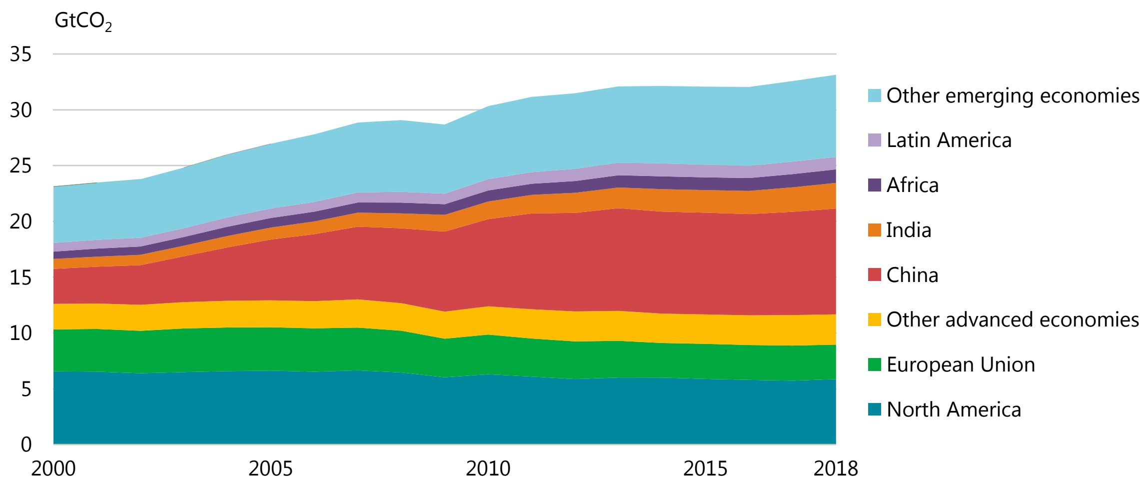
The IEA Sustainable Development Scenario, introduced in the *World Energy Outlook 2017*, provides an alternative low-carbon scenario that recognises these multiple priorities and illustrates an integrated approach to achieve the energy-related aspects of the SDGs (IEA, 2017). It considers determined action on climate change, as well as universal access to modern energy by 2030 and a dramatic reduction in air pollution. For more information, see: www.iea.org/weo2018/.

This chapter brings together diverse IEA data and expertise to set the scene for the in-depth analysis of the buildings sector and its related polices and technologies that can help deliver the clean energy transition. First, we take the pulse of the global clean energy transition: recent energy and emissions trends provide mixed signals about its pace and direction. Three trends are highlighted: energy-related CO_2 emissions; tracking clean energy technology deployment; and volume and type of energy investment. Next, a scenario approach considers the role of the buildings sector in the global context, using the Faster Transition Scenario to consider a rapid transition of the energy sector in the period to 2050.

Energy demand and CO_2 emissions are rising

Global energy-related CO_2 emissions rose in 2018, increasing by nearly 2%, following a 1.6% increase in 2017 from the previous year (IEA, 2019). This is a reversal from the 2014-16 period, during which CO_2 emissions from the energy sector remained flat. Increased emissions in 2017 and 2018 suggest that global CO_2 emissions may not have yet peaked. While the rise in emissions is more significant in emerging economies with higher rates of economic growth, including the People's Republic of China ("China") and India, preliminary estimates for 2018 also point to an increase in CO_2 in some advanced economies, notably the United States (Figure 1.1). The growth in emissions was not universal: Germany, Japan, Mexico, and France were among large economies showing a decline in emissions.

Figure 1. 1. Energy-related CO_2 emissions by region, 2000-18



Notes: Solid areas represent advanced economies; hatched areas are emerging economies.
Source: IEA (2019), Global Energy and CO_2 Status Report 2019, https://www.iea.org/geco/.

Global energy-related CO_2 emissions increased by 1.4 % in 2017 and 1.7% in 2018 to reach a historic high of 33.1 $GtCO_2$ after a three-year flattening trend, with the strongest rise in emerging economies.

Many underlying drivers affect global CO_2 emissions. The increase in emissions in 2018 was driven by a rapidly growing global economy and atypical weather conditions that saw increased demand for fossil fuels for electricity generation (driven in particular by rapidly rising space cooling demand in buildings) and for meeting space heating needs in buildings. The result was that global energy demand grew by 2.3% in 2018, which is 0.2% higher than growth in 2017 and more than twice the growth rate in 2016.

Continued reliance on fossil fuels is a critical contributing element to the energy-climate nexus. Renewables are playing an expanding role in the power sector, where hydropower and other renewables powered over a quarter of electricity generation in 2018. Yet, fossil fuels still met around 70% of overall energy demand growth.

The power sector is another critical element of the energy-climate nexus, as it was responsible for over 38% of energy-related CO_2 emissions in 2018. After falling for three years, CO_2 emissions from power generation increased by 2.5% in 2018. As a positive sign of progress, the overall share of fossil fuels in electricity generation decreased by about 0.7 percentage points, reaching 64.1% in 2018. At the same time, coal use in power generation increased in 2018, with 2.6% growth putting an upward pressure on CO_2 emissions from the power sector.

In addition, the rate of decline in global energy intensity (defined as the energy consumed per unit of economic output) slackened to only 1.3% in 2018, down from the 1.9% and 2.0% improvement seen in 2017 and 2016, respectively. This slowdown is significant, as global energy intensity improvement was the main driver behind the flattening of energy-related CO_2 emissions in 2014-16. The energy intensity improvement was closely linked to energy efficiency progress in those years, but the increase in coverage and stringency of policies slowed in 2017.

On the end-use side, CO_2 emissions from the transport sector worldwide accounted for 24% of direct emissions in 2017, up 0.6% from 2016 (compared with 1.7% annually over the past decade). Lower growth in emissions was spurred by improved vehicle fuel efficiency and more biofuel use, as well as increased electrification of various transport modes. Road transport – cars, trucks, buses, heavy freight and two/three-wheelers – accounted for over 75% of global energy demand and CO_2 emissions in the transport sector, a proportion almost unchanged since 2000. Global CO_2 emissions from road transport increased by 40% between 2000 and 2017, while total distance (in vehicle kilometres) almost doubled, highlighting strong improvements in the energy performance (and resulting CO_2 intensity).

Emissions from the industry sector rose by 0.3% in 2016 from the previous year, a slight rebound from the 0.5% decline in 2014-15. To be on course with the clean energy transition, industrial activity needs to decouple from CO_2 emissions and its energy intensity needs to improve. Industry is an important driver of global energy demand growth in all fuel categories. For example, the petrochemical industry is rapidly becoming the biggest driver of oil demand. Petrochemicals are set to account for over a third of oil demand growth to 2030 and nearly half to 2050, ahead of the primarily oil-based demand in trucks, aviation and shipping (IEA, 2018c). Pathways to reduce the emissions impact of petrochemicals will be important in the clean energy transition.

The buildings sector was responsible for almost a third of global final energy consumption in 2017, a slight increase over 2016. Direct CO_2 emissions from the sector have remained relatively stable since 2013, accounting for around 10% of total global energy-related CO_2 emissions. Yet, buildings consume more than 55% of global electricity. When these indirect emissions are taken into account, the total footprint of the buildings sector rises to nearly 30% of global CO_2 emissions. Energy demand for cooling is a main driver in the buildings sector; it doubled between 2000 and 2017, making it the fastest growing end-use in buildings (IEA, 2018d). Without efficiency gains, electricity demand for cooling could more than double by 2040, with even higher growth in rapidly emerging economies.

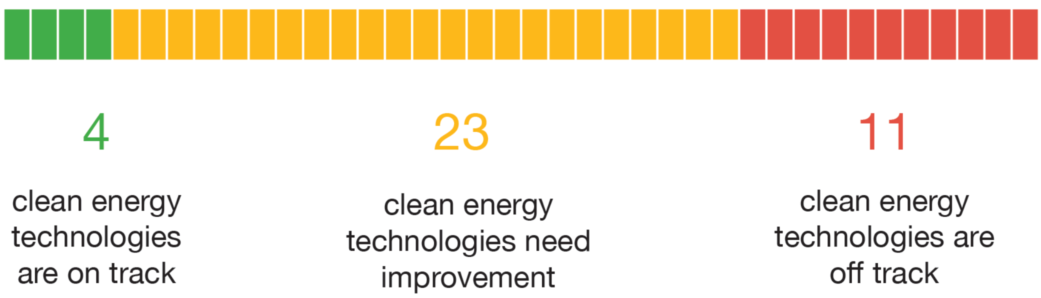
These trends underscore that the clean energy transition is a complex, uneven, multi-speed process in a system that is under pressure to meet rising demand for energy services. The growth of global energy-related CO_2 emissions in 2017 and 2018 stresses a critical juncture in the climate agenda. Despite efforts to reduce GHG emissions, the world's energy supply still is almost as carbon intensive as it was nearly two decades ago. Carbon intensity needs to improve dramatically by 2030 in order to limit the rise in average global temperature to less than 2°C above pre-industrial levels. Moreover, it needs to start today: a rapid reversal of the recent global emissions rebound is necessary in imminently to put the world on track towards long-term climate mitigation targets.

Is clean energy deployment on track for a low-carbon transition?

Energy-related emissions trends are dependent on how technology is produced and used across the economy, so assessing progress in technology deployment shifts is an important means of tracking the transition. An accelerated clean energy transition requires technology change at an unprecedented scale, across all technologies. Co-ordination is needed to ensure that advances in parts of the energy sector are not held back due to a lack of progress in other areas, for example advances in storage and battery technologies.

Some clean energy-related technologies have made tremendous progress in recent years, but most are not on track. Only 4 out of 38 energy technologies followed by the IEA Tracking Clean Energy Progress (TCEP) initiative have shown sufficient progress to mark them as "on track" in 2018 (Figure 1.2).[2] Among these bright spots, solar photovoltaic (PV) has shown phenomenal progress, with electricity generation from solar PV growing by 40% globally in 2017. The global stock of electric cars surpassed 3 million vehicles in 2017 after crossing the 1 million threshold in 2015 and the 2 million mark in 2016 (IEA, 2018e). Sales of light-emitting diode (LED) lamps also saw impressive sales in 2017, hitting a critical turning point that year, overtaking incandescent and halogen lamp sales in the residential market.

Figure 1. 2. Clean energy transition progress by technology and deployment status, 2018



Note: For more information, see www.iea.org/tcep.
Source: IEA (2018e), *Tracking Clean Energy Progress 2018*, https://www.iea.org/tcep/.

Of 38 technologies, only solar PV, electric vehicles, lighting and data centres are on track with the low-carbon global energy transition.

[2] The IEA TCEP initiative includes up-to-date information on the status of technologies and where they need to be for the world to achieve sustainable development ambitions, improve air quality and enhance energy access. For more information, see: www.iea.org/tcep.

Deployment of other technologies has slowed recently. Energy storage and onshore wind were recently downgraded, the latter based on several factors including the rate of overall capacity additions. In 2018, 23 technologies were ranked as needing improvement, and 11 of 38 technologies were significantly not on track. This last category includes the persistence of unabated coal-fired electricity generation (without carbon capture, utilisation and storage [CCUS]), which was responsible for 90% of power sector emissions growth in 2017.

Tracking technology progress in the buildings sector

In energy terms, the buildings sector comprises a diverse range of energy consuming and producing technologies, many of which have an important role to play in the clean energy transition. Six buildings-related technology areas were assessed; only lighting is on track to meet clean energy transition targets. Building envelopes and heating – which represent half of global energy consumption in buildings – are well off-track. Cooling equipment and appliances show some improvement, but significant policy efforts are needed to accelerate technology progress in these end uses, particularly with substantial growth in appliance and air conditioner (AC) ownership expected in the coming decade.

To tap the energy and emissions savings potential in the buildings sector, use of more efficient technologies needs to be triggered by more effective policies and stronger investment in sustainable buildings. Lessons can be learned from the deployment of LED lighting, which increased its share in global lighting market sales from 1% in 2010 to more than a third in 2017, thanks to major reductions in costs, improved quality and reliability, and more options for lighting applications. This was underpinned by a basket of policy measures, including policy support for research and development (R&D) to improve technology quality and applications, market incentives to reduce consumer purchase prices through rebate schemes in many markets, innovative business models such as the "Ujala" bulk procurement programme in India, and international collaboration, such as the Global Lighting Challenge led under the Clean Energy Ministerial.[3]

By contrast, building envelopes (i.e. its "shell") remain stubbornly off-track, with two-thirds of countries around the world still lacking mandatory building energy codes in 2017. A handful of countries did introduce or update building energy codes in 2017 and 2018, and several countries implemented building energy certification or incentive programmes. However, that progress was not enough to keep up with rapid growth in floor area. The number of new, high-efficiency buildings being constructed needs to increase more than 25-fold by 2030, with deep energy renovation of existing stock also needing to more than double within the coming decade.

Progress on heating technologies used in buildings equally remains off-track, with fossil fuel equipment continuing to outpace both more efficient heating alternatives such as heat pumps and renewable options such as solar thermal equipment. While sales of heat pumps and renewables-based technologies continued to increase by around 5% per year in the last decade, representing 10% of overall sales in 2017, fossil fuel equipment still represented 50% of sales that year, and conventional electric heating another 25%. To get on track with the clean energy transition, the share of heat pumps, renewable heating and clean district heating needs to triple to reach more than one-third of new sales by 2030.

Fortunately, cooling technologies in buildings have shown some signs of progress, given exceptionally rapid growth in recent years. Mandatory policy coverage and stringency continues

[3] For more information, see: http://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/global-lighting-challenge.

to improve at a slow, but steady pace, and energy performance standards for ACs are in place in nearly all the major markets that have cooling demand today. Further improvement is needed to ensure energy policies keep up with technology potential to address rapidly rising energy demand for cooling services. Sales of ACs are rising three times faster than efficiency improvements globally, and AC performance needs to improve by more than 50% by 2030 for the sector to be on track.

Finally, progress in the improvement of appliances and equipment performance also needs to accelerate for the buildings sector to be on track. Energy standards and labels cover only a third of appliance energy use today, and policy coverage is poor in markets expected to grow rapidly in the next decade. Small plug-loads (e.g. telephones and tablets) and connected devices, which are proliferating rapidly, also continue to go unregulated in most countries.

Tracking technology progress in power, transport and industry

Progress in technologies related to efficient energy use in buildings is insufficient, but most other sectors are not faring much better. For power sector technologies, only solar PV was judged to be on track in 2017. Solar PV continues to make impressive strides in terms of annual capacity additions, particularly in China, but it cannot deliver power sector decarbonisation alone. Other renewables and supporting power sector technologies do not match the strong progress in PV towards clean generation of electricity and heat. None of the other power sector technologies were on track in 2017, including for instance onshore and offshore wind. Reducing coal-fired power and deploying CCUS were well off-track in 2017.

In the transport sector, existing measures to increase efficiency, reduce fossil fuel dependence and accelerate electrification must be urgently strengthened to achieve clean energy transition ambitions. Electric vehicles continue to be the only transport technology on track, but recent trends also shed light on potential roadblocks ahead. There is much more to the transport sector than light-duty vehicles. More effort is needed to put trucks, buses and rail on track, and aviation and transport biofuels are significantly off-track. International shipping, while still heavily carbon intensive showed a major positive sign in 2018 with the agreement of a first global climate framework for shipping, through the International Maritime Organization.[4]

In industry, progress in the clean energy transition is lacking in all major subsectors. Improvements in energy efficiency and shifts towards best-available technologies can help reduce energy demand, and the uptake of energy-efficient motors has increased in recent years. Innovative technologies are needed for the long-term transition of the industrial sector. Two main approaches being pursued to develop innovative low-carbon industrial processes are the direct avoidance of CO_2 emissions (by relying on renewables-based electricity, bioenergy or alternative raw materials) and reduction of CO_2 emissions by minimising process energy and integrating CCUS, which is also currently off-track.

Closing the innovation gaps

Near-term technology deployment will not be enough to deliver the clean energy transition. The deployment of innovative technologies over the medium to long term is also essential. Innovation has been fundamental to energy sector evolution and it needs a significant boost as the world pushes to achieve its climate, health and energy access goals. While many clean energy technologies are now cost competitive, innovation efforts need to be redoubled to make

[4] For more information, see: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx.

sure those technologies are fit-for-purpose in all markets and locations, and so that less mature clean energy technologies can start to outcompete their rivals.

To ensure alignment of short-term R&D priorities with long-term clean energy transition needs and to track innovation efforts, the IEA identified key long-term "technology innovation gaps" that need to be filled (IEA, 2018e). This progressive, expanding clean energy technology framework for innovation tracking highlights around 100 innovation gaps across 35 key technologies and sectors to highlight where R&D investment or general innovation activity needs improvement.[5] For instance, it includes improved performance of the main renewable power technologies, as well as ways to use hydrogen as a next-generation energy storage technology. In industry, it assesses a variety of innovative technologies and production methods that need stronger focus in the cement, steel, chemicals, pulp and paper, and aluminium branches.

Extensive innovation opportunities also exist for the buildings sector. For example, integrated thermal storage, advanced insulation to reduce heat loss and gain, and low-emissivity windows have significant potential. Innovation gaps in solar thermal technology and advanced district energy have been identified, as well as R&D needs for solar cooling and integrated renewable façades. Lighting improvement areas include commercialisation of organic LED technologies, while innovation in appliance efficiency needs to play an important role in energy use in buildings.

What do energy investment trends reveal about the transition?

Energy investment is a key determinant of the rate of change of technology innovation and deployment. Looking at the volume and direction of energy investment decisions taken in recent years previews the type and scale of technologies likely to influence the energy sector. It also gives an indication of how the energy sector is evolving and whether it is on track for the clean energy transition.

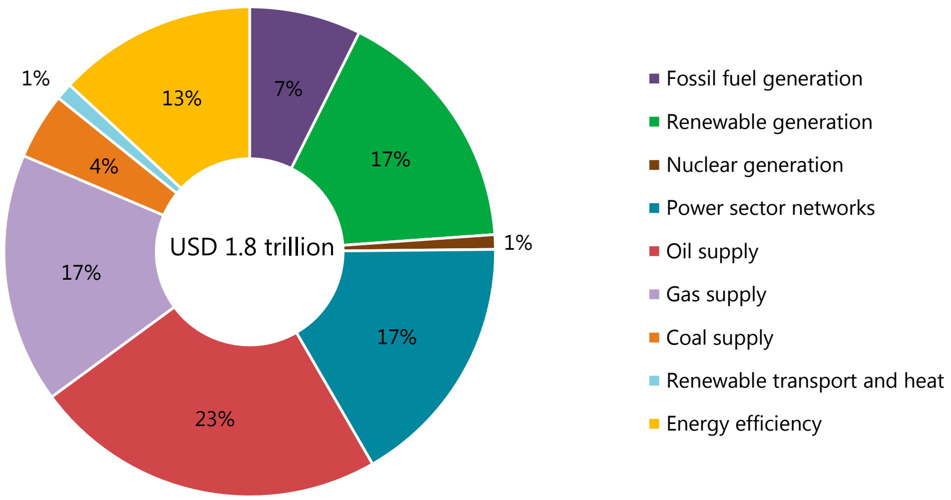
In 2017, total energy investment worldwide was USD 1.8 trillion (United States dollar), a fall of 2% in real terms from 2016, the third year in a row of a decline (IEA, 2018f). Recent investment trends, including capital spending on energy supply and improvements in end-use efficiency, vary across sectors, but nevertheless indicate that an energy transition is underway, although it is more evident in some areas than others. The power sector was the largest recipient of global energy investment in 2017 at around 40%, having overtaken the oil and gas sector in 2016 (Figure 1.3). This reflects the ongoing electrification of global economies and is supported by robust investment in networks and renewables-based power. Yet, it masks a more mixed picture at the subsector level.

Investment in electricity networks and storage – key enablers of the clean energy transition – increased by 1% in 2017 from the previous year, continuing a trend that has seen investment in networks increase from a third to 40% of total power sector investment since 2012. However, the share of investment in power generation declined with fewer additions of coal, nuclear and hydropower capacity, which accounted for most of the decline in overall energy investment.

[5] For further information please see: https://www.iea.org/topics/innovation/.

Fewer capacity additions in those technologies more than offset strong solar PV investment – which set a new record in 2017 – leading to an overall drop in the share of renewables in power generation investment. However, investment in low-carbon power sources (including renewables and nuclear) maintained a share of more than 70% of total generation capacity investment. This share has grown quickly from less than 50% a decade ago.

Figure 1. 3. Global energy sector investment by category in 2017



Notes: Investment is shown in 2017 USD billion.
Source: IEA (2018f), *World Energy Investment 2018*, https://www.iea.org/wei2018/.

Oil and gas supply investment rebounded in 2017, while growth in renewables slowed and investment in energy efficiency had a slower pace of growth than in previous years.

Energy efficiency investment in buildings and appliances

Energy investment discussions tend to focus on the supply and transformation side of the energy equation (power plants, refineries, networks and so on), too often overlooking the importance of investments made on the demand side. Yet, investments made in end-use equipment will have profound impacts on future total energy demand, and in turn on the likelihood of achieving a rapid energy transition.

In 2017, USD 236 billion was invested in energy efficiency in the buildings, transport and industry sectors, USD 8 billion more than in 2016, but still only about 13% of total energy investment.[6] Investment in energy efficiency was robust in recent years, though it dropped from 9% of total energy investment in 2016 to 3% in 2017. This mirrored a slowdown in implementing efficiency policies, as well as in improvements in energy intensity (IEA, 2018g).

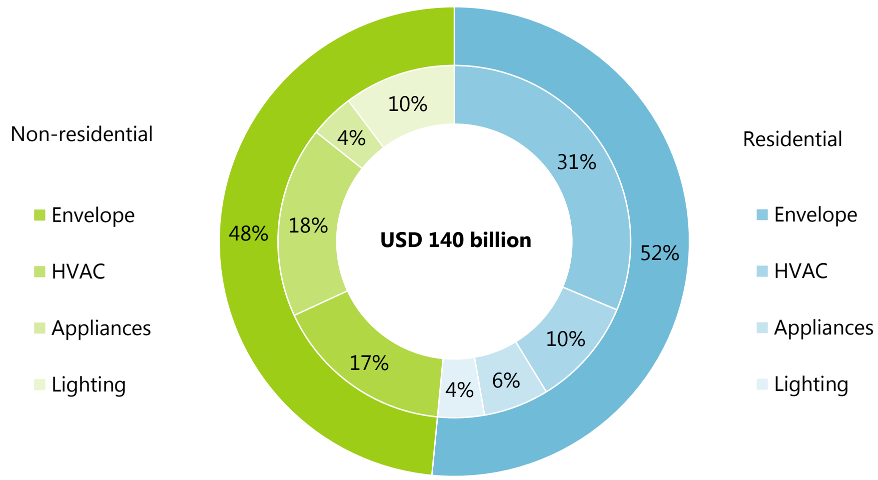
Energy efficiency and technology investment trends differ considerably across sectors. In the buildings sector, there was a substantial increase in 2017 from the previous year for heating,

[6] Estimate of energy efficiency spending corresponds to the incremental spending on products that consume less energy than would have been used had the purchaser opted for a less efficient model or, in the case of building refurbishments, not undertaken the efficiency improvements.

cooling and lighting efficiency. Investment in efficiency improvements in the transport sector also saw strong growth (11%), while spending on industrial energy efficiency declined slightly in the 2016-17 period.

In 2017, total incremental spending on energy efficiency investments for buildings increased by 3% compared to 2016 to around USD 140 billion, around half of it in the non-residential sector, despite accounting for less than a quarter of total buildings sector floor area (Figure 1.4). While this represents 59% of the total incremental efficiency improvement investment across all end-use sectors, the same share as in 2016, it is only a small portion of total spending in the global buildings sector, which is estimated to have amounted to nearly USD 5 trillion in 2017. It is an even smaller share of the estimated USD 217 trillion in global real estate value (Savills, 2017). Yet, the growth rate of energy efficiency investment as a share of total buildings investment has slowed from the 6-11% annual growth rates observed from 2014 to 2016.

Figure 1. 4. Energy efficiency investment in buildings by subsector and end use, 2017



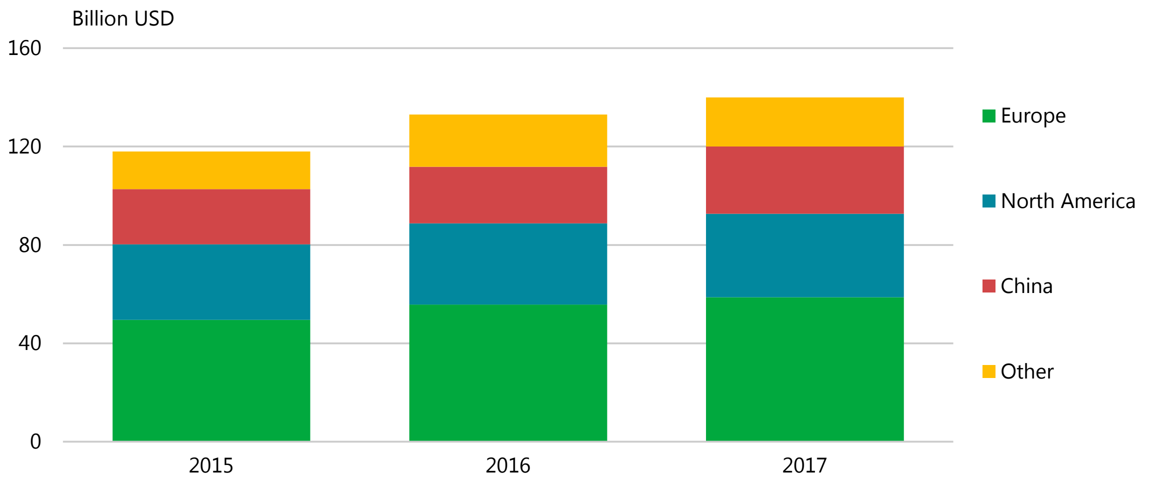
Notes: Investment is shown in 2017 USD billion. HVAC = heating, ventilation and air conditioning.
Source: IEA (2018g), *Energy Efficiency 2018*, https://www.iea.org/efficiency2018/.

While investment is split about equally between residential and non-residential buildings, a higher proportion of residential investment is spent on building envelope measures.

Improvements in the energy efficiency of building envelopes – the material components of a building's structure such as insulation, walls, roofs, windows and air sealing – is the largest component of investment in buildings, representing almost half of buildings spending. However, this investment dropped 3% over 2016 to USD 67 billion in 2017. On the other hand, there was a 17% increase in spending on energy efficiency in heating, ventilation and air conditioning (HVAC) systems in 2017 and a 14% increase in incremental spending on energy-efficient lighting, climbing to 19% and 23% share of spending, respectively. In part, this reflects low-cost measures using technologies that can be replicated across different building types. There is also increasing standardisation of building measures and upgrades that do not require bespoke or intrusive solutions. As this results in more dependable energy savings, it enables the development and continued growth of financing mechanisms for efficiency projects, such as dedicated credit lines, green bonds for infrastructure and energy service companies (see Chapter 3) (IEA, 2018g).

While the share of overall energy investment targeted for efficiency contracted in 2017, the share of efficiency investment in the buildings sector increased in major countries and regions, thanks to continued and improved policy push for energy efficiency. The People's Republic of China (China), Europe and North America combined represented 85% of global energy efficiency investment in the buildings sector in 2017 (Figure 1.5). China had the largest investment in energy efficiency in buildings with USD 27 billion in 2017, a notable 20% increase (about USD 4 billion) between 2016 and 2017. Investment in the European Union in 2017 increased by 5% (about USD 3 billion) to USD 59 billion, accounting for 42% of global efficiency investment in the buildings sector, followed by North America, which represented 24% of such investment in 2017.

Figure 1. 5. Energy efficiency investments in buildings by region, 2015-17



Note: Investment is shown in 2017 USD billion.
Source: IEA (2018g), *Energy Efficiency 2018*, https://www.iea.org/efficiency2018/.

Energy efficiency investment in the buildings sector in China has increased significantly.

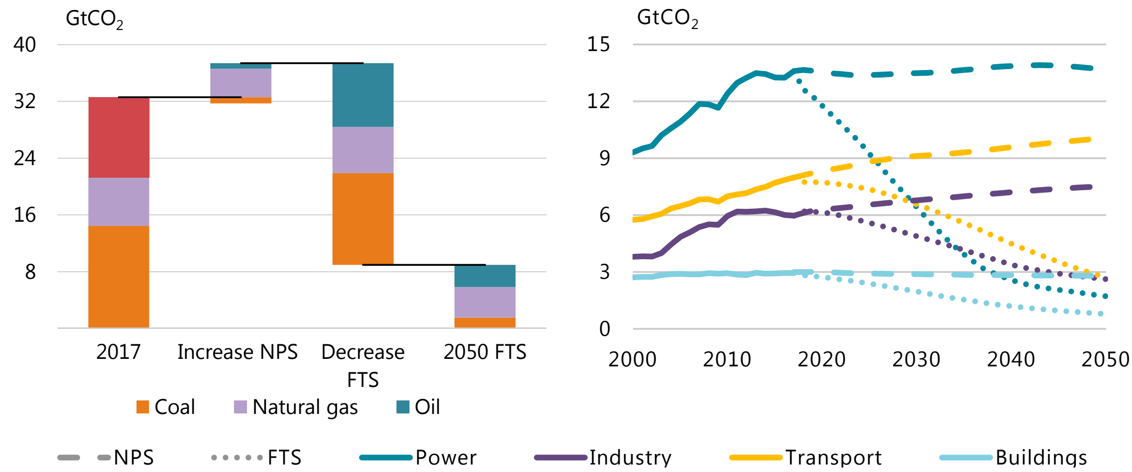
Enabling the clean energy transition to 2050

The clean energy transition requires a comprehensive and rigorous transformation of the global energy sector to achieve ambitions to limit the impact of climate change. Yet, the world is currently not on track to meet those ambitions, and energy-related investment and clean energy technology deployment are both lacking the necessary momentum to affect the required change.

This section considers the Faster Transition Scenario compared with the New Policies Scenario, the main scenario in the IEA *World Energy Outlook*. The New Policies Scenario is a scenario out to 2040 that aims to provide insights of today's policy ambitions seem likely to take the energy sector based on existing policies and announced plans, including the NDCs that countries pledged in the context of the Paris Agreement (IEA, 2018b). The New Policies Scenario does project some promising trends. For example, CO_2 emissions from coal decline steadily to 2050, in line with falling global coal demand, and global energy demand growth that is about half as large as it would be if current and announced energy efficiency policies were excluded from the projection. The New Policies Scenario also sees substantial growth in renewables, with renewables-based power generation more than tripling from today's level by 2050 and the average CO_2 intensity of power generation being cut in half by 2050.

Despite those projections, the global emissions trajectory in the New Policies Scenario is very far from what is required to achieve the objectives of the Paris Agreement. Energy-related CO_2 emissions under the New Policies Scenario continue to rise to 2050, gradually increasing from around 32.6 $GtCO_2$ today to over 36 $GtCO_2$ by 2050. By contrast, the Faster Transition Scenario sets out a clean energy transition well in line with internationally agreed objectives on climate change (Box 1.2). Energy-related CO_2 emissions in the Faster Transition Scenario peak around 2020 and then see an annual average decline of 3.6%, dropping to around 10 $GtCO_2$ by 2050 (Figure 1.6). This requires extremely rapid changes to the global energy system, representing an energy transition of exceptional scope, speed and depth, which leads to an energy sector that is fundamentally different than that which is likely to happen under current and announced policies.

Figure 1. 6. Global CO_2 emissions to 2050 from fuel combustion, by scenario and sector



Notes: FTS = Faster Transition Scenario. NPS = New Policies Scenario.

Energy-related CO_2 emissions in the Faster Transition Scenario decrease rapidly over the next three decades, reaching one-quarter of their current levels and 75% less than in the New Policies Scenario.

Box 1. 2. Challenges of modelling long-term climate outcomes

The ambitious objective of the Paris Agreement is "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C". Many energy pathways could lead to the world achieving this outcome. A large number of various combinations of energy supply and demand technologies could lead to a similar long-term GHG emissions profile. Just as importantly, it is becoming increasingly challenging to attribute reliably a long-term climate outcome to any particular global energy sector emissions profile.

The concept of a global "carbon budget" has often been used to simplify the complexity of how the global climate system responds to an increasing stock of GHG emissions in the atmosphere. The simplification is possible thanks to a near-linear relationship between the global temperature increase and cumulative CO_2 emissions. This allows for calculation of the remaining "budget" of

CO_2 emissions that can be emitted while holding global temperature rise below a certain level.

This seductive simplicity hides a number of complications. Recently, scientific literature has revealed increasing uncertainty about the size of the carbon budget remaining to limit warming to particular levels. For example, the 2018 special report by the Intergovernmental Panel on Climate Change (IPCC) on the impacts of global warming of 1.5°C (IPCC, 2018) provided new – and generally much higher – estimates of the remaining CO_2 budget than those previously used in the literature (such as in the 2014 IPCC Fifth Assessment Report [IPCC, 2014]). The 2018 assessment also gives broader ranges of uncertainty of how budgets match particular temperature outcomes.

This comes on top of other long-standing difficulties with the concept of a carbon budget. For example, carbon budgets refer only to CO_2, yet the atmosphere responds to many GHGs and other climate forcers such as aerosols. A host of additional assumptions are therefore required about emissions of these other gases, including assumptions about when they are emitted, because different substances affect the climate over various timescales.

Further, the carbon budget refers to the total cumulative emissions of CO_2 released to the atmosphere over a very long period: from pre-industrial times (the precise date of which can vary according to different interpretations) to a point in the future, which can also vary according to different definitions. For example, some carbon budgets take cumulative emissions until the time when CO_2 emissions fall to zero, others until the time when global average temperature crosses a certain threshold.

All of these issues complicate the challenge of defining the precise outcome of a long-term energy pathway. The energy system in the Faster Transition Scenario is modelled out to 2050, but the longer-term trajectory is important for the climate outcome. Assumptions about the post-2050 implications are inherently more speculative. In particular, if assumptions allow total emissions to become substantially net-negative in the second half of the century, this can have important implications for the projected long-term climate outcome of shorter-term energy scenarios.

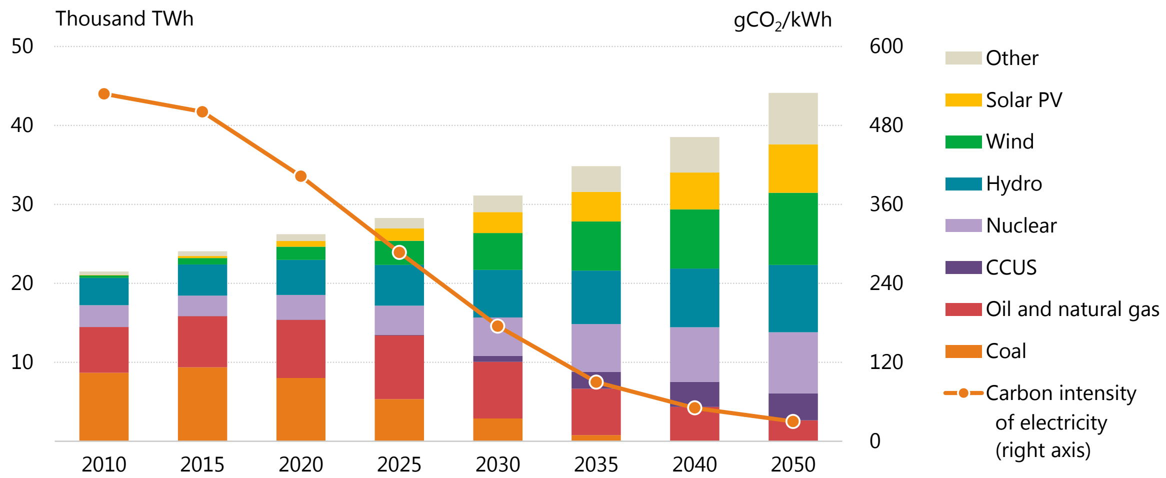
Together these evolving factors mean that the deceptive simplicity of carbon budgets is of more limited use to policy makers than has often been perceived. The traditional approach of quoting a percentage referring to the likelihood of the long-term temperature outcome resulting from a particular pathway (such as the "66% 2°C" scenario label used in IEA, 2016 and IEA, 2017) is becoming less informative.

Increasing attention therefore is focusing on alternative means to assess and compare the level of ambition of energy-related CO_2 emissions reduction targets. The Paris Agreement itself sets three parameters for emissions trajectories: that GHG emissions peak soon, enter a steep decline thereafter and ultimately reach net zero in the second half of this century. A number of other factors are important to clarify fully any emissions pathway, such as the reduction in non-CO_2 emissions and the magnitude of carbon sinks or other means to remove CO_2 from the atmosphere. However, focusing on the date when GHG emissions fall to net zero, and stages to get there, could provide a more concrete goal for policy makers to define the ambition of their emission reduction pathways. The emissions profile of the Faster Transition Scenario is very much in line with these characteristics defined by the Paris Agreement: global CO_2 emissions peak by 2020 and enter a very steep decline out to 2050. If emissions reduction continues at that rate thereafter, it would be on course to hit net zero before 2060. That trajectory is lower than most publicly available emissions scenarios aiming for a global temperature rise of around 1.7-1.8°C.

All major sectors in the Faster Transition Scenario show rapid and sharp CO_2 emissions decline to 2050. In the power sector, CO_2 emissions drop by around 90% by 2050, requiring an annual reduction of around 5.6%. The power sector delivers those reductions even while total electricity use continues to grow strongly, as more end-use sectors turn to electricity.

Globally, power generation very quickly pivots towards low-carbon sources, leading to a drastic decline in the average carbon intensity (in grammes of CO_2 [gCO_2] per kilowatt-hour [kWh]) of electricity (Figure 1.7). Renewables in particular take the lead for power generation by the 2030s, and then CCUS-equipped coal and gas power plants help to ensure that much of the remaining fossil fuel use is carbon neutral or negative. By 2050, CCUS-equipped power generation rises to about 8% of the total, with unabated coal completely removed from the global power generation mix. To achieve this, existing coal plants are progressively retired, reaching nearly 100 gigawatts (GW) of capacity are retired each year by 2030. Conversely, 84% of capacity additions by 2025 are renewables. New nuclear also plays a strong role, with annual capacity additions doubling by 2030. That cleaner mix means that the power sector's share of total emissions in Faster Transition Scenario drops from 42% in 2017 to 20% in 2050.

Figure 1. 7. Power generation fuel mix and CO_2 intensity in the Faster Transition Scenario, 2010-50



Renewables take the lead in the power sector from the mid-2020s, leading to a rapid decline in the emissions intensity of the global power sector.

In total, direct CO_2 emissions from end-use sectors drop by nearly 65% by 2050 in the Faster Transition Scenario. In general, the reductions are driven by very rapid improvements in energy efficiency, combined with a sharp reduction in the use of fossil fuels, in particular activities that are not equipped with CCUS (e.g. in industry). In addition, most end uses see a marked shift towards increased use of electricity, meaning that overall CO_2 savings are dependent on the deep emissions cuts in the power sector.

Today, electricity accounts for just under 20% of global final energy consumption. This share has been steadily increasing in recent years – with electricity demand growing at twice the rate of global energy demand growth. In the Faster Transition Scenario, the electrification rate rises to about 35% of total final energy by 2050. That increase in electrification mainly reflects a rapid adoption of heat pumps in buildings and the increased provision of low-temperature heat in industry, as well as a swift evolution in the transport sector that puts almost 3 billion electric vehicles on the road by 2050.

The buildings sector sees the most abrupt emissions reduction in percentage terms. Direct CO_2 emissions (i.e. not including indirect carbon emissions from consumption of electricity and commercial heat) are abated by more than 75% from today's level by 2050, despite a near doubling of floor area and dramatic growth in demand for energy services such as cooling and household appliance ownership. This substantial drop is achieved by almost total elimination of coal in buildings, an 85% reduction in oil use in buildings and a 50% drop in overall natural gas demand relative to today. Energy efficiency across the buildings end uses, including major improvements in the performance of building envelopes (i.e. the building shell, including windows, walls, doors and roofs, etc.) helps to reduce the need for fossil fuel use in a rapidly growing buildings sector. Shifts to high-performance equipment (e.g. electric heat pumps) and renewables-based technologies (e.g. solar thermal heaters) progressively supplant the sales of new fossil fuel equipment. As a result, electricity use in buildings swells by 60% by 2050, despite strong efficiency improvements, and direct use of renewables expands sixfold over the period.

The transport sector reduces its direct CO_2 emissions by around 65% in the Faster Transition Scenario. This reflects a strong shift to electric mobility, which leads to a jump in transport electricity demand by a factor of more than 300 by 2050, albeit from a current low base. Additional improvements in vehicle fuel economy performance, increased used of biofuels (e.g. in aviation), efforts to avoid unnecessary travel (e.g. through land use planning and use of freight logistics) and shifts to more efficient travel modes, such as public transport and non-motorised travel (e.g. bicycling), also help wean transport off oil dependence. Total transport oil demand in the Faster Transition Scenario drops by around 70% by 2050.

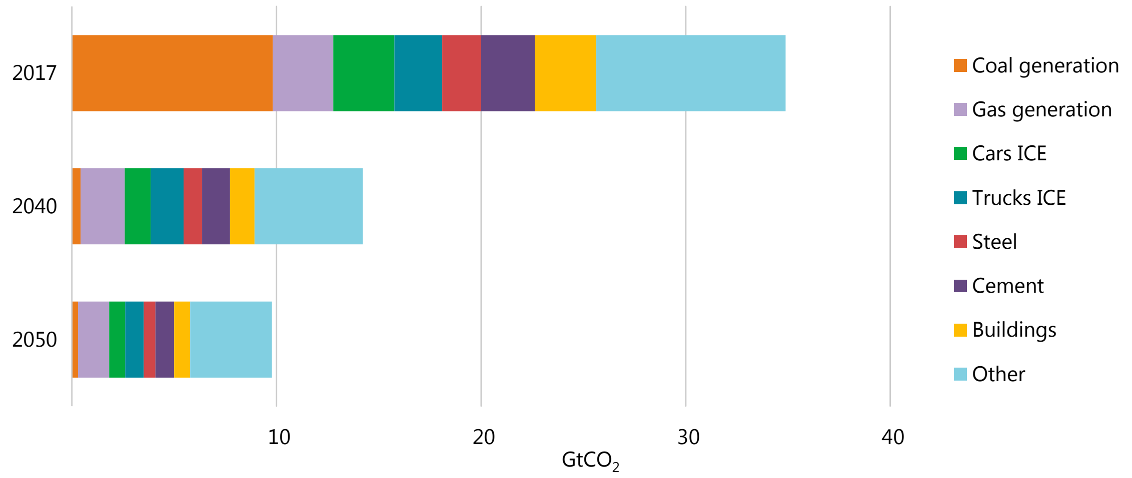
CO_2 emissions from industry fall on average by about 55% from today's level in the Faster Transition Scenario. However, this masks significant differences between the main industry sectors. Energy-related emissions from cement drop by more than 80%, despite production of cement staying almost constant over the period. The iron and steel sector, which currently makes up nearly a third of industry emissions, sees emissions fall around 70%, with a lower fall in the chemicals subsector (around 50%), reflecting the reduced range of technical abatement options, even under the projected conditions of the Faster Transition Scenario.

The buildings sector is essential for the clean energy transition

Seven categories account for more than 75% of global energy-related CO_2 emissions today. Direct emissions from the buildings sector are the second largest category, making up 9% of today's global CO_2 emissions from energy and process-related emissions. Only coal-fired power generation emits more, accounting for 27% of energy-related CO_2 emissions in 2017. Other big emitters include gas-fired power generation and petroleum-fuelled cars (more than 1 billion vehicles today), which each account for around 8.5% of total emissions, cement and road freight (each around 7%) and just over 5 % for steel manufacturing.

In the Faster Transition Scenario, these seven source categories still dominate CO_2 emissions in 2050, but their relative importance is very different from today (Figure 1.8). Coal-fired power generation all but disappears, with emissions dropping by more than 95% by 2050, whereas emissions from gas-fired power generation only decrease by 50%. Buildings see greater proportional reductions than other sectors by 2050, dropping to the fourth largest CO_2 ranking by 2050. Direct emissions in the buildings sector decline by 75% by 2050, underlining its essential contribution to the clean energy transition. Chapters 2 and 3 explore in detail the technological and policy options that could deliver on such an ambitious trajectory for the buildings sector.

Figure 1. 8. Energy sector emissions by category in the Faster Transition Scenario, 2017-50



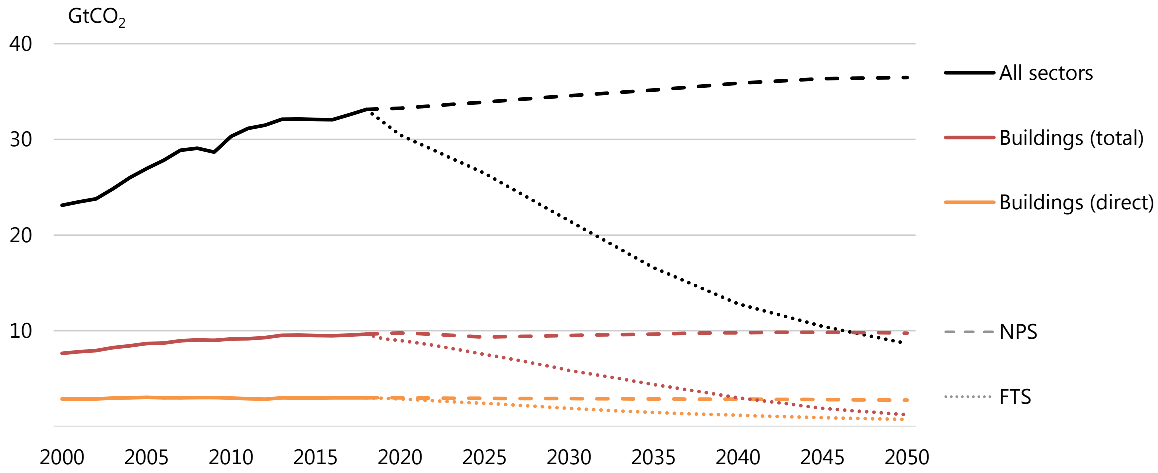
Notes: Includes CO_2 emissions from energy and industrial processes. ICE = internal combustion engine. "Other" includes emissions from fossil fuel combustion in power, industry, transport and other sectors (e.g. agriculture) not shown here.

Buildings represent the second largest of the seven sectors that account for 75% of global CO_2 emissions today and see drastic reductions in emissions to 2050 in the Faster Transition Scenario.

The importance of the buildings sector is further highlighted by combining its direct emissions with indirect emissions from its consumption of electricity and district heat. Those combined emissions accounted for nearly 30% of energy-related CO_2 emissions in 2017. Both enter a sharp decline in the Faster Transition Scenario. Direct emissions fall partly due to electrification of end uses, in particular space and water heating. This adds to rapidly increasing electricity demand for services such as cooling. However, it is equally offset by significant efficiency improvements in practically all end uses in buildings. Combined with low-carbon power generation, indirect emissions from buildings decline dramatically in the Faster Transition Scenario, where energy efficiency measures in the buildings sector account for around one-third of the indirect emissions reduction to 2050.

By contrast, both direct and indirect emissions from the buildings sector increase in the New Policies Scenario, the latter due to a slower decarbonisation of power, alongside rapidly rising electricity demand. This implies that if current trends continue to 2050, combined emissions from buildings could nearly equal the total energy sector emissions projected in the Faster Transition Scenario (Figure 1.9). This reinforces the importance of strong action not only to reduce direct emissions from buildings, but also to concentrate efforts on energy efficiency to support the power sector contribution to the clean energy transition.

Figure 1. 9. Direct and indirect emissions from buildings in the Faster Transition Scenario to 2050



Reduction of direct emissions from buildings needs to be accompanied by significant energy efficiency gains to support the rapid decarbonisation of the power sector.

Ramping up investment to achieve the Faster Transition Scenario

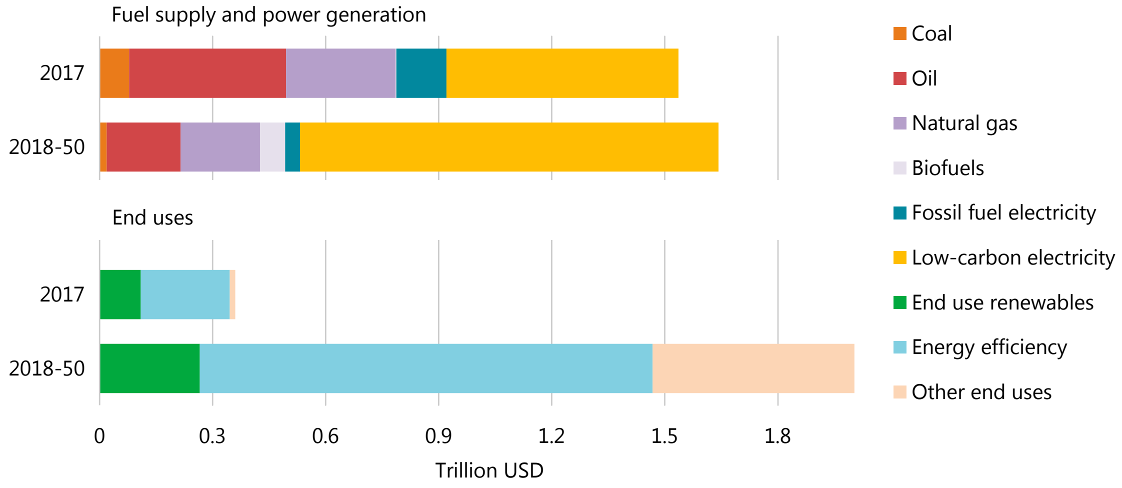
To achieve the clean energy transition, global investment in energy needs to not only increase overall but also undergo a rapid reallocation of capital relative to today's energy investment portfolio. In 2017, the share of overall clean energy investment, covering both low-carbon energy supply and energy efficiency, was only 32%, relative to 51% for fossil fuel investment.

Achieving the Faster Transition Scenario will require a substantial and rapid shift towards investment in clean energy technologies. The share of clean energy in global energy investment would need to increase substantially to enable the clean energy transition described by the Faster Transition Scenario – more than doubling to 70% by the mid-2030s, and reaching around three-quarters of investment by 2050. By contrast, the share of fossil fuel investment falls to just over 10% by 2050. The share of networks in total investment remains relatively stable at around 15% in 2050 (compared to 17% in 2015), although the total number is increasing as overall global investment increases.

This distinct shift towards investment in clean energy is accompanied by a substantial increase in overall investment. In the Faster Transition Scenario, total average annual energy investment increases by about 65% from today's level. However, this overall increase masks substantial differences across sectors (Figure 1.10).

Despite the overall increase in energy sector investment, combined total investment in fossil fuel supply and power generation remains close to today's level until 2050. This is because declining fossil fuel supply investments are almost entirely offset by a doubling of investment in low-carbon power generation, as the power sector plays an important role in supporting increased electrification and decarbonisation efforts. Even within the fall in fossil fuel supply investments, the picture is heterogeneous. Coal supply suffers the biggest fall, while oil and gas investment decline over time but are nevertheless bolstered by the need to continue investments in the face of rapidly declining production rates for existing fields.

Figure 1. 10. Average annual investment needs in the Faster Transition Scenario relative to 2017



Notes: Low-carbon electricity includes renewables, CCUS, nuclear, networks and storage. Fossil-fuel electricity excludes CCUS. Other end-use includes CCUS in industry and alternative power trains in transport.

Average annual supply side investment in the Faster Transition Scenario increases modestly from today's level, while demand-side investment increases substantially.

The vast majority of the increase in total energy sector investment needed to deliver the Faster Transition Scenario is driven by the demand side of the energy sector. This includes a substantial increase in investment to improve efficiency in the buildings, industry and transport sectors; to enhance direct use of renewables in buildings and industry; and to build-out electric vehicle infrastructure and improve efficiency of internal combustion engine vehicles.

In the buildings sector, average annual investment related to the energy transition, including renewables and efficiency improvements, increases more than threefold by 2050. The most marked investment increase is in the near term, resulting in a doubling of average annual clean energy investment before 2025. Even with this increase, the investment in energy efficiency and renewables in buildings remains fairly small relative to overall spending in the buildings sector. Total investment (e.g. including infrastructure investment in new building construction) in the global buildings sector amounted to over USD 4.9 trillion in 2017. Investment in renewables and energy efficiency in buildings accounted for only about 9% of this total. By 2050, this proportion doubles to around 18% of the total annual investment, which by that time rises to around USD 5.4 trillion. Investment in enhanced efficiency is far greater in the Faster Transition Scenario, with average annual investment in high-performance products quadrupling by 2050. Renewables investment doubles in the same timeframe.

Investing in energy efficiency in the end-use sectors, as projected in the Faster Transition Scenario, would deliver cost savings over the lifetime of more efficient equipment. For instance, the energy efficiency potential in the buildings sector would be sufficient to keep energy demand close to current levels. By 2050, the cumulative energy savings in the Faster Transition Scenario, relative to the New Policies Scenario, would total around 15 800 million tonnes of oil equivalent in buildings worldwide (equivalent to more than five-times the energy consumption of the buildings sector today). These energy savings translate into cost savings for households and businesses. In fact, the share of household income spent on energy in the Faster Transition Scenario drops to around 2.5% globally by 2050, relative to 3.5% in New Policies Scenario, and down from nearly 5% today.

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2. Buildings and the clean energy transition

- The buildings sector accounted for 28% of global carbon dioxide (CO_2) emissions in 2017. Its emissions grew more than 25% since 2000, despite lower energy intensity per square metre (m^2). Floor area increased rapidly, demand for energy services swelled and the use of electricity intensified, which fuelled the increase in CO_2 emissions in the buildings sector.
- Energy policy progress is not keeping pace with buildings sector growth. Mandatory policies covered less than 40% of energy use and less than half of CO_2 emissions from buildings in 2017. Progress on building energy codes in particular is not keeping up with floor area growth, and more than two-thirds of additions to 2050 are expected in countries without policies in place.
- Technology can reduce buildings emissions while improving comfort and energy services. Near-zero energy construction and deep energy renovations can reduce the sector's energy use by nearly 30% to 2050, even with doubling of global floor area. Energy use is further cut by a doubling in the efficiency of air conditioning equipment, even as 1.5 billion households gain access to cooling comfort. Heat pumps cut typical energy use for heating by four or more, while solar thermal delivers carbon-free heat to nearly 3 billion people.
- Effective policies are needed to address current market barriers. Multiple cost-effective technologies, from high-efficiency lighting to low-cost building envelope measures, can unleash an average savings of 500 million tonnes of oil equivalent (Mtoe) per year worldwide over the 2020-50 period. This requires clear and ambitious policy signals to address market failures, encourage economies of scale and enable further innovation in building products and services.
- Efficient and flexible buildings will reduce the impact of electrification on power. Efficient air conditioning can reduce power capacity needs by 1 330 gigawatts (GW) by 2050 – equivalent to today's installed capacity in the United States and Canada. Coupled with building envelope improvements and demand-side measures, high-performance buildings can support power system flexibility and higher penetration of variable renewables in the electricity mix.
- Realising sustainable buildings will save USD 1.1 trillion (United States dollars), but requires upfront investment. Annual capital expenditure needs to increase between USD 200-400 billion over the coming decade, with 70% of that for high-performance construction and renovations. Over the period to 2050, spending on energy consumption is USD 4.8 trillion lower in the Faster Transition Scenario, more than offsetting the net investment to achieve a sustainable buildings sector.
- Delaying action will have major economic implications. Delaying high-performance construction and renovations by ten years would increase spending by USD 2.5 trillion to 2050 and result in as much as 3 500 Mtoe of additional energy use and more than 2 gigatonnes of additional CO_2 emissions. Effective policies need to address energy performance, access to finance and innovative market solutions to unlock the energy savings potential of the global buildings sector and its many economic co-benefits.

Introduction

The global buildings sector encompasses a vast variety of structures that use a wide range of materials for diverse activities related to trade, finance, real estate, public administration, health, food, lodging, education and commercial services. It covers multiple energy-consuming activities that provide basic energy services, including space and water heating, cooling, lighting, cooking and the use of appliances. Those energy services are delivered by a wide array of technologies using different energy sources that range from solid biomass to coal, oil, natural gas, electricity, solar and other renewable energy sources.[1]

With estimates of a global population increase of nearly 2 billion people over the next three decades, anticipated improvements in economic development and rising living standards, energy use in the buildings sector is set to rise sharply. This will place additional pressure on the energy system and influence socio-economic ambitions, such as local air quality and access to affordable and reliable energy services.

Clean energy technologies and best practice measures already exist that allow the buildings sector to be more energy efficient and sustainable, thus playing a part in the global energy transition. The transformation of the buildings sector will have many positive benefits, and existing examples from all corners of the globe bear out the potential.[2]

Achieving that promise is a challenging policy goal, but it can be done, using a combination of best-available technology and effective public policy. This chapter builds upon previous International Energy Agency (IEA) analyses of the global clean energy transition and outlines the technology strategies needed to achieve major reductions in energy consumption and CO_2 emissions in the buildings sector to 2050 (Box 2.1). Chapter 3 discusses a range of policy tools and market instruments that can help deliver those reductions.

Box 2.1. Energy technology and policy perspectives for the global buildings sector

Detailed insights in this chapter on the clean energy transition of the global buildings sector are derived from the IEA Energy Technology Perspectives (ETP) model, which was linked with the IEA World Energy Model for the purposes of this report. The ETP model provides technology-rich model scenario analysis, interlinking four sectoral models focused on buildings, industry, transport and power. The buildings model is framed on a simulation stock accounting that disaggregates the residential and non-residential (i.e. commercial and public) subsectors across 35 world regions. This is used to analyse the impacts of policy measures such as energy efficiency regulations, technology choices and their evolution over time in the Faster Transition Scenario featured in this report. For more information, see: www.iea.org/etp.

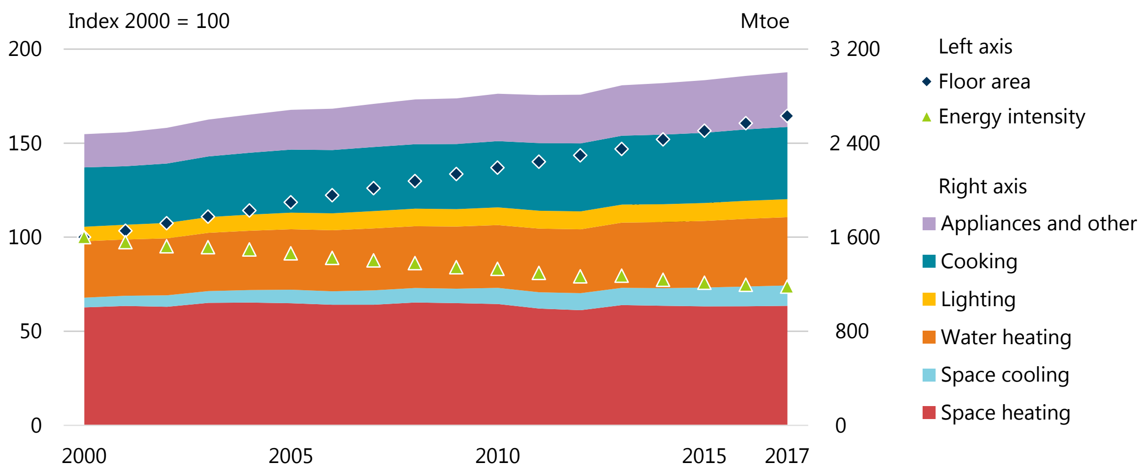
[1] While solar photovoltaic (PV) is used increasingly in the buildings sector, both for on-site electricity consumption and to feed to the network, it is not considered explicitly within the final energy consumption discussed in this chapter. Solar in buildings sector final energy consumption in this chapter refers e to solar thermal energy, unless otherwise noted.
[2] For more information and examples of progress, see the *2018 Global Status Report: Towards a zero-emission, efficient and resilient buildings and construction sector* (IEA-UN Environment, 2018), available at https://webstore.iea.org/2018-global-status-report.

Starting with a look at the current status of the buildings sector and recent energy technology and policy trends, this chapter sets out a low-carbon trajectory for buildings and construction, highlighting the near-term actions and future strategies to ensure wide deployment of low-carbon and energy-efficient technologies across the global buildings sector. It includes discussions of the principal options related to building energy performance and CO_2 emissions reduction, including building envelope technologies, heating and cooling equipment, appliances and lighting. It also discusses the energy system implications of a low-carbon buildings sector and potential technology trade-offs within long-term energy systems planning. In addition, it considers the investment needs to deliver the transformation of the global buildings sector, as well as the benefits that the clean energy transition can deliver.

Energy demand and emissions from buildings are increasing

Buildings consumed more than 3 000 Mtoe in 2017, accounting for 30% of global final energy use.[3] Energy use in the buildings sector has increased steadily since 2000, at an annual average growth rate of around 1.1%. Floor area – driven principally by expanding population, increasing purchasing power in emerging economies and growing commercial activity – is a critical driver of rising energy demand in the buildings sector. Constructed floor space in buildings worldwide has increased by around 65% since 2000, reaching 240 billion m^2 in 2017 (Figure 2.1). Yet, the average energy use per m^2 declined by nearly 25% over the 2000-17 period. This progress, however, did not offset floor area growth, resulting in the steady increase of energy use.

Figure 2.1. Global buildings sector energy use and intensity by end-use, 2000-17



Note: "Appliances and other" includes major household appliances such as refrigerators, clothes washers and dryers, dishwashers and televisions as well as small plug-loads and energy use related to other electrical equipment (e.g. printers, computers and network servers).

Buildings sector energy demand rose more than 20% between 2000 and 2017, as energy intensity reductions did not offset rapidly growing floor area and rising demand for energy services.

[3] When energy from materials use for buildings construction and renovation is included, the share of global final energy is 36% and the share of energy-related emissions from buildings and construction to 39%. For more information, see the *2018 Global Status Report* (IEA-UN Environment, 2018).

Today, space heating is the largest buildings energy end use in the buildings sector, consuming more than 1 000 Mtoe annually on a global basis. It represents more than a third of energy demand in buildings, three-quarters of which is consumed in the United States, the European Union, the People's Republic of China (China) and the Russian Federation (Russia). The introduction, enforcement and revision of building energy codes, along with policies to improve equipment performance, such as condensing boiler requirements, have helped to keep energy use for space heating relatively constant since 2000, while allowing increased thermal comfort in buildings, even with the addition of nearly 30 billion m^2 of floor space in China since 2000. Building envelope renovations, led by the European Union and North America in particular, have also helped to offset the impact of increasing floor area, while improving overall thermal comfort and energy used for heating. However, low-efficiency heating technologies including coal, oil and natural gas boilers as well as basic electric resistance heating technologies still dominate heat production in most buildings, making space heating the most energy-intensive end use and the largest source of energy-related emissions in buildings.

Water heating consumed 580 Mtoe in 2017, up from 480 Mtoe in 2000. Excluding the traditional use of solid biomass in developing countries, sanitary hot water production in buildings is also dominated by fossil fuel use and low-efficiency electrical technologies. Sales of solar thermal technologies, led by growth in China, and energy-efficient heat pump water heaters, particularly in Japan, the United States and the European Union, have progressively been taken up since 2010 but were not enough to offset rapidly rising energy service demand.

Cooking consumes about as much energy as water heating, but relies much less on fossil fuels globally. Around two-thirds of estimated energy consumption for cooking is from inefficient, traditional use of solid biomass, with nearly a quarter of households worldwide depending on this basic energy source for daily cooking needs. Coal, oil and natural gas account for about 27% of energy use for cooking, while a very small share of renewables (e.g. modern biomass cookstoves) and electricity – despite being used as a principal energy source for cooking by roughly 20% of households – accounts for 6% of energy consumption for cooking purposes.

Global electricity use for lighting and appliances grew by an average of 2.2% per year between 2000 and 2017, twice as fast as overall buildings sector energy demand, and accounted for consumption of 430 Mtoe in 2017. This was driven primarily by emerging economies, where household appliance ownership rates increased substantially over the period. For instance, ownership of major appliances (e.g. refrigerators, clothes washers and televisions) has doubled in China and Indonesia, and more than tripled in India since 2000. Energy use from other electrical plug-loads, such as smaller electronics and connected devices, also have increased significantly since 2000, a trend that was common in both advanced and emerging economies. By contrast, energy efficiency improvements, notably the mass deployment of light-emitting diode (LED) technologies in recent years, helped to improve the average energy intensity of lighting per m^2 by more than 15% since 2010, even with rising demand for lighting services.

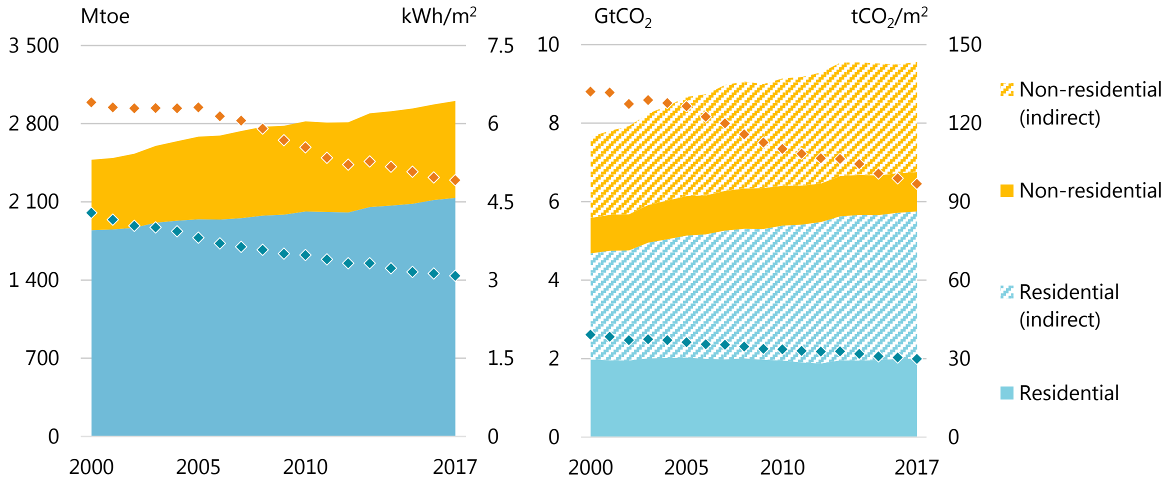
Space cooling, which today only accounts for 6% of energy use in the buildings sector, is by far the fastest growing end use worldwide as more and more air conditioners (ACs) are acquired and used. Ownership in China proliferated from around 15% of households having an AC in 2000 to more than 60% in 2017. In many hot places such as India, Southeast Asia and Africa, AC ownership remains limited, but that is changing quickly. For example, in India, where the average daily temperature for 1.3 billion people is typically above 25 degrees Celsius (°C), AC ownership in 2010 was only around 3% but increased to an estimated 6% in 2017.

Overall, global energy-related emissions from the buildings sector increased by 25% over the 2000-17 period and accounted for 28% of global energy and process-related CO_2 emissions in

A corrigendum has been issued for this page. See: https://www.iea.org/corrections/ and http://www.oecd.org/about/publishing/corrigenda.htm

2017. Direct emissions from coal, oil and natural gas combustion in buildings have increased only slightly since 2000, reaching 3.0 gigatonnes of CO_2 ($GtCO_2$) in 2017, 9% of total energy-related CO_2 emissions. Indirect emissions from electricity and district heat consumption in buildings accounted for 6.5 $GtCO_2$ in 2017 (Figure 2.2).

Figure 2.2. Global buildings sector energy use, intensity and CO_2 emissions by subsector, 2000-17



Notes: Energy and carbon intensities represent total final energy use in kilowatt-hours (kWh) and resulting CO_2 emissions in tonnes of CO_2 (tCO_2) per m². Indirect CO_2 emissions are from upstream generation of electricity and heat used in buildings.

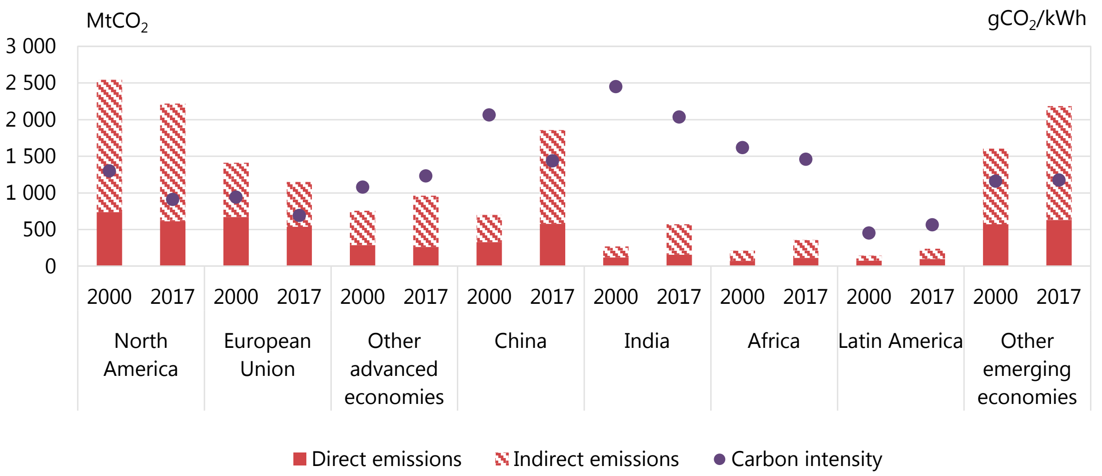
Residential buildings account for over 70% of energy demand and around 60% of CO_2 emissions from the buildings sector.

Unlike direct emissions from fossil fuel use in buildings, indirect emissions rose more than 35% between 2000 and 2017, as electricity demand in buildings soared. The buildings sector now represents more than 55% of global final electricity consumption, and surging demand for equipment like ACs and connected devices in buildings is placing increasing onus on the need to decarbonise the power sector. In fact, in the last 20 years, electricity demand in buildings globally grew more than five times faster than improvements in power sector carbon intensity.

The principal source of energy demand and related CO_2 emissions in buildings is the residential subsector, which is responsible for nearly 70% of energy consumption in buildings. Residential buildings represent about 80% of global floor area, although they only account for around 60% of buildings-related CO_2 emissions. This is due to a few notable differences between residential and non-residential (e.g. commercial, public and other services) buildings. Non-residential buildings consume 46% of electricity use in the sector, and consequently around 43% of indirect CO_2 emissions. In addition, a substantial share (30%, or 665 Mtoe) of residential energy use is from the traditional use of solid biomass in developing countries. That biomass is generally considered as carbon neutral, although it is extremely energy-intensive and causes hazardous indoor and local air pollution. It can also contribute to deforestation and land erosion (Hussaini, Hazma and Usman, 2018).

The important role of traditional use of solid biomass for meeting energy needs in buildings in emerging economies is evident when looking at CO_2 emissions across advanced and emerging economies (Figure 2.3). In 2017, 45% of buildings energy-related CO_2 emissions were in advanced economies (two-thirds if China is included). When indirect emissions from electricity and heat consumption are excluded (to remove the effect of power sector carbon intensities across countries), advanced economies represented half of buildings-related emissions in 2017, or nearly 70% if China is included. That share is changing, however, as growing demand for modern energy services (notably electricity) in emerging economies is driving up energy-related emissions. In places like India, CO_2 emissions related to buildings more than doubled between 2000 and 2017, while indirect emissions nearly tripled, despite falling carbon intensities of electricity generation. By contrast, indirect emissions from electricity and commercial heat use in North America and the European Union fell, thanks to low-carbon electricity generation and relatively stable electricity demand in recent years, and despite increasing electrification of buildings.

Figure 2.3. Buildings-related CO_2 emissions and power sector carbon intensity by region, 2000-17



Notes: $MtCO_2$ = megatonnes of CO_2. Indirect CO_2 emissions result from upstream generation of electricity and heat used in buildings. Carbon intensities for the power sector represent the total grammes (g) of CO_2 emissions per kilowatt-hour (kWh) of electricity consumption.

Rapidly increasing electricity demand in emerging economies is contributing to growth in CO_2 emissions related to buildings energy use, despite improving carbon intensity of power generation.

In addition to fossil fuel combustion and emissions related to upstream power generation, the buildings sector also represents a considerable portion of emissions from material consumption (e.g. cement, steel, bricks, aluminium and glass) and the buildings construction value chain. Production, transport and use of construction materials for buildings emitted an estimated 3.8 $GtCO_2$ in 2017. When added to emissions from energy consumption, this means buildings and construction accounted for around 39% of global CO_2 emissions in 2017.

Policy coverage is improving, but not quickly enough

Policy actions to encourage and enforce improved energy performance of buildings and end-use equipment are a critical element to put the buildings sector on a clean energy path. Existing, new and announced policies only covered around 38% of energy use in buildings in 2017, representing only half of CO_2 emissions from the sector. While energy efficiency policies have expanded rapidly since the early 2000s, when they covered less than 20% of buildings sector energy consumption, annual improvements in mandatory policy coverage only grew 2-3% in recent years (compared with 5-8% previously). Overall stringency improvements (i.e. increase in the relative strength of the policies over time) also diminished in recent years (IEA, 2018a).

Minimum energy performance standards (MEPS) have long been the most widespread policy instruments in the buildings sector, covering a broad range of building components and energy-consuming equipment. MEPS for major household appliances such as refrigerators, washing machines and televisions, exist in most large markets (e.g. North America, the European Union, China and India) and continue to expand to additional countries. Nearly all of the major markets for ACs also have MEPS in place, and coverage across countries continues to expand. Overall, policies for appliances and heating and cooling equipment cover around 40% of energy demand for those end uses, which together accounted for two-thirds of energy use in buildings in 2017.

Lighting regulations are one of the most widespread policy tools used in the buildings sector today, largely due to efforts in the mid-2000s to phase out the use of incandescent lighting technologies. More than 80% of electricity use for lighting globally was covered by energy efficiency policies in 2017, up from less than 10% in 2005. This impressive improvement, alongside the emergence of cheaper, more efficient technologies (due to support measures beyond MEPS, such as government funding for research and development [R&D], rebate programmes and international co-operation on testing procedures), led to rapid growth in compact fluorescent lamp (CFL) sales in the late-2000s, followed by the surge of LEDs starting in 2012. The latter represented around one-third of residential lighting sales in 2017 and is one of the few clean energy technologies that is "on track".[4]

Building energy codes are another important policy tool, although their implementation in emerging economies is far less common than lighting regulations. As of 2017, building energy codes were mandatory for both residential and non-residential buildings in 54 countries, covering around 78% of useful heating and cooling demand (Figure 2.4). The useful energy coverage has increased considerably since 2000, in particular due to increases in overall heating service demand in China, where building energy codes have been in place since 1995, and from the introduction of new building energy codes, for example in Turkey and India. Yet, coverage itself is not indicative of stringency, which has improved less globally since 2000. Coverage also does not reflect a changing dynamic in the buildings sector: while most countries with major heating needs have had codes in place since 2000, far fewer countries in places where cooling demand is likely to expand significantly and rapidly in the coming decades have mandatory building energy codes in place.

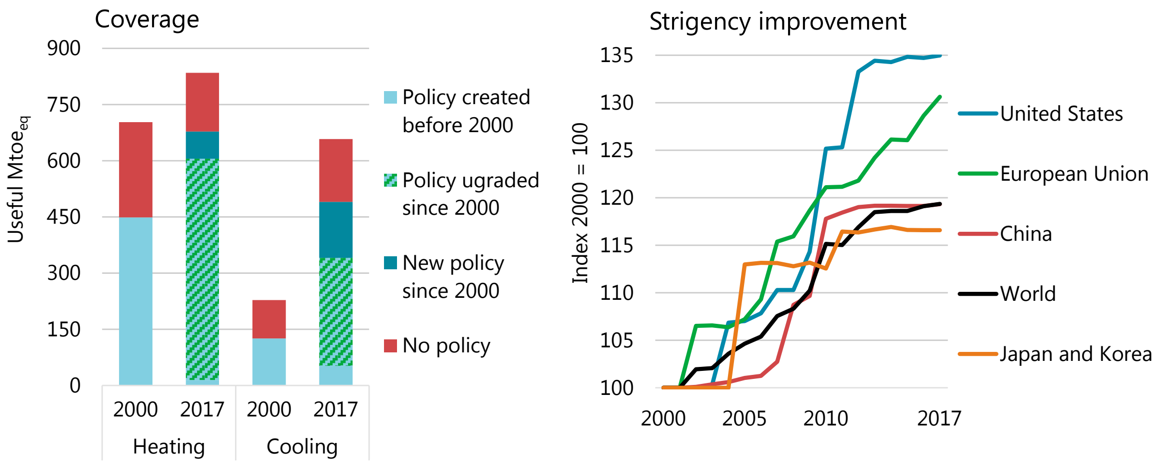
Almost all mandatory building energy codes in place in 2000 have been revised to include requirements that are more ambitious. Overall, the stringency of building energy codes has improved by around 20% at the global level since 2000. In the United States and the European Union, stringency in the thermal performance requirements for new construction has improved by about 35% and 30%, respectively. Further revisions are underway. For instance, the Energy Performance of Buildings Directive requires all new buildings in the European Union to be nearly zero energy by the end of 2020.

Another 16 countries have energy codes that are voluntary or mandatory for only part of the buildings sector (or part of the country's territory). Another eight countries are developing codes. They are mostly sub-Saharan African countries, including Kenya, Tanzania, Uganda and Senegal, which is a positive step for a region with a rapidly expanding buildings sector. Other countries are revising and updating regulations, including the recent release of Canada's National Energy Code (a model code for provinces and territories) and the recast of the European Union's Energy Performance of Buildings Directive in 2018.

[4] For more information on the IEA's efforts on Tracking Clean Energy Progress, visit www.iea.org/tcep.

Building certification programmes are another useful policy tool and are now present in nearly 60 countries. Mandatory or partial mandatory programmes tend to be more common in advanced countries, such as the United States and the European Union, while voluntary programmes are generally more common in emerging countries. For instance, a pool of voluntary certifications exists in India, Indonesia and Brazil. An additional 26 countries have a few voluntary certification projects, but mandatory certification is still not widespread.

Figure 2.4. Useful heating and cooling demand covered by mandatory building energy codes and estimated stringency improvements for selected regions, 2000-17



Notes: Useful energy demand refers to thermal energy delivered in Mtoe-equivalent (Mtoe$_{eq}$) to the end user in terms of heating or cooling service. Stringency improvement is assessed on prescriptive requirements relative to the performance of building components mentioned in national or sub-national energy codes. It is not an indicator of building energy performance in a given country relative to another.

Mandatory building energy codes covered more than three-quarters of current heating and cooling demand in 2017, and global stringency has improved on average by 20% since 2000.

While overall mandatory policy coverage of buildings sector energy use is not progressing quickly enough, the call to address building energy consumption and carbon impact has grown in recent years (Box 2.2).

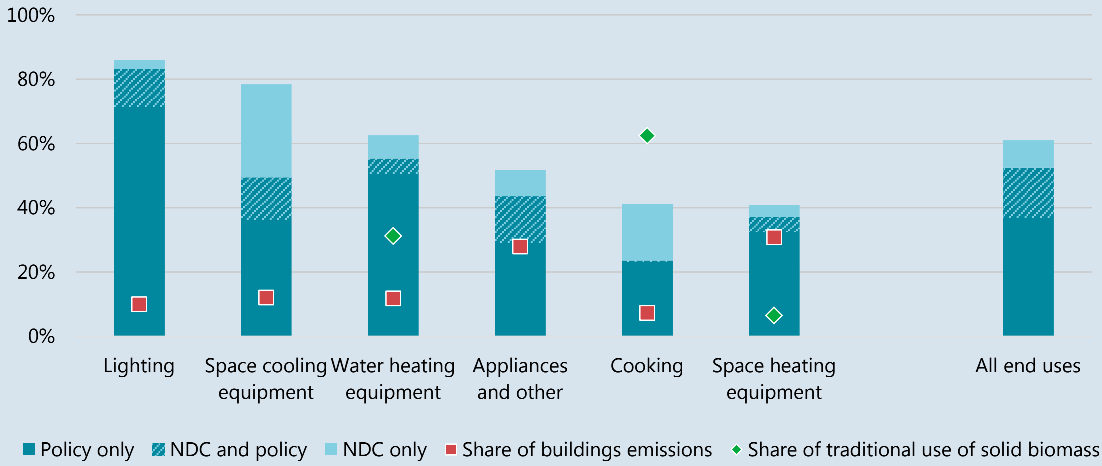
Box 2.2. International efforts to mobilise commitments and actions for sustainable buildings

The first Buildings Day on "Mobilizing the Building and Construction Sector for Climate Action" was held at the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in 2015. In addition, the Global Alliance for Buildings and Construction (GlobalABC) was launched. It aims to mobilise all stakeholders related to the buildings and construction sector to scale up climate actions. It focuses on achieving the clean energy transition through fostering the development of appropriate policies for sustainable, energy-efficient buildings that allow a value-chain transformation of the sector.

Specifically, the GlobalABC aims to support and accelerate the implementation of Nationally Determined Contributions (NDCs), which are building blocks of the Paris Agreement on climate change. Since COP21, 181 Parties to the UNFCCC have submitted NDCs, 136 of which include buildings as part of their climate mitigation and adaptation ambitions. Should those NDCs become policy, buildings sector CO_2 emissions coverage would increase by an additional 10% (Figure 2.5).

Most NDCs do not mention specific technology or policy actions to achieve their long-term objectives. For instance, only 72 of the 181 NDCs submitted to date mention building end-use equipment efficiency. Only three explicitly mention heat-pumping technologies, and only 25 NDCs mention energy-efficient air conditioning as a way to achieve their climate targets, despite the central importance of heating and cooling in buildings sector energy consumption and its consequent emissions.

Figure 2.5. Share of buildings sector CO_2 emissions covered by policy or NDC ambitions, 2017



Notes: The hatched area represents CO_2 emissions addressed by current policies and NDCs. NDCs may extend emissions coverage (light blue) and may also increase ambitions for the reduction of emissions already covered by existing policies (hatched area).

NDCs, if implemented as policy, would extend coverage of CO_2 emissions in the buildings sector, but only by about 10% more that existing mandatory policy coverage.

39 NDCs mention clean cooking, which is closely linked to a number of Sustainable Development Goals, such as achieving affordable and clean energy access for all by 2050 (see Box 1.1). Around 550 million households relied on the traditional use of solid biomass for cooking in 2017. Clean cooking actions under the NDCs could affect as many as 300 million of households, and unlike other buildings sector mentions in NDCs, there is almost no overlap between existing policies and countries mentioning cooking in their NDCs.

The GlobalABC, with its 24 member countries and 72 non-governmental organisations, is working to raise awareness and engagements to increase the magnitude of actions that enable low-carbon, energy-efficient and resilient buildings. Its recent *A Guide for Incorporating Buildings Actions in NDCs* is an example of how the Alliance is supporting countries to extend the scope and ambition of buildings sector actions. For more information, visit www.globalabc.org.

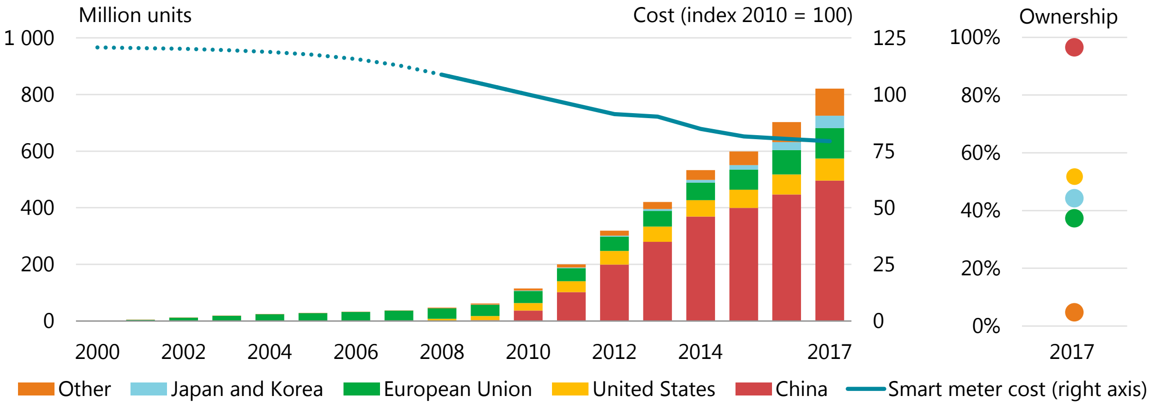
Energy demand in buildings affects the broader energy system

The evolution of energy demand in the buildings sector has great impact on the energy system, particularly on additional capacity and infrastructure needs for the power sector. For example, rapidly rising demand for space cooling in buildings is putting enormous strain on electricity systems in many countries, pushing up not only overall power generation needs but also the need for peak generation capacity, which often uses coal and gas (IEA, 2018b). Averaged across all countries, cooling demand from buildings accounted for over 15% of global peak electricity consumption in 2017, with numbers reaching higher than 50% on hot days in some countries.

In addition, growing energy use by household appliances and plug-loads reached more than 3 000 terawatt-hours (TWh) in 2017, nearly twice as much as all the electricity used in Africa and the Middle East that year. This trend shows no sign of slowing as electricity demand for household appliances and small plug-loads has consistently increased by nearly 3% a year since 2010. Like space cooling, household appliances and electrical devices affect the load curve of power systems, especially in the evening hours when households typically operate multiple electrical devices at the same time.

There are a number of opportunities to reduce the impact of increased electricity demand in the buildings sector on power systems, including digitalisation and demand-side response tools. Deployment of smart meters is rolling out quickly and will facilitate interactions between buildings and the broader electricity system. More than 800 million smart meters were installed globally at the end of 2017 (Figure 2.6). Italy was a front-runner in that deployment, where the Enel distribution company replaced 30 million conventional meters throughout the country between 2001 and 2006. China rapidly caught up around 2010 and had rolled out around 500 million smart meters under its nationwide deployment plan as of 2017.

Figure 2.6. Smart meter deployment, cost and penetration, 2000-17



Note: Smart meters installed in buildings are not necessarily used at their fullest potential.

The European Union led the deployment of the first 30 million smart meters, but after 2008, China took the lead with the installation of about 500 million smart meters by 2017.

Smart meters can improve the interface between power grids (reflecting the availability of supply) and energy management systems in buildings using real-time signals. For example, the cost of sensors in buildings has decreased by about 90% since 2010, and active controls can be used to enhance building automation or to increase incentives for consumers to respond to electricity prices accordingly. New business models and product proposals are already taking advantage of this potential in some countries. For instance, EnergyHub in the United States manages a wide range of distributed energy resources (including smart thermostats and connected water heaters) through a contractual agreement with end users, allowing the aggregation, monitoring and dispatching of multiple building energy loads (SmartGridToday, 2018). Other examples include the Green Button, an industry-led initiative to provide utility customers in the United States with easy and secure access to their energy usage information, and the Smart Buildings Alliance, which brings together more than 250 organisations across the buildings sector to work on all things digital in the built environment.

Yet, deployment and use of intelligent and responsive building technologies is still rather limited, and increasing digitalisation itself is adding to growing demand for electricity. Data centres worldwide consumed around 200 TWh of electricity in 2017. Billions of connected devices in buildings – ranging from televisions and set-top boxes to clothes washers and doorbells – also add to growing electricity demand for network connectivity. While this is unveiling potential opportunities for resource efficiency, broadly speaking the potential energy savings remain untapped.

Leveraging existing equipment and infrastructure to enhance demand-side flexibility also favours better integration and synergies of buildings in the energy system. For instance, district energy systems can use thermal inertia in buildings to compensate for fluctuations in the network. They can also use the thermal mass of the network with thermal storage capacity to balance fluctuations in the power grid. Beyond flexibility, district energy systems can enable the use of various energy sources including industrial excess heat, geothermal and solar energy.

Globally, district energy systems provide only a small portion (10%) of total heat demand in buildings, although it is quite extensive in some countries (e.g. around 50% in Sweden). The development of high-efficiency district energy networks (e.g. low-temperature 4^{th} generation district heat) has the potential to unlock flexibility levers to accommodate low-grade heat (e.g. from industry) and intermittent renewable sources (e.g. with large-scale heat pumps and storage). Yet, it also highlights the current challenge of decarbonising heat production (Box 2.3). The potential shift to carbon-neutral and low-temperature networks on large-scales will depend on local resource availability, buildings improvements and urban land use configurations. Best practice examples illustrate important opportunities to modernise district energy networks, but policy support needs to encourage more efficient, flexible and integrated district energy systems.

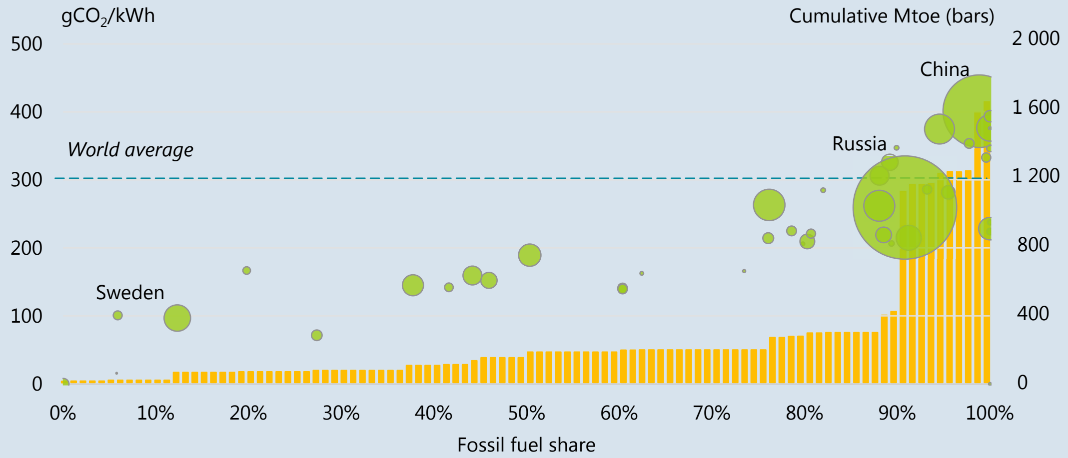
Box 2.3. Leaner and cleaner district energy systems are part of the clean energy transition

Globally, district energy systems supplied roughly 150 Mtoe of energy to buildings in 2017. Overall, district heating networks supply around 285 million households, or 12% of the world's population. Russia alone accounts for 42%, with nearly half of its energy use in buildings coming from district heating networks. China has the second largest network, accounting for 21% of global district heat consumption in 2017. District heat use in buildings in China increased more than fourfold between 2000 and 2017 to meet over 10% of the country's space heating demand in 2017.

In 2017, direct use of fossil fuels (even excluding fossil fuel use in co-generation of heat and electricity) supplied 89% of district heat production worldwide. The average carbon intensity of district heat was around 300 grammes (g) of CO_2 per kWh (Figure 2.7). Fossil fuels account for 91% of district heat production in Russia and 99% in China. Globally, the potential for leaner and cleaner district energy systems remains largely untapped. Multiple examples in European countries show that it is possible to operate low-carbon district heating systems. In Sweden, for example, more than two-thirds of district heat production is using renewable energy sources, making its carbon intensity one-third lower than the world average.

Modern district energy networks can take advantage of various energy inputs and technologies, while also offering increased flexibility for heat (or cooling) production than what is generally possible at the scale of a single building. Economies of scale at the district level also enable investment in multiple technologies (e.g. use of heat pumps, thermal storage, renewables and heat recovered from industrial or commercial processes) that would likely not be cost effective at the building scale. Many examples of these types of energy-efficient, low-carbon and integrated energy solutions for district energy systems exist. For example, among possible low-grade heat solutions, recent analyses show the possibility of exploiting geostructures (e.g. metro stations) to heat or cool buildings (Barla, Di Dona and Santi, 2019).

Figure 2.7. Carbon intensity of district heat relative to the share of fossil fuels, 2017



Notes: Each bubble indicates the carbon intensity of district heat in a given country (right axis) relative to the share of fossil fuels in district heat production (horizontal axis) and total heat demand (bubble size). Cumulative heat demand is shown on the left axis. The share of fossil fuels excludes fossil fuels used for co-generation.

District energy systems offer potential to integrate low-carbon energy sources, but nearly 90% of global heat supply today comes from the use of fossil fuels.

Buildings will play a central role in the clean energy transition

Buildings will play a key role in the global clean energy transition, including reducing stress on power sector investment, enabling more flexibility in the energy system and supporting the decarbonisation of material manufacturing industries. To do so, a strategic plan for the swift and assertive clean energy transition of the global buildings sector is of the essence, especially given the long life of building assets, which places significant constraint on achieving ambitious CO_2 emissions reduction without costly changes (e.g. early retirement of equipment) once those investments have been made.

The Faster Transition Scenario strategy for the buildings sector rests on three central pillars:

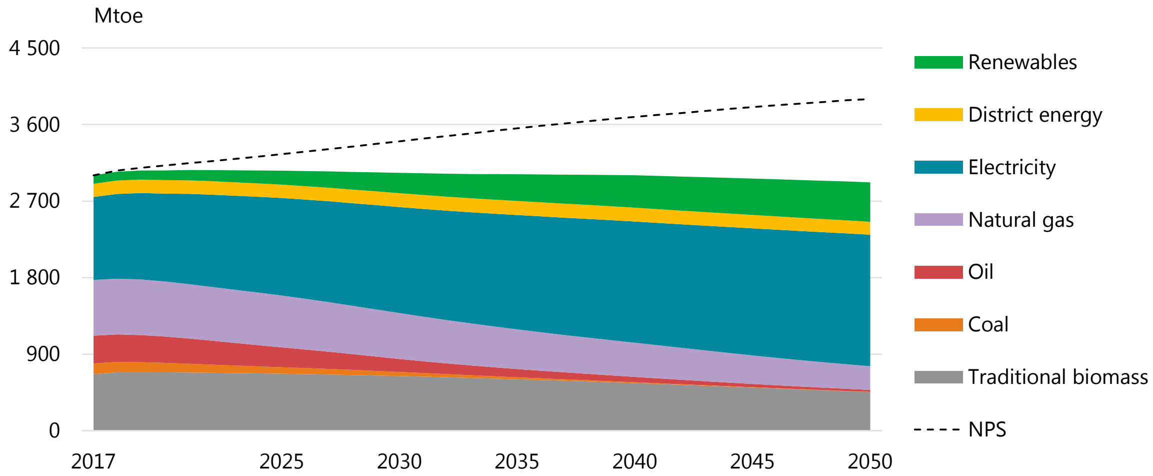
- **Sufficiency:** Avoiding unnecessary energy demand and technology investment through planning, building design and energy technology measures that address the underlying need for energy use without reducing (or possibly improving) service levels in buildings.
- **Efficiency:** Improving the energy performance of building technologies through policy and market frameworks that encourage shifts to energy-efficient solutions and that deliver innovation to enhance the performance of energy-consuming products.
- **Decarbonisation:** Shifting from energy- and carbon-intensive technologies to high-performance, low-carbon solutions that address emissions from the buildings sector, reduce energy demand and enhance flexibility to support the decarbonisation of power generation.

This strategy hinges on a disruptive (i.e. radically faster), but technically feasible adoption of high-performance and low-carbon building technologies. Those solutions start as quickly as possible with best-performing products that are already available in most markets today. The accelerated uptake will require strong "push" (e.g. mandatory performance targets) and "pull" (e.g. upfront incentives such as consumer rebates) policy measures to overcome known barriers (e.g. high upfront costs and availability of less efficient products) and drive global market transformation towards energy efficiency in the coming years.

Major energy demand improvements can be realised in buildings

Total building energy demand in the Faster Transition Scenario decreases gradually from more than 3 000 Mtoe in the early 2020s to around 2 900 Mtoe in 2050 (Figure 2.8). This is despite a 30% increase in global population, a 175% increase in global gross domestic product and a near doubling in buildings sector floor area. Energy efficiency measures are central to the energy demand reduction, while equally providing substantially more energy services to consumers and businesses, leading to an average energy savings of 500 Mtoe per year between 2020 and 2050 compared to the New Policies Scenario. That level of energy savings is equivalent to the total energy demand of in France, Germany and the United Kingdom in 2017, or more than the energy consumed by 1 billion people in sub-Saharan Africa.

Figure 2.8. Energy use by subsector in the Faster Transition Scenario, 2017-50



Notes: NPS = New Policies Scenario. "Renewables" include modern use of solid biomass and solar thermal energy use.

The Faster Transition Scenario leads to dramatic shifts away from fossil fuel use and saves an average of 500 Mtoe of energy each year to 2050, thanks to wide adoption of high-efficiency technologies.

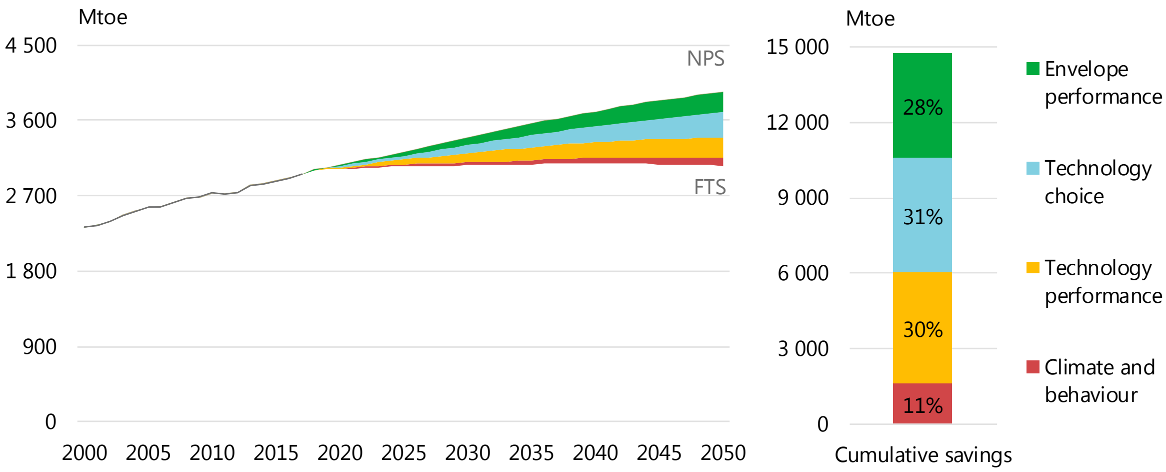
The Faster Transition Scenario also leads to significant changes in energy carriers to supply energy needs in buildings. In particular, the demand for electricity in the buildings sector accelerates considerably, jumping from 33% of energy use in 2017 to 53% in 2050. Growing energy service demand in emerging economies for end uses that are already electrified (e.g. lighting, appliances and cooling) plays a strong role in that increasing share, but energy efficiency measures help to dampen that effect. Indeed, the electricity consumption of those three end uses is 30% lower in 2050 than under the New Policies Scenario, thanks to major energy efficiency improvements. Those efficiency gains also allow for electrification of other end uses such as space and water heating, whose share of electric equipment sales jumps from less than 30% today to 45% by 2050. Even with those shifts, overall electricity use in buildings in the Faster Transition Scenario in 2050 is still 3 400 TWh less than in the New Policies Scenario.

The use of renewable energy in the buildings sector also sees substantial growth in the Faster Transition Scenario, including the modern use of solid biomass and solar thermal technologies for space and water heating. Renewables represent 16% of energy demand in buildings in 2050, up from 3% in 2017. By contrast, coal and oil are almost completely phased out by 2030, while natural gas consumption is cut by nearly 60% by 2050, thanks to efforts to switch to high-performance electrical and solar thermal equipment and a strong push to improve natural gas technologies beyond current performance levels.

While total buildings energy consumption in the buildings sector decreases between 2020 and 2050 in the Faster Transition Scenario, energy services (i.e. useful energy) supplied to households and non-residential buildings continue to grow. For example, the global stock of household refrigerators, clothes washers and televisions nearly doubles between 2018 and 2050, and dishwasher and clothes dryer stocks more than triple. Similarly, AC ownership increases from a global average of 33% in 2017 to around 70% in 2050.

The improvement in energy services in buildings in the Faster Transition Scenario – without parallel increases in energy use – is feasible because of avoided need for energy, through measures that address the underlying requirement for energy to meet those services. For example, heating and cooling needs are realised with less energy because of improved building envelope performance, which accounts for 28% of the cumulative sector energy savings to 2050 (Figure 2.9). The introduction and regular upgrading of building energy codes helps drive the construction of nearly 4 billion m^2 per year by 2030 towards high-performance standards such as near-zero energy buildings. Achieving high-performance envelopes is critical in emerging economies, where as much as 75% of buildings that will be standing in 2050 are yet to be built.[5]

Figure 2.9. Change in buildings energy use in the Faster Transition Scenario, 2017-50



Notes: FTS = Faster Transition Scenario. "Envelope performance" accounts for the reduction of heating and cooling service demand from improved envelope components. "Technology choice" represents shifts from one technology, such as a gas boiler, to another, such as a heat pump. "Technology performance" reflects enhanced energy performance through technical improvements and continued product innovation. "Climate and behaviour" account for lower heating and cooling service demand from climate change impacts as well as other behavioural effects such as moderate changes in temperature setpoint. Digitalisation, controls and connectivity affect these four key factors.

Envelope improvements, technology choice and equipment performance are the three most relevant levers to reduce energy demand in buildings in the Faster Transition Scenario.

A doubling of current renovation rates and performance improvements is central to address the thermal performance of the world's existing buildings stock, especially in colder climates such as the European Union, United States, Canada, Russia, China, Japan and Korea. In advanced economies like the United States and the European Union, more than half of buildings that will be standing in 2050 already exist. Building envelope renovation measures in the Faster Transition Scenario lead to improvements in energy intensity (in terms of heating and cooling services per m^2) of more than 35% on average globally by 2050, while allowing for continued improvement in overall comfort.

Technology choice, including shifts to low-carbon and energy-efficient equipment such as heat pumps or LED lighting, is the second tier of the Faster Transition Scenario for buildings sector decarbonisation. It includes a rapid shift away from technologies for heating purposes that use coal, oil and natural gas, such that their stock drops to only 12% worldwide by 2050. Coal and oil heating equipment are progressively phased out and even high-efficiency natural

[5] Average for India, Southeast Asia, Latin America, Africa and other emerging economies.

gas thermal heat pumps are only 10% of heating equipment sales by 2050. Electric heat pump sales, by contrast, see a steep rise, tripling by 2030.

Unsurprisingly, space heating accounts for the largest energy savings from fuel switching, as heat pumps are already typically around two to three times more efficient than today's efficient condensing gas boilers. Significant savings also come from the accelerated uptake of LED lighting, where the efficacy of LEDs is more than five-times higher than conventional halogen and incandescent lamps, and two-times higher than CFLs. The sales share of LEDs jumps from 33% in 2017 to 80% in 2030 and more than 95% of sales by 2050.

Improving the performance of energy technologies in buildings is the third pillar of the Faster Transition Scenario strategy. Multiple cost-effective efficiency gains can be captured from products already available. For example, in some countries such as the United States, China, Korea, Viet Nam and Thailand, there is a factor of two difference between the efficiency of median ACs and typically available, energy-efficient products. Immediate policy actions in the Faster Transition Scenario lead to the phase-out of the least efficient products and progressively increase AC performance, which improves on average by around 50% in the next decade. Household appliances also move to high-efficiency technologies in the coming decade.

These "low-hanging fruits" are complemented with longer-term rollout of best-in-class and innovative technologies to achieve much higher levels of energy performance. For instance, typical performance for ACs improves as much as twofold by 2050. Heat pump performance increases to an efficiency factor[6] of 3.5 in cold climates and to 5.0 or more depending on climate conditions in the Faster Transition Scenario. In places where heat pumps are used for both heating and cooling, overall systems efficiency can achieve values of 8.0 to 9.0.

An additional 11% of the cumulative energy savings to 2050 in the Faster Transition Scenario is the result of lesser impact of climate change (relative to the New Policies Scenario within the global context of the clean energy transition) and some energy behaviour improvement in buildings. Lesser global average temperature rise in the Faster Transition Scenario helps to limit both the increase in average cooling degree-days and the number of extreme heat events in the future, which play a central role in the need and demand for cooling services.[7] Slight changes in energy behaviour, either through improved consumer awareness or through use of digital technologies, also help to reduce total energy use. This includes relatively simple measures such as turning off lights and programming slightly higher or lower temperature set points on heating and cooling equipment.

Energy improvements in buildings lead to big CO_2 reductions

The various energy efficiency and low-carbon technology measures in the Faster Transition Scenario, paired with low-carbon power generation, lead to very significant drops in buildings-related CO_2 emissions (Figure 2.10). Those emissions peak around 2020, decreasing notably soon after at an average annual rate of 6% to reach 1.2 $GtCO_2$ by 2050 – one-eighth current

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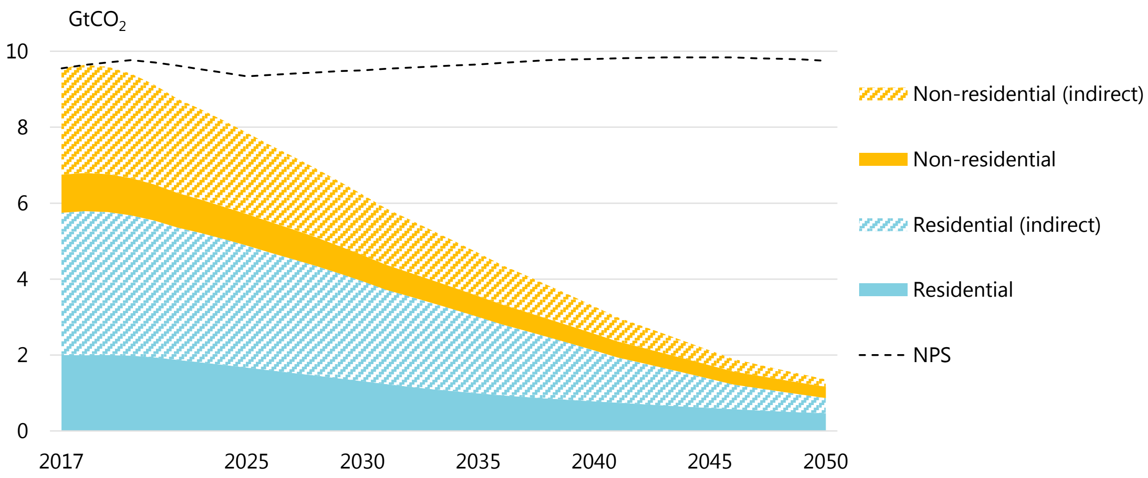
[6] The efficiency factor refers to the average energy performance. For example, an efficiency factor of 3.0 indicates that three units of useful heat are produced or extracted from one unit of energy input. The higher the factor, the more efficient the device is. Additionally, a seasonal factor can be used to take into account the overall performance of the equipment during a typical heating (or cooling) season, assuming the same indoor temperature but over a range of outside temperatures.

[7] Rising average temperatures because of climate change will lead to an increase in cooling degree-days around the world, though at differing rates across regions. A 1°C increase in global average temperature by 2050 (compared with today) will lead to an average increase in cooling degree-days of around 25%, averaged across regions (IEA, 2018b).

levels. Globally, energy efficiency measures contribute to around one-third of emissions reduction from buildings to 2050, or 50 $GtCO_2$ in cumulative emissions.

Direct emissions from the buildings sector decrease rapidly after 2020 in the Faster Transition Scenario, thanks to a swift shift away from conventional fossil fuels. By 2050, they amount to less than 0.75 $GtCO_2$, compared with 3.0 $GtCO_2$ in 2017. These reductions relative to 2017 amount to 4.7 $GtCO_2$ in annual emissions savings to 2050 – or half CO_2 emissions produced by the buildings sector in 2017.

Figure 2.10. Buildings-related CO_2 emissions in the Faster Transition Scenario, 2017-50



Note: Indirect CO_2 emissions result from upstream generation of electricity and heat used in buildings.

Efficient and clean energy technology solutions, coupled with low-carbon power generation, cut buildings-related CO_2 emissions by 87% by 2050, while global floor area nearly doubles.

Indirect emissions decline dramatically as well, thanks to a combination of energy efficiency measures and low-carbon power generation. By 2050, indirect emissions from the buildings sector are less than 8% of current levels, or slightly more than the energy-related CO_2 emissions in the European Union in 2017. Energy efficiency measures in buildings account for about one-third of the decarbonisation and support cleaner power generation, especially through reducing peak electricity demand and its accompanying emissions.

Decarbonising the buildings sector requires strategic thinking

Shifting away from fossil fuel use in buildings will not be easy. Perhaps the most difficult energy service to decarbonise is heating (including water heating), nearly two-thirds of which was met using fossil fuels in 2017. This is due to a number of factors, including: energy prices (natural gas is considerably less expensive than electricity in many markets, often due to subsidies and imbalanced fuel taxation); technical barriers (transitioning from boilers can require important infrastructure changes); and consumer preferences, including, but not limited to, lack of awareness or familiarity with alternative heating technologies.

In the Faster Transition Scenario, the share of fossil fuels in global buildings sector energy use drops to 10% by 2050 (Table 2.1). Coal- and oil-fired boilers, which represent around 30% of global heating equipment today, are almost phased out by 2030. Natural gas, which covered

22% of global energy consumption in buildings and more than 35% of space and water heating energy demand in 2017, also declines (Figure 2.11).

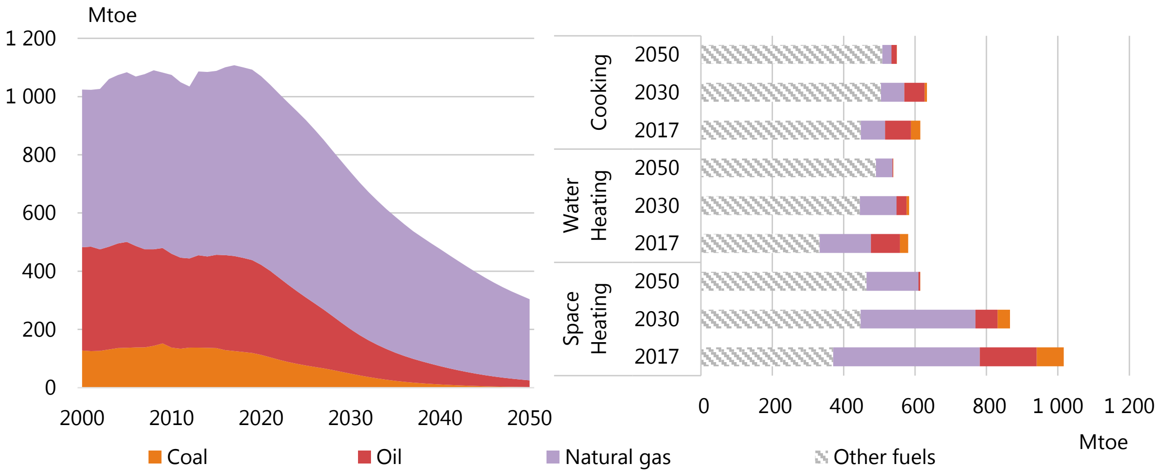
By 2050, natural gas use for those end uses is less than half of the 2017 level, reflecting a number of factors including building envelope improvements as well as ongoing gains in gas technology performance in which all gas use for heating moves at a minimum to condensing gas boilers and then to more efficient gas heat pumps. Additionally, some gas use is replaced by high-performance and low-carbon technologies, such as electric heat pumps (e.g. air-to-water units) and solar thermal technology. As a result, buildings-related CO_2 emissions from fossil fuels decrease by more than 75% by 2050 compared with 2017.

Table 2.1. Fuel use in the Faster Transition Scenario relative to 2017

	Energy use (Mtoe)			Change relative to 2017	
	2017	2030	2050	2030	2050
Coal	126	48	2	-62%	-98%
Oil	326	153	23	-53%	-93%
Natural gas	656	540	278	-18%	-58%
Electricity	981	1 250	1 547	27%	58%
District heat	154	163	152	6%	-1%
Renewables	101	239	464	137%	359%
Biomass*	665	643	455	-3%	-32%
Total	**3 009**	**3 036**	**2 921**	**1%**	**-3%**

* Biomass only includes traditional use of solid biomass.
Notes: "Renewables" include efficient use of solid biomass as well as solar thermal.

Figure 2.11. Evolution of fossil fuel use in buildings in the Faster Transition Scenario, 2017-50



Drastic shifts away from fossil fuels to high-efficiency and low-carbon solutions lead to nearly 800 Mtoe in energy demand reductions by 2050.

Achieving such shifts away from fossil fuel use, especially for heating, requires co-ordinated and long-term strategies (Table 2.2). Growth of existing networks and installation of fossil fuel equipment in new buildings is avoided, particularly given the long life of gas infrastructure and known challenges of getting buildings off natural gas. Installation of low-carbon, high-efficiency technologies is a priority for new construction, especially as they can be easily integrated at the building design phase. In existing buildings, fossil fuel equipment is shifted to low-carbon and high-performance alternatives when technically feasible and cost effective. When fossil fuels remain in use, improved energy performance, alongside strategies to improve the carbon intensity of natural gas supply, is critical. In all cases, these measures are combined with building envelope improvements, to reduce the underlying need for fossil fuel use in buildings.

By 2050, the share of renewables in energy use for heating purposes in buildings in the Faster Transition Scenario reaches 44% (compared to only 7% in 2017). Around 36% of installed heating equipment in buildings globally by 2050 uses renewable energy, including notably solar thermal units, which account for more than 85% (Figure 2.12). The remaining renewables-based heat is mostly from energy-efficient use of modern biomass, such as pellet stoves, particularly in North America and in Europe.

Highly efficient electric technologies represent another important technology for new construction and can be easily connected to smart devices and paired with on-site renewables-based electricity generation. Electric heat pumps (which also replace a sizeable share of fossil fuel and electric resistance technologies in existing buildings) see an impressive growth from 3% of installed equipment in 2017 to around 30% by 2050 in the Faster Transition Scenario. Performance improvements over time (from an average seasonal efficiency of 3.0 today to 3.5-5.0 in the next decade) also mean that shifts to heat pumps result in a major performance jump.

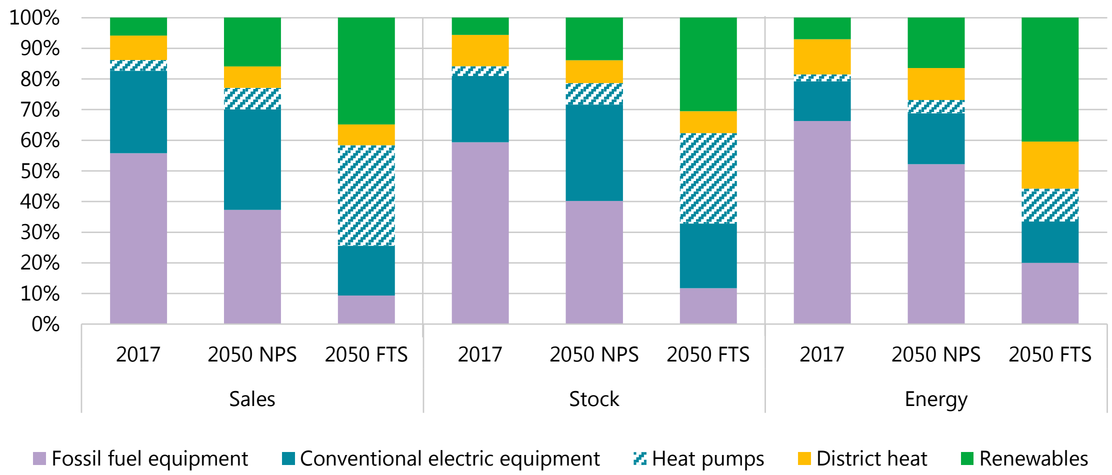
Table 2.2. An energy-efficient and low-carbon strategy to reduce fossil fuel use in buildings

Avoid new fossil fuel demand and shift existing demand where possible	
Target	Technology choice in new construction and in existing buildings when compatible
Actions	• Avoid addition (and potential lock-in) of inefficient and carbon-intensive technologies in all new construction • Enable deployment of high-efficiency, low-carbon technologies such as electric heat pumps and solar thermal units • Exploit opportunities to move away from fossil fuels (e.g. to district energy)
Examples	The Netherlands aspires to reduce CO_2 emissions by 80-95% by 2050, including a drastic reduction of natural gas demand in buildings (MEA, 2016). Amsterdam set an ambitious target to be natural gas-free by 2050. Part of the strategy is to connect around 160 000 buildings to district heat and to integrate geothermal and large-scale solar energy into the district heat network (Municipality of Amsterdam, 2016)
Barriers	Energy access, upfront costs, energy prices and competition with existing gas infrastructure, consumer preferences and awareness, compatibility or challenges with existing building technologies
Facilitators	Energy/climate planning and policies, stakeholder engagement, heat mapping and energy system analyses, improved statistical data
Achievable reductions in energy consumption*	• Advanced economies: 78 Mtoe (roughly the gas consumption in the buildings sector in France, Germany and the United Kingdom in 2017) • Emerging economies: 102 Mtoe (roughly as much as residential gas consumption in Russia, Africa and the Middle East in 2017)

Deploy highly efficient equipment where fossil fuels remain and decarbonise energy supply	
Target	High-performance technologies for remaining fossil fuel use
Actions	• Support commercialisation and deployment of very high-performance gas technologies (e.g. gas thermal heat pumps and micro-cogeneration) • Promote use of advanced controls and integration of renewables and integrated storage in fossil fuel heating systems • Improve the carbon intensity of gas supply (e.g. biogas)
Examples	Canada set ambitious aspirational goals for heating equipment standards to require: minimum performance of 90% or higher for fossil fuel-burning technology by 2025; natural gas heat pumps with a seasonal efficiency factor greater than 1.2 by 2030; and efficiency above 100% for all space heating equipment by 2035 (NRCAN, 2016, 2018)
Barriers	Upfront costs, technology availability and consumer awareness
Facilitators	Policies to optimise performance of heating equipment (including mandating efficiencies above 100%), deployment of demand-side management measures and advanced controls, incentives to lower upfront investment cost
Achievable reduction in energy consumption**	• Advanced economies: 28 Mtoe (roughly the gas consumed by buildings in Canada in 2017) • Emerging economies: 14 Mtoe (nearly the residential gas use in the Caspian region in 2017)

*: Influence of technology choice on changes in total energy demand for space and water heating from 2017-50 in the Faster Transition Scenario. **: Influence of fossil fuel technology performance on changes in total energy demand from 2017-50 for space and water heating in the Faster Transition Scenario.

Figure 2.12. Share of sales, stock and energy use for heating equipment, 2017-50



Notes: Traditional use of solid biomass is not included. District heat sales and stock are in the number of household or non-residential building connections rather than installed capacity.

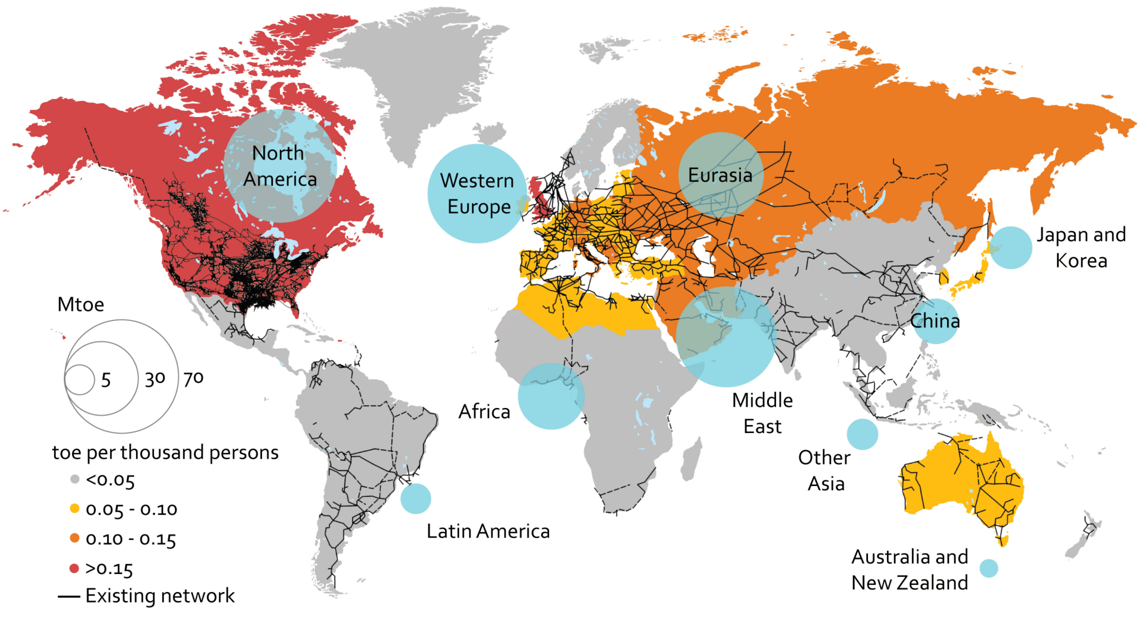
Rapid deployment of heat pumps, renewables and modern district energy is a central pillar of decarbonised heat in the buildings sector in the Faster Transition Scenario.

For existing buildings, switching from fossil fuels will be a challenge. While not infeasible, fully phasing out natural gas use in buildings is unlikely, both because of embedded infrastructure, especially in dense urban areas with large shares of multi-family buildings, and also existing extensive natural gas networks in many countries. Globally, there are around 2.8 million kilometres of natural gas pipelines today (SNAM, International Gas Union and Boston

A corrigendum has been issued for this page. See: https://www.iea.org/corrections/ and http://www.oecd.org/about/publishing/corrigenda.htm

Consulting Group, 2018; Speirs at al., 2017). It is not surprising that the highest concentration of gas-based heating is in regions with existing infrastructure, including notably the European Union, the United States, Canada, Russia and the Middle East, which accounted for around 70% of natural gas consumption in buildings in 2017. In the Faster Transition Scenario, those regions still account for about 70% of natural gas use in buildings in 2050 (Figure 2.13). Aiming to achieve major shifts to replace fossil fuel technology with alternatives will require ambitious policy, such as the current agenda to phase-down gas use in the Netherlands.

Figure 2.13. Per capita and total natural gas consumption in the Faster Transition Scenario, 2050



Note: toe = tonnes of oil equivalent.

Natural gas use in the Faster Transition Scenario is concentrated in the critical heat markets with existing gas infrastructure, but even there natural gas demand in buildings diminishes.

While challenging, considerable reduction in natural gas use can be accomplished through strategic shifts to alternatives such as heat pumps and modern district heating systems and through effective measures to ensure that gas-based equipment is as efficient as possible, where it makes sense to maintain existing gas networks. Where heating demand densities are adequate, district heating networks are an evident substitute for gas-based equipment, particularly as distribution devices such as radiators can typically be maintained. In such areas, the infrastructure can eventually be designed to supply both heating and cooling. In the Faster Transition Scenario, the share of commercial heat for space and water heating in buildings increases by nearly 30% by 2050, reaching 15% of energy consumption for heating in 2050 (compared to 11% in 2017 and excluding the traditional use of solid biomass).

Residual natural gas demand in the Faster Transition Scenario can be significantly improved through high-performance technologies, including mandating best-available condensing gas boilers (which are common in many countries today) and policy support for deployment of gas therma heat pump technologies (including continued R&D to reduce capital costs and improve adaptability to existing heating applications). By 2050, around three-quarters of gas-based heating equipment sales globally and around 60% of installed gas-using heating stock use gas thermal heat pumping technologies, and the remainder is exclusively condensing gas boilers.

Overall, gas consumption in the Faster Transition Scenario decreases to around 10% of global energy consumption in buildings by 2050 and less than a quarter of global heating energy use. In regions with mature gas networks, the share of natural gas in total building energy use drops to around 18% (compared to 37% today). This means that gas-based technologies represent less than 10% of global heating stock and sales by 2050. As a result, emissions from natural gas use in buildings decrease by around 60% by 2050 in the Faster Transition Scenario, and as much as 70% or more in some regions, such as China and Southeast Asia.

Additional emissions reductions are possible through eventual measures to "green" gas networks, including the sustainable local production of renewable gases to fuel networks (Box 2.4). Such options might be attractive for regions with mature gas networks to exploit the value of existing assets, but strategies around low-carbon alternatives should still consider where green gas solutions make the most sense in terms of carbon abatement, investments and broader energy system needs (e.g. use of biofuels for transport). For example, carbon emissions intensities associated with different biological or synthetic gases can vary from -371 to 642 grammes (g) of CO_2 equivalent per kWh – compared to 185 gCO_2/kWh for natural gas – depending on the type of gas, the production technique and supply chain (Speirs et al., 2017). Replacing current global natural gas demand in buildings (e.g. using biomethane) is equally questionable; this would require nearly five-times the level of global liquid biofuel production in 2017.

Box 2.4. Research and demonstration projects for greener gas networks

Several R&D projects are investigating the feasibility of "green" gas options. Evidence-based reports on sustainable gas, including the impact on consumers according to technological choices, suggest that the additional cost of converting consumers to a hydrogen gas network could be over GBP 3 000 (British pound sterling, roughly USD 3 900) per household. They highlight that future projects coordinating practical demonstration and whole-system modelling analysis are key to quantify the system-wide impacts of gas decarbonisation and, therefore, to understand future investment options (Speirs et al., 2017). The "Heat in the Pipe" project in Turin is also looking to understand how electricity, gas and district heat infrastructure can find synergies. The project also seeks to identify what role gas networks will have in the future for buildings and transport (Heat in the Pipe project, 2018).

Hydrogen and hydrogen blending demonstrations are being tested in several places. The H21 project in the United Kingdom aims to demonstrate the potential of hydrogen to reduce the carbon intensity of heat demand in buildings, which could help set long-term strategies to decarbonise heat (e.g. by distributing 100% hydrogen in the gas network). This demonstration project is based on steam methane reformers with carbon capture and storage, plus geological hydrogen storage (salt caverns). The carbon intensity of the obtained hydrogen is estimated at 27 gCO_2/kWh, 85% less compared to natural gas (H21 project, 2016).

Another example is the GRHYD demonstration project in France, which is a trial of hydrogen blending in the natural gas network. This approach uses renewables-based power such as wind to produce hydrogen that can be injected in the network (up to 20% in volume) or stored. The project involves around 200 residential buildings (GHRYD project, 2018).

Beyond production issues, some gas alternatives may equally require changes in buildings heating equipment. For instance, low blends (e.g. 3 to 5%)[8] of hydrogen could be used (depending on production pathways) in existing natural gas networks, but heating and auxiliary equipment such as meters and piping would likely need to be upgraded or replaced beyond those low-level blends. More flexible devices (e.g. fuel cell micro-co-generation units) can work with higher gas blending, but those technology shifts would nonetheless need to be designed and deployed according to eventual building and energy network needs (Pellegrino, Lanzini and Leone, 2015).

In short, building energy technology strategies for natural gas heating equipment need to be treated within broader systemic considerations to avoid costly future changes or eventual lock-in of carbon-intensive assets. Shifts from natural gas in the Faster Transition Scenario require assertive policy measures and market signals that assess when gas use (or gas substitutes) in buildings is compatible with the long-term clean energy transition. Research and demonstration projects are also needed to deliver further evidence on the benefits, feasibility and affordability of the eventual transformation of existing networks.

Electrification needs to be considered within the broader energy picture

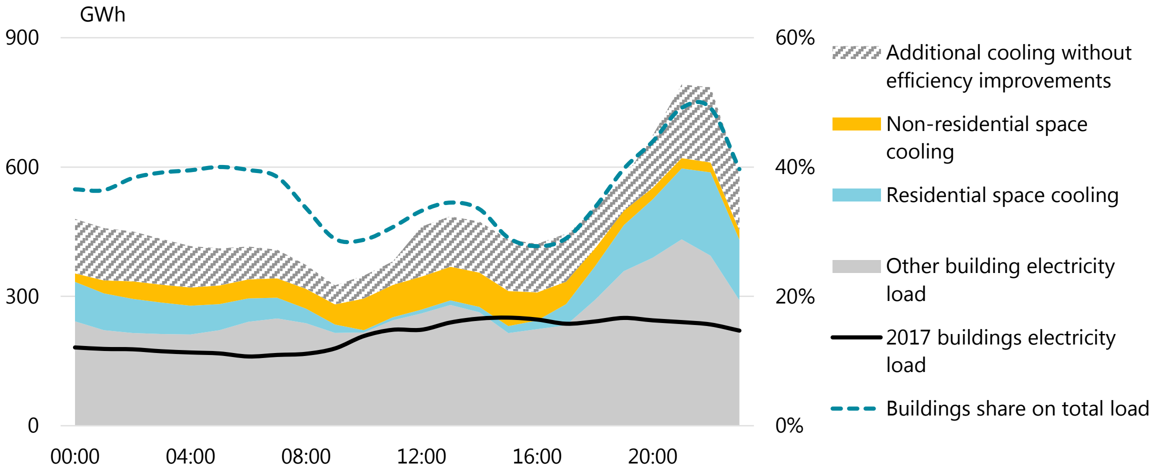
Electricity is an important pillar of buildings sector decarbonisation. In the Faster Transition Scenario, growth in electricity in the buildings sector demand adds the equivalent of more than one-fourth of global electricity demand in 2017 by 2050, around 6 560 TWh. The growth is primarily in emerging economies, driven by population growth, increasing income and rising demand for energy services such as cooling. Conversely, electricity consumption in advanced economies is flat or declining, despite more electricity demand, thanks to improved envelope performance and diffusion of more efficient technologies.

Increasing demand for electricity in the buildings sector, even with energy efficiency measures, would place pressure on the power system and requires better and smarter management of energy demand in the Faster Transition Scenario. For example, global electricity demand for space cooling increases by 35% by 2050 in the energy-efficient Faster Transition Scenario, adding new demand that is more than total electricity consumption by Canada and Russia today. In many countries, this will stress peak electricity loads if uncontrolled, even if using efficient ACs. For instance, cooling demand in China continues to grow rapidly in the Faster Transition Scenario, with ownership of more than 900 million ACs by 2030 and 1.1 billion units by 2050. On hot summer days, that would place considerable demand on the electricity system, especially when people return home in the evening (Figure 2.14). Highly efficient AC technologies will limit the stress on the power system, for example cutting the evening peak to

[8] The opportunity space for hydrogen use in buildings will be further explored in the IEA's forthcoming report on hydrogen for the 2019 G20 Presidency of Japan.

188 GW on a typical weekday in July (or 170 GW less than if those high energy performance AC technologies and building envelope improvements had not been pursued). Yet the evening peak would still be more than 1.5 higher than the average daily load.

Figure 2.14. Buildings sector electricity consumption in China on a typical July weekday without demand-side management in the Faster Transition Scenario, 2050



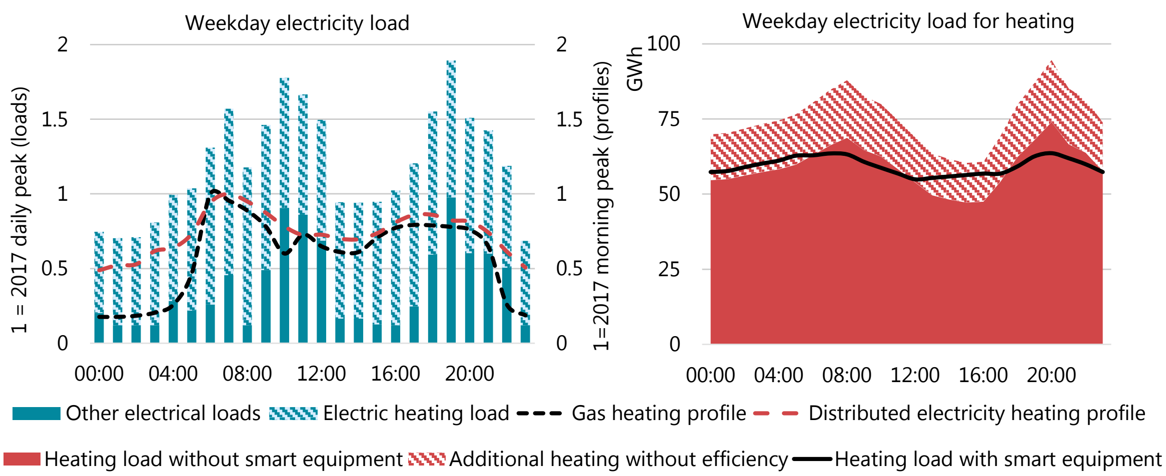
Notes: GWh = gigawatt-hours. Electricity load profiles are derived using information from daily profiles estimated with building survey data from Tsinghua University Building Energy Research Center. Additional cooling energy demand is a result of lower AC performance improvements to 2050, weaker building envelope improvements and different temperature profiles because of higher energy sector emissions.

Energy efficiency significantly reduces the impact of cooling demand, but better demand-side management is required to reduce peak load impacts on the power system.

Globally, energy-efficient ACs will drastically reduce the impact of electricity demand for cooling, where every 10% improvement in AC performance in the Faster Transition Scenario reduces the electricity demand for space cooling by around 165 TWh in 2050, more than the total electricity consumption of the buildings sector in Australia and New Zealand today. However, addressing the peak load demand, even with efficient ACs, requires better demand-side management to shift cooling loads off-peak hours. Pairing high-efficiency ACs with connected and intelligent sensors, for example to capture and predict occupant presence while managing cooling loads relative to information from the grid and weather forecasts, can reduce daily peak demand (and equally reduce overall energy consumption). Smarter ACs could also increase the share of space cooling met by variable renewables, for instance pre-cooling when power from solar PV peaks. This could be paired with storage capacity or used with multiple energy-efficient technology solutions in a district cooling network to achieve not only high efficiencies but also broader system benefits.

Similar solutions can be used to dampen the impact of electric space heating demand, moderating load peaking in the winter and improving the overall shape of load curves related to electric space heating. By 2050, the global buildings sector share of electric heat production accounts for about 19% of space heating energy consumption in the Faster Transition Scenario (compared to 13% in 2017). That growth, even with building envelope improvements and high-efficiency heat pumps, could increase the magnitude of peak electricity demand if unmanaged. For example, the shift from a gas boiler to an electric heat pump (assuming a seasonal efficiency factor of around 3.2) in a traditional multi-family apartment building in Europe could triple early morning electricity use and nearly double the demand in the early evening, even if the peak of the overall heat load profile is improved compared to the former gas boiler (Figure 2.15).

Figure 2.15. Example weekday electricity load profile for an apartment in continental Europe and overall heating profile for Europe in the Faster Transition Scenario, 2050



Notes: This example of a residential electricity profile represents a family living in a multi-family apartment building in a European continental climate (Delmastro et al., 2016). The gas profile and electricity profiles refer to space and water heating demand only. The shape of the electricity profiles by end-use for Europe was derived using typical building demand load profiles with an illustrative example of the load curve using smart heat pump technologies.

Efficient equipment will dampen the impact of electrification of space heating, but better demand-side measures are required to shift demand from peak load hours.

Applied across millions of households, such a peak load demand is even more problematic. For instance, a 50% penetration of unmanaged heat pumps for space heating in the United Kingdom would potentially increase national electricity peak loads by as much as 60% in 2050 (Eggiman, Hall and Eyre, 2019). In the Faster Transition Scenario, more than 45% of space and water heating equipment in the European Union is electric by 2050, compared to 25% in 2017. Unmanaged, even if the majority is high-efficiency heat pump technologies, peak load on a typical January weekday could require as much as 68 GW for heating (or 12% of the daily peak) during the evening peak and as much as 69 GW during the morning peak (or 18% of the morning peak load).[9]

Peak demand has important consequences for electricity systems, especially at the distribution level (McKenna and Thomson, 2016). Serving peak load demand is particularly costly. It is also often not well paired with electricity generation from variable renewable sources, and so requires installation and maintenance of additional generation units to meet demand. Such reserve units tend to operate with low efficiency related to ramp up of generation and can translate into higher consumer electricity prices. To effectively manage electrification of space heating and cooling and avoid major peak loads for electricity systems, three measures are pursued simultaneously in the Faster Transition Scenario:

[9] That peak load is still less than it would be with poor building envelope performance and use of conventional electric resistance heaters.

- Capturing efficiency potential through enhanced envelope measures (e.g. deep energy renovation of existing buildings) and high-performance equipment.
- Using building controls such as sensors and smart thermostats to better manage, distribute and improve responsiveness of heating and cooling loads, both temporally and within the building space.
- Taking advantage of thermal inertia (i.e. how quickly a building losses or gains heat) and other storage solutions to both reduce and shift electricity loads to off-peak hours.

Reductions of space heating and cooling needs through improved envelope performance and much higher equipment efficiencies help reduce electricity demand in the Faster Transition Scenario. This is particularly reflected in the share of useful heat provided by heat pumps: electricity is responsible for less than 20% of space heating energy consumption in 2050 but is responsible for more than 40% of useful heat production in buildings. The electricity demand needs to be better managed and be flexible in order to enable the widespread deployment of renewables in the electricity system and improve electricity flows across the various energy sectors.

Demand-side flexibility is enhanced with the use of smart and responsive building controls and equipment. This can be as simple as programming gradual power ramp-up before building occupants wake in the morning or using more complex tools such as artificial intelligence in building energy management systems to manage and mitigate peak electricity load profiles. Globally, digitalisation of end uses in buildings could reduce energy demand by more than 10% by 2050, while enabling demand-side response for as many as 1 billion households and 11 billion smart appliances (IEA, 2017a). The "Rush Hour Rewards" project in the United States delivered an average reduction of AC load of 55% during peak hours (BPIE, 2016).

Additional demand-side response is available from exploiting the thermal mass of buildings to temporarily displace or store energy. This can be as simple as using a connected device such as a smart thermostat to shift demand profiles and subsequent electricity use, for example to take advantage of low-cost surplus renewable electricity (Romero et al., 2018). It can equally be through more formal storage solutions. For example, a residential heating system in United Kingdom using a connected 8.5 kilowatt capacity heat pump linked to a 180 litre water storage unit could shift nearly 15% of peak heating load to off-peak hours on a typical winter day (Renaldi, Kiprakis and Friedrich ,2015).

The integration of heat and electricity networks can extend demand-side management opportunities in buildings. In the case of district energy networks, for example, flexibility can be enabled using both the thermal inertia of buildings and the network, or eventually using district level or on-site integrated storage. This pairing can exploit excess electricity (e.g. to avoid curtailment or renewable electricity production) through large-scale heat pumps in the district energy network, enabling synergies across network infrastructure. For example, the estimated energy flexibility of an office building served by a district system in Sweden using integrated heating measures could shave around 35% of annual electricity consumption (Zhang et al, 2018). Potential power to heat in Sweden using integrated solutions could unlock as much as 0.4% to 19.3% (or 0.17-0.74 Mtoe) of building district heat consumption in Sweden, depending on the specific conditions of the district heat system and the technology choice (Schweiger et al., 2017). At the district energy scale, the "ectogrid" technology combines heat pumps and cooling equipment with a local thermal energy distribution network, which is used for storage and system flexibility (Ectogrid, 2018). In the Medicon Village in Sweden, for example, the "ectogrid" is working to balance energy flows of 15 commercial and residential buildings to optimise overall energy supply needs by reusing available thermal energy from those buildings.

The current energy use for heating and cooling in the buildings (about 14 GWh) is expected to decrease 70% or more through the technology coupling and system balancing.

The clean energy transition will be borne out at the local level

Rapid progress is needed in the Faster Transition Scenario to achieve high-performance construction and deep energy renovations in buildings that reduce the sector's overall energy demand and carbon intensity. Buildings sector strategies need to consider the appropriate and cost-effective technology options to meet energy needs with respect to building type, location, climate factors and occupant profiles. For example, deep energy renovations may be cost prohibitive or technically difficult for certain vintage building types, but modern district energy solutions may be more feasible to achieve net zero carbon emissions in those buildings. Building energy renovations (and subsequent reductions in heat demand) would need to be planned with respect to strategies around decarbonising district energy networks (e.g. to avoid major impacts on the cost-effectiveness of providing heat if demand densities are too low).

The interactions between and across various technical considerations to achieve an efficient and low-carbon buildings sector are generally borne out at the local level. For instance, the most cost-effective energy savings and emissions reduction for buildings served by district heat in Stockholm are most likely to be achieved through moderate levels of building renovation coupled with zero-carbon district heat investments (IEA, 2016). In other district energy networks, achieving zero-carbon district heating may require greater co-ordination of building energy performance improvements, for example to lower heat demand intensity and enable greater use of flexible or renewable heat inputs.

Strategies identified at the global and national level, while useful in putting forward expectations around the strategic direction of the clean energy transition for buildings, need to be considered in further detail at the local level, where technical solutions are site specific (Box 2.5). The strategies will be most effective if considered in a local energy context, where building solutions (e.g. high-performance ACs) may not be in sync with broader energy considerations (e.g. electricity production from variable renewables). This should be enabled and supported by national and regional policy frameworks, where proper planning strategies, stakeholder engagements and energy mapping activities can help identify local building solutions, reconcile potential issues across technical solutions and energy needs, and ensure flexible, cost-effective technology measures for a low-carbon and energy-efficient buildings sector. The IEA Technology Collaboration Programme (TCP) on Energy in Buildings and Communities (EBC) is developing several relevant projects in this area to improve understanding and implementation of local level actions. The IEA EBC TCP has also established a working group on cities and communities to improve decision-making practices within cities.

Box 2.5. Integrating buildings sector strategies within local energy planning

Energy system analyses for generating explorative or normative scenarios can support local decision makers in selecting cost-effective options to meet buildings sector energy demand. In the assessments, buildings are typically represented through typologies or reference examples that represent the average characteristics of the buildings stock, geographic location and related energy performance conditions (Corgnati et al., 2013). This can be linked to mapping and visualisation techniques (e.g. geospatial tools) to support the implementation of a comprehensive decision platform for the definition of economically affordable and environmentally sustainable energy plans.

One example is the Integrative Smart City Planning (InSmart) project in which an integrated energy systems approach is being tested directly in four European cities in Greece, Portugal, Italy and the United Kingdom (InSmart, 2017). The participative multi-model procedure supported the definition of the Sustainable Energy Action Plans for each city, identifying cross-sectoral and cost-optimised measures through which buildings exploit possible synergies with other energy sectors. This approach is rarely incorporated into the decision-making process and could help cities to improve planning practices and clean energy transition strategies. Encouraging greater utilisation of such approaches might improve co-ordination of national climate ambitions with local actions.

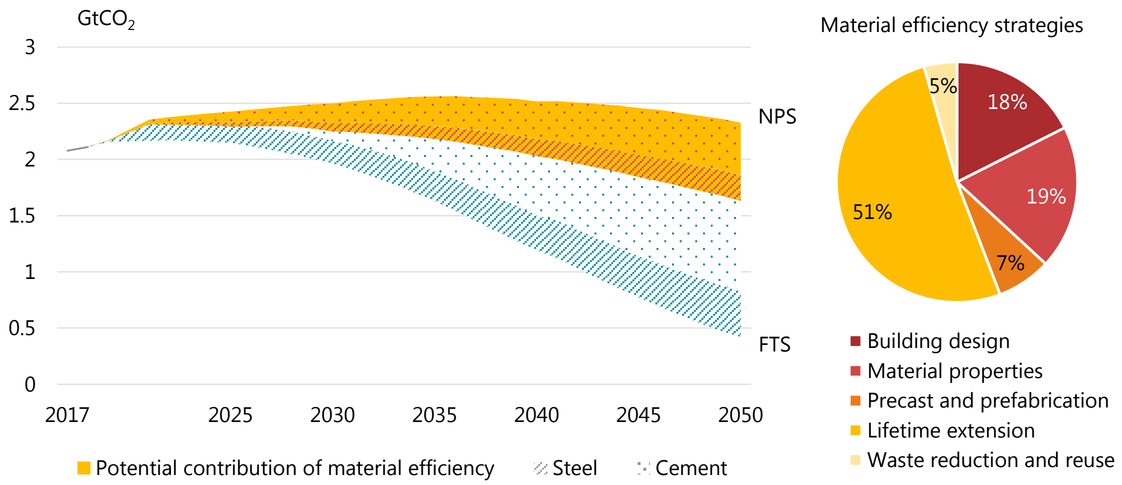
Sustainable construction can support greener industry

Demand for materials in the buildings sector represents a substantial portion of global energy-related emissions. Globally, cement and steel consumption for construction of buildings accounted for slightly less than 2 $GtCO_2$ in 2017 (IEA, 2019). With floor area expected to nearly double by 2050 globally, the burden of demand the buildings sector will place on industry will impact strategies and investment to decarbonise materials manufacturing. Better building practices and material efficiency strategies can therefore play a strong role in improving those carbon-intensive industries. Switching to low-carbon building frames such as wood or bio-sourced materials may also reduce CO_2 emissions, but broader considerations must be taken into account such as resource availability and sustainable allocation across all energy sectors.

Reinforced concrete and steel frames underpin most of today's global buildings construction, although other materials may dominate specific markets such as wood for single-family dwellings in the United States or local materials in sub-Saharan Africa. With increasing urbanisation and more high-rise buildings, cement and steel will likely continue to be preferred construction materials in the future, and around two thirds of new builds in the Faster Transition Scenario are projected to have reinforced concrete or masonry frames, while 5% (particularly non-residential buildings) are framed with steel. As a result, cement and steel demand increases by 35% over current levels by 2050. India accounts for nearly half of that growth.

The Faster Transition Scenario relies on significant industry sector investment to upgrade cement and steel production processes, improve manufacturing yields and deploy carbon capture, utilisation and storage (CCUS) technologies to reduce emissions intensity. These ambitious measures cut the CO_2 intensity of material manufacturing by roughly 80% for both steel and cement by 2050, which leads to a drop in emissions related to cement and steel use in buildings to 420 $MtCO_2$ in 2050 (Figure 2.16).

Figure 2.16. Emissions reduction from cement and steel use in buildings using material efficiency strategies, 2017-50



Note: The carbon abatement potential of material efficiency strategies is considered outside the Faster Transition Scenario trajectory and is illustrative of the potential emissions reduction achieved through those buildings and construction material demand strategies.

Material efficiency measures could reduce upstream emissions from cement and steel use in buildings by 23% and support decarbonisation of those industries.

While more efficient and low-carbon manufacturing of materials is central to reducing the carbon footprint of industry, other opportunities in the buildings sector could alleviate part of the industry effort. For example, cost-effective material efficiency strategies, leveraged across the buildings and construction value chain, could lower material-related emissions by 23% and avoid on average as much as 370 $MtCO_2$ of emissions per year until 2050. In fact, applying material efficiency strategies in the buildings sector represents around 38% of emissions reduction from cement and steel manufacturing in the Faster Transition Scenario. That would support the decarbonisation of industry not only by reducing needs for material production but also by lessening the need for specific measures such as CCUS in order to achieve industry CO_2 abatement.

Material efficiency strategies in buildings would be particularly effective to decrease CO_2 emissions from cement production. The lack of maturity and uncertainties around low-carbon cement production processes translates into a delayed and lower reduction of the carbon intensity of cement production in the Faster Transition Scenario. As the need to capture process emissions from cement calcination in particular is a barrier to achieving Faster Transition Scenario ambitions, reducing overall cement demand from buildings would lower the need for carbon abatement and lessen other environmental impacts from cement production (e.g. by alleviating pressure on sand extraction). Reducing steel demand from buildings could avoid as much as 230 $MtCO_2$ in 2050, even if decarbonising steel production is currently more promising than cement.

Material efficiency strategies in buildings typically have a limited upfront cost. This is especially true for measures that can be incorporated at the design phase, such as improved architectural specification of material needs. Material-oriented optimisation in building design could reduce steel and cement demand by as much as 15-35%, depending on the building frame and height. Integrating adaptive capacity and durability into building design is another strategy that could improve material demand at reasonable costs. For example, building lifetime extensions (and subsequently lesser need for new buildings) could be achieved in the design stage if buildings were conceived to be modular and adapt to changing activities over time.

During construction, on-site management could reduce cement waste rates from 5-7% today to 4-6%, depending on the market. These reductions could be achieved through relatively simple and cost-effective management practices. Further savings could be achieved by integrating alternative and improved materials, potentially reducing cement content in concrete by 20% while achieving equivalent structural properties, depending on building height.

Further measures can be taken to improve building material efficiency, including precasting and prefabrication that would facilitate the uptake of design, material-based and waste reduction strategies while also allowing for increased material recycling and reuse. The industrialisation of material-efficient construction processes can enable appropriate scaling up of production, helping to lower costs. Digital machinery and tools also would provide better control over building material and component production. This includes tracking tools that can allow construction companies to define, monitor and achieve waste reduction targets.

Technology and design are at the heart of the clean energy transition

Capturing the enormous energy savings potential worldwide in the buildings sector would deliver a broad range of benefits, including improved energy services in buildings, as well as significant reductions in CO_2 emissions and other pollutants that pose a threat to human health. Achieving the clean energy transition requires an unprecedented effort to develop and deploy energy-efficient and low-carbon technologies for use in the buildings sector. The positive news is that high-efficiency and low-carbon energy technology solutions already exist in most markets, and they very often are cost-effective over the lifetime of the product.

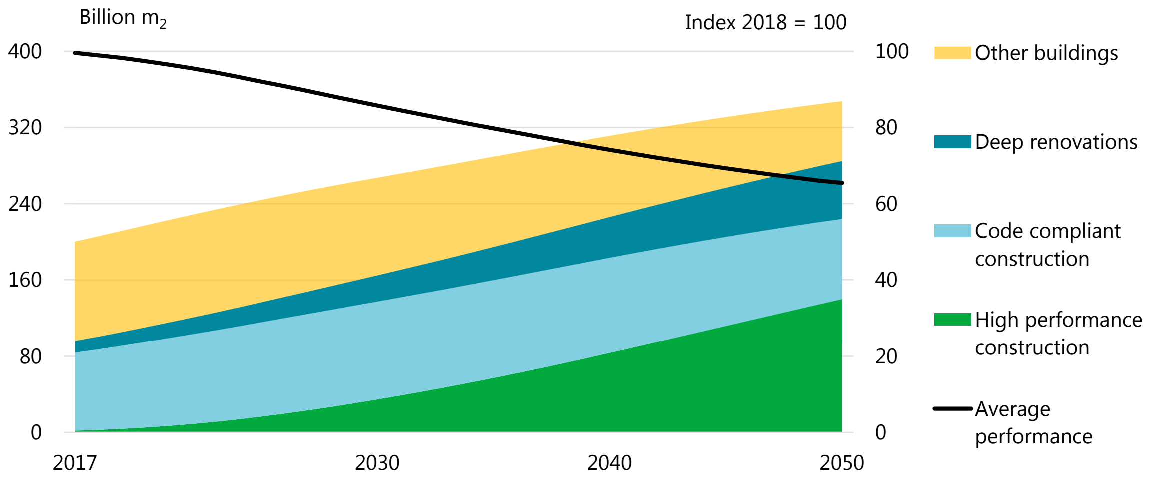
Significant improvements in buildings sector energy and carbon intensity are achieved in the Faster Transition Scenario through a combination of clean energy technologies, ranging from near-term opportunities like LED lighting to critical long-term measures such as high-performance building envelope improvements. Technology choices need to be supported by swift and effective action to expand and strengthen existing policies and regulations for energy-consuming equipment in all countries to cover the vast majority of end-use equipment in buildings (see Chapter 3). This would drive the demand for and adoption of efficient technology solutions, while also helping to drive down costs, boost affordability and reduce energy consumption and emissions in the buildings sector, despite expected growth in global population and buildings sector activity.

A portfolio of clean energy solutions are available today

Building envelope improvements are essential

Improved building thermal performance in the Faster Transition Scenario accounts for more than 40% of the energy savings potential from space heating and cooling in buildings to 2050. By 2050, high-performance and near-zero energy buildings become the construction norm globally, with standards fit to national, regional and local conditions. Renovation rates, both in terms of number of retrofits and depth of energy performance improvements, double globally and dramatically reduce energy demand for heating and cooling services. The net result is a 35% improvement in the average thermal performance of the global building stock by 2050 relative to 2017 (Figure 2.17).

Figure 2.17. Buildings sector by building type, 2017-50



Notes: Surfaces heated by traditional solid biomass are excluded. A net performance improvement of 35% for the global buildings stock means that improvement in new construction must be even higher (because of slow stock turnover).

Deep energy renovations and high-performance construction mean the average thermal performance of the global buildings stock improves on average by 35% by 2050.

Near-zero energy construction is a limited market today. Less than 5% of new buildings are built under a near-zero energy performance standard, with a few exceptions such as France, which has ambitious building energy codes mandating all new construction to be at the near-zero energy level. In the Faster Transition Scenario, high-performance and near-zero energy buildings make up more than half of new construction in 2030, with higher shares in advanced economies. Mandatory building energy codes are established in all countries in the coming decade in the Faster Transition Scenario, effectively meaning that all buildings construction globally will be covered by energy policies beyond 2030. Building energy codes and policies mandating energy renovations are expanded and strengthened in the following decade.

Depending on objectives set at the national, regional and local levels, the relevance of building envelope technologies may vary (Table 2.3). In countries with large heating loads, advanced insulation is key to reduce thermal losses. Architectural choices and building energy management systems also contribute to reduced thermal energy needs. Building envelope technologies for the clean energy transition.

In hot climates where cooling loads are set to increase substantially, reducing heat gain can be done through many low-cost and local material components, such as cool roofs and shading. Heat flows can be better managed, preferably through natural ventilation or with mechanical ventilation systems that manage air flow and reduce unnecessary cooling energy demand.

Table 2.3. Building envelope technologies for the clean energy transition

Targets	Examples of building envelope solutions in the Faster Transition Scenario
Reduce thermal losses **(especially in cold climates)**	• Advanced insulation, including reduction of thermal bridges, air sealing, foam sprays, aerogel panels, external wall cladding, double- or triple-pane windows (Historic retrofit of the De Schipjes housing zone, Belgium) • Diagnostics such as thermographic measurements for assessment of thermal bridges, air tightness and effects of external urban elements (Commercial streets of Seoul, Republic of Korea) • Ventilation with heat recovery units to manage air exchange with minimal heating losses (University Arms Hotel, Cambridge, United Kingdom)
Reduce heat gains **(especially in hot climates)**	• Low-cost components including controllable shutters and blinds, cool or green roofs, exterior shading and reflective colours on façades (Mario-Hoarau de bois de Nèfles, La Réunion, France) • Architectural choices including building orientation, wall-to-window ratios or innovative façade designs (O-14 building, Dubai, United Arab Emirates)
Control heat flow **(especially in mixed climates)**	• Managing heat gains and losses with low-emissivity windows (Devon Energy Center, Oklahoma City, United States) • Smarter ventilation using better building design for natural air flow or minimally using mechanical ventilation with sensors and controls (Cilincing District, North Jakarta, Indonesia) • Improved thermal inertia including potentially integrated thermal storage or advanced phase changing materials (Royal FloraHolland office building in Naaldwijk, Netherlands)
Manage energy demand **(in all climates)**	• Building energy management through sensors, equipment controls and other systems optimisation tools (e.g. learning algorithms) (Energy Centre, Turin, Italy) • Demand-side management, energy consumption monitoring and optimisation of storage capacities based on energy prices or incentives (Senior Center, City of Hawthorne, Los Angeles)

Note: This list is not exhaustive and building technology solutions listed here may be applicable for other purposes and for different building types or climatic conditions.

In mixed climates with both space heating and cooling loads, the multiplicity of seasonal constraints requires solutions to address both. For example, low-emissivity windows can reflect solar radiation during the summer to minimise heat gain as well as reflect radiative heat from the inside during winter to minimise heat loss.[10]

Additional building envelope solutions include more advanced solutions such as dynamic or electrochromic glazing for windows or phase change materials that could increase thermal inertia. However, payback times for some of these options currently are longer than 8-10 years and require further R&D to bring them to mass market (Navarro et al., 2019; Lizana et al. 2018; Arteconi, Hewitt and Polonara, 2012). The IEA EBC TCP started a project to establish the long-term performances of superinsulation materials with demonstration projects. The

[10] Low-emissivity windows make sense for nearly all climates. For more information on building envelope technologies see: https://webstore.iea.org/technology-roadmap-energy-efficient-building-envelopes.

project also aims to raise awareness on the potential of such technology and to develop guidelines for their correct installation (IEA EBC, 2019).

Space heating and water heating intensities can be substantially improved

Energy savings from space and water heating in the Faster Transition Scenario amount to 460 Mtoe in 2050, the equivalent of Russia's total energy consumption in 2017. Space and water heating account for 30% of CO_2 emissions reduction. To achieve this, the Faster Transition Scenario depends on substantial improvements in the energy intensity of heating in buildings.

Conventional coal and oil heating technologies (with efficiencies typically below 80-85%) are gradually phased out over the coming decade. Conventional gas boilers (generally below 85% efficiency) are phased out by the early 2030s. By 2040, nearly all remaining fossil fuel use for heating is either gas heat pump technologies (with efficiency factors typically between 1.2 and 1.4) or condensing gas boilers that retrieve the latent heat of exhaust gases through water vapour condensation (performance around 0.95 or higher). Electric resistance heaters (efficiency factor of 1.0) are also progressively replaced with more efficient equipment, such as electric heat pumps. By 2050, conventional electric equipment only makes up around 10% of global sales, mostly for occasional or nominal heating needs like small instantaneous hot water units.

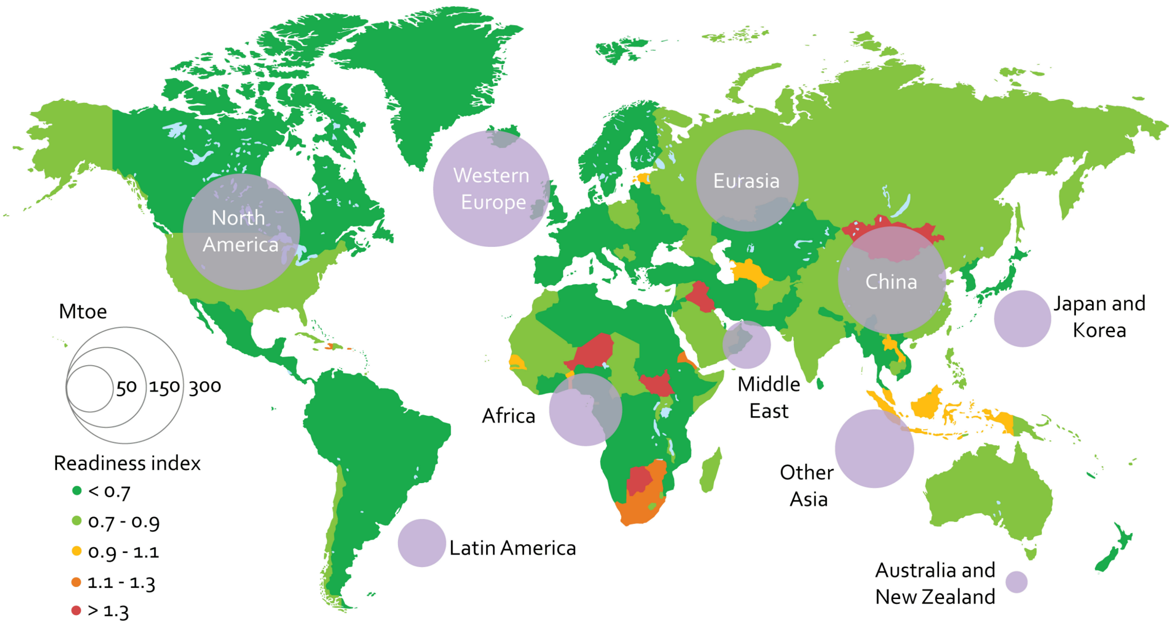
Heat pumps are the dominant heating technology worldwide by 2050. Market scale and innovation increase their average efficiency to nearly 4.0, which equally helps generate quicker return on investment. Improvements can also include optimisation of storage capacities with hot water production using heat pump technologies to avoid high utilisation of electric resistance integrative heaters (Lizana et al. 2018; Renaldi, Kiprakis and Friedrich, 2017). In the Faster Transition Scenario, heat pump sales increase threefold by 2030 and around one billion households rely on them for space heating in 2050. That shift drastically improves the carbon intensity of heat production in buildings out to 2050, especially as the power sector decarbonises. In fact, heat pumps are already less CO_2 intensive than gas boilers in most major heat markets today, including North America, Eurasia and China (Figure 2.18). Globally, heat pumps already can supply about 90% of space heating demand with a lower carbon footprint than condensing gas boilers.

Heat pump market penetration in the Faster Transition Scenario is uneven, depending on overall building heating needs, energy prices and the availability of heat sources, such as district heat. Penetration rates are generally highest in moderate climates (all the more since reversible heat pumps can provide both heating and cooling) such as the United States and Western Europe, where they represent above 50% of sales in 2050. This is more nuanced, however, as many buildings in those same regions may also switch to renewables or district energy systems, depending on building type, location and other considerations (e.g. lack of space for an exterior heat pump unit).

In some markets, for instance in Russia, Northern Europe and Canada, increased adoption of modern biomass stoves (10-20% of the market in 2050) and gas thermal heat pumps (25-30%) may be more attractive, particularly given local availability and prices of those options. By 2050, the average global efficiency of biomass stoves increases notably from around 45% or less today to 70% or more in 2050, while gas heat pumps drive average gas equipment performance globally above 110%.

In other regions, especially where hot water dominates heating needs in buildings, the share of solar thermal heating rises substantially. In regions with high solar irradiance such as the Middle East, Southeast Asia and Mexico, solar thermal reaches 25-40% of heat production.

Figure 2.18. Heat pump readiness index relative to regional heating demand, 2017



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Notes: The heat pump readiness index takes into account the carbon intensity of electricity and compares the CO_2 footprint of market median heat pump seasonal performance (e.g. roughly 3.0 for Western Europe) relative to high-performance condensing gas boiler technology with an efficiency of 95%. If the index equals 0.8, heat pumps would be around 20% less carbon-intensive than a condensing gas boiler.

Today heat pumps could supply around 90% of heating needs with a lower CO_2 footprint than gas boilers, particularly in major heating markets such as Canada, China, Europe and the United States.

The Faster Transition Scenario also favours the deployment of integrated options for enhanced flexibility and broader energy system benefits. District heating represents around 13% of global heating and hot water energy use by 2050, enabling the use of surplus electricity production from wind and solar. Large-scale heat pumps for district energy systems reach higher efficiency levels, with seasonal efficiency factor typically around 4.0 and up to 7.0 when using waste heat (EHPA, 2017). Their deployment in the Faster Transition Scenario unleashes additional thermal storage capacity to manage better daily variations in energy supply, which complements power-to-gas seasonal flexibility.

Space cooling services can improve without major energy demand increases

Over the next 30 years, as many as ten ACs may be sold every single second, leading to a potential tripling of global AC energy demand if measures are not taken to address AC energy performance (IEA, 2018b). In the Faster Transition Scenario, however, cooling demand is met using highly energy-efficient ACs, which helps save an average of 1 500 TWh of electricity every year until 2050, or more than half the total electricity consumed by the European Union in 2017. Improved system design (e.g. connecting ACs to roof top solar and cold water or ice storage) would also help to address the challenge.

In the Faster Transition Scenario, the energy performance of ACs increases nearly 50% by 2030 to tap into the energy efficiency potential already available in most markets today. By 2050, the average performance of ACs nearly doubles relative to today, thanks to measures to bring best-available technology to markets and further innovation to address equipment performance (e.g. operational efficiency at low loads). Additional improvements include better treatment of latent and sensible loads, for example using solid or liquid desiccants to reduce water vapour content (latent load) separately from dry air (sensible load).

Additional options not considered in the Faster Transition Scenario include technologies that can meet cooling demand outside the conventional electric vapour-compression cycle. For instance, a fluid heated by renewables could drive the thermodynamic cycle instead of an electricity-powered compressor. Thermally driven heat pumps (e.g. absorption and adsorption chillers using renewable heat) can also achieve high efficiencies, depending on operating conditions and system complexity. New designs show a potential to reduce today's cost by 30% (IEA SHC, 2018). These technologies, among others, can equally be applied at the district level, taking advantage of multiple energy inputs and cold storage (e.g. chilled water or ice storage) to enable increased system flexibility and overall energy performance.

Ensuring the efficient production of hot air, hot water and cold air (i.e. tri-generation) reduces cost for the multiple services provided. For example, the IEA TCP on Heat Pumping Technologies and the Energy Storage through Energy Conservation TCP are developing a "comfort and climate box" that aims to make integrated heating and cooling solutions marketable, affordable, efficient and responsive to signals from the grid. In addition, the IEA EBC TCP started a new research annex to quantify the benefits of different technology solutions by country and building typology, ranging from various building envelope measures to different technology choices to achieve energy-efficient and low-carbon cooling services (IEA EBC, 2018).

Appliance and lighting efficiency gains are ripe for the taking

Appliances and lighting account for 35% of electricity demand growth to 2050 in the Faster Transition Scenario. Despite rapid growth, particularly in emerging economies, energy-efficient lighting and appliances generate 1 300 TWh of energy savings relative to the New Policies Scenario in 2050.

One of the most prominent trends of the Faster Transition Scenario is the accelerated deployment of LED lighting technologies in the next decade. While LEDs represent a third of global lighting sales today, they reach 80% by 2030 and more than 95% by 2050. Rapid adoption of MEPS (which have not been updated in most countries since the late 2000s) leads to a rapid ramp-up in the adoption and energy performance of LEDs sold in the markets. By 2030, the efficiency of LED sales reaches 150-160 lumens per watt (lm/W), nearly as high as best-in-class products available on shelves today (about 160-180 lm/W). This continues to improve to 180 lm/W or more by 2050.

LED performance improvements also generate significant savings from televisions. The on-mode power of LED liquid-crystal displays varies greatly today, from 0.02 Watts per square centimetre (W/cm^2) to 0.009 W/cm^2. Capturing that twofold difference (outside other potential evolutions in the ever-changing television market) can limit energy growth for a rapidly increasingly television stock, which is anticipated will increase almost twofold to reach

4.8 billion units worldwide by 2050. By contrast, energy use for televisions only increases 6% in 2050 in the Faster Transition Scenario.

Efficiency gains from major household appliances, small plug-loads and electrical equipment could save an additional average of 260 TWh per year in the Faster Transition Scenario, or nearly 8% of their consumption level in 2017. Rapid energy efficiency gains, supported by MEPS that push markets to best-available technologies in the coming decade, and further technology advances (e.g. vacuum insulated panels for refrigerators and heat pump technologies for dishwashers and dryers) along with better design (e.g. larger capacities to clean more clothes with the same number of cycles) help to deliver increasingly more efficient products to 2050.

The share of small plug-loads in total energy use continues to increase to 2050 in the Faster Transition Scenario. Despite efforts to regulate on-mode and standby power of the most widespread devices (e.g. portable computers and smartphones), their diversity and complexity make it difficult for energy efficiency policies to keep up. Further digitalisation of building energy services promises to enable more flexibility and eventual energy savings of the connected devices, but also risks increasing electricity demand (Box 2.6).

Box 2.6. Digitalisation and the potential proliferation of building plug-loads

In the Faster Transition Scenario, active controls (or energy management systems ensuring that energy services are delivered at the right time and place) reduce energy demand in buildings by around 10%. The most straightforward applications are occupancy and daylighting sensors for heating, cooling, ventilation and lighting systems, for example that turn off or dim lights based on occupant needs and daylight conditions. Connected and smart thermostats (e.g. with learning algorithms) could also save as much as 15% or more of heating and cooling energy demand with real-time information such as weather forecasts and predictive energy behaviour. Further savings are possible, but may be limited to active controls in non-residential buildings, partly due to higher commercial interests in energy management and more predictability of energy use patterns.

Digitalisation and the rapid proliferation of connected devices risks driving up energy consumption in buildings. In addition to the energy consumption for network-connected devices, the wide range of data requires substantial energy use for components such as data networks, which consumed between 115 and 250 TWh in 2017. That information, along with improving analytical tools for and in buildings, can help capture energy efficiency opportunities in the Faster Transition Scenario. For example, regulators can use multiple sets of energy consumption data (measured on-site) to understand better market dynamics when they define or upgrade performance standards. Labelling programmes could also capture the actual energy performance of building equipment during operation, providing better information to consumers when choosing equipment.

Real-time data can also be used to identify product failures or other exceptions in the energy performance of technologies. Utilities are developing initiatives that allow third parties such as customers, building managers, academic researchers or local governments to access energy data for analysis and support. Among other applications, the analysis of building energy data and other information relative to demographics, consumers and neighbourhoods, improves conventional energy audits to deliver more energy savings. These applications, paired with better market conditions, favour improved demand-side flexibility and sector coupling. To enable this, policies need to adapt legal frameworks for market design, both for electric and thermal energy markets.

Cooking is both an efficiency and an access issue

Energy consumption for cooking in 2050 decreases by 11% compared to 2017 and represents nearly 20% of buildings energy use globally in the Faster Transition Scenario. This trend is essentially due to shifting from the traditional use of solid biomass in developing countries. This is both an energy efficiency issue (traditional use of solid biomass for cooking typically has an efficiency of less than 5%) as well as an energy access issue, which represents a major ambition under the Sustainable Development Goals to achieve universal access to modern energy for all by 2030. It also helps to reduce significantly the 2.6 million premature deaths due to energy-related household air pollution (IEA, 2018c).

Energy efficiency improvements, such as induction cooking technology, also help to diminish growing electricity demand for electric cooking, which almost triples by 2050 in the Faster Transition Scenario, even with efficiency gains. Today, around 1 billion households use oil or natural gas for cooking. Yet, less than 50% of the energy consumed by an oil or gas stove is used to cook the food, and the other half is lost through heat to the ambient air. The efficiency of smooth-top electric hotplates approaches 75% while induction plates are the highest energy performing products (around 90%), as changing magnetic fields generate heat through the cookware directly (ACEEE, 2014).

In the Faster Transition Scenario, gas cooking declines to around 3% of energy use for cooking in 2050 and is mostly in areas with existing gas distribution infrastructure. Coal and oil are progressively phased out, as 450 million households switch to more efficient electric cooking. Traditional use of solid biomass, aided by electricity access improvements and other shifts to cleaner cooking in Asia and Latin America (e.g. liquefied petroleum gas), drops by 25%. However, in Africa, nearly 220 million households still rely on traditional use of solid biomass in 2050, even more than today, outlining the need for policies that address more than simply carbon abatement (Box 2.7).

Box 2.7. Access to energy and clean cooking facilities

In 2017, around 3 billion people used open fires or polluting stoves for cooking, despite significant energy, health, environmental and social consequences. In particular, household air pollution from the combustion of solid fuels is responsible for around 2.6 million premature deaths each year (IEA, 2018c). Most of the population without access to clean cooking use traditional solid biomass such as wood, animal dung or crop waste, while others rely on kerosene or coal. In addition, people without access to modern energy services spend an average of 1.4 hours per day collecting fuel, which often hinders the professional and personal development of women and can limit opportunities for children to go to school (IEA, 2017b).

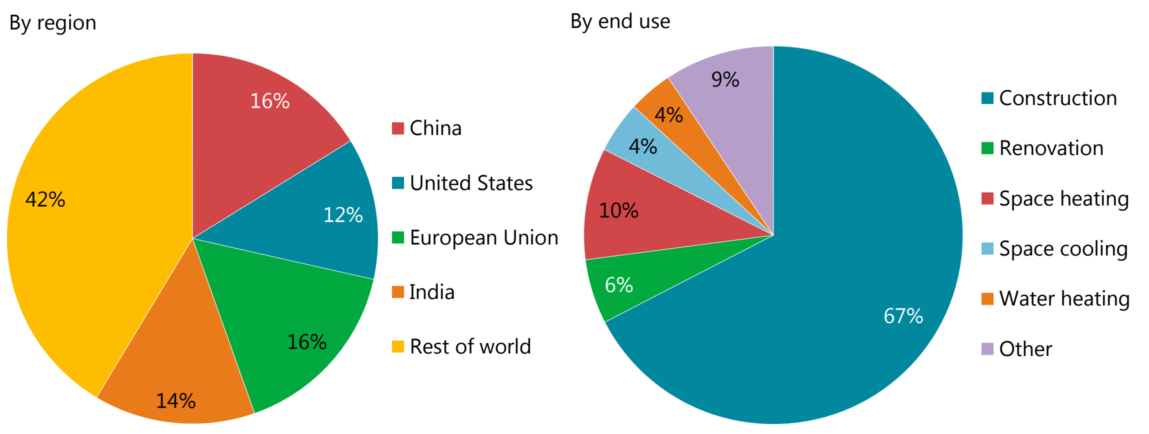
Without more ambitious policies, 2.3 billion people remain without access to clean cooking in 2030. Deployment of modern cookstoves using liquefied petroleum gas, natural gas and electricity could deliver on multiple Sustainable Development Goals with limited additional investment and no increase in global CO_2 emissions (IEA, 2017b). The achievement of clean cooking for all by 2030 does however require major transformations of business models (e.g. combining off-grid solar PV with energy efficiency services), energy networks (e.g. with a complementary deployment of on-grid, mini-grid and off-grid solutions), finance mechanisms (e.g. reducing upfront costs through pay as you go pricing) and stakeholder engagement (e.g. involvement of local communities and women). For more information, see: www.iea.org/energyaccess.

Investment for the clean energy transition in the buildings sector

Investing in sustainability pays for itself, but depends on energy prices

Total investment in the global buildings sector in the Faster Transition Scenario increases from around USD 4.9 trillion in 2017 to more than USD 5.4 trillion in 2050. More than 70% of the investment is for building construction and renovation (Figure 2.19). Heating and cooling (including hot water production) equipment represent 18% of cumulative investment to 2050, or more than two-thirds of the non-envelope portion of investment projected in the Faster Transition Scenario.

Figure 2.19. Capital expenditure in buildings to 2050 in the Faster Transition Scenario, by region and end use



Note: Capital expenditure includes costs related to construction, renovation and purchase of new energy-consuming equipment for new builds and for replacements in existing buildings.

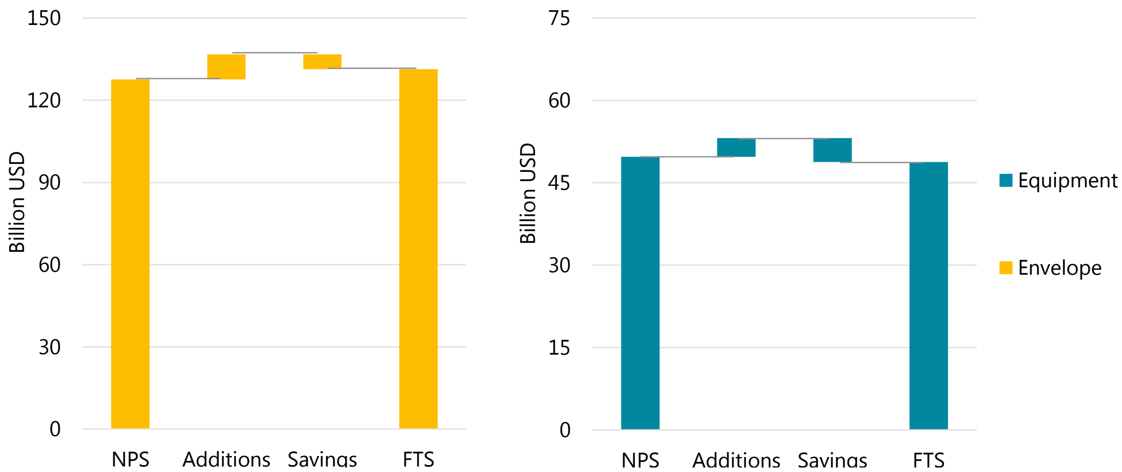
The bulk of investment in the buildings sector to 2050 is for high energy performance construction and renovation, and energy-efficient, low-carbon heating and cooling account for an additional 18%.

Nearly 60% of investment in the buildings sector in the Faster Transition Scenario is in China, India, the European Union and the United States, which collectively represent 55% of global floor area and half of total buildings energy consumption in 2050. The allocation of the investment differs. The European Union and United States spend more on renovating building envelopes and replacing heating equipment, given the large stock of existing buildings and the substantial stock of equipment that will need replacing in the coming decades. China also spends an ample share on building renovations (around 6% of cumulative investments to 2050), but the bulk of those are made after 2030, as new building additions continue to slow down in the 2020s and China moves to renovate and rebuild the roughly 30 billion m^2 of floor area built prior to 2000. In India, new construction represents around 80% of cumulative spending to 2050, as floor area is projected to nearly quadruple.

Buildings sector investment in the Faster Transition Scenario represents a significant shift away from fossil fuel use in buildings, with the annual spending on equipment using coal, oil and natural gas being cut in four by 2050. Investment in renewables (solar thermal units and modern biomass equipment) increases nearly sixfold by 2050, while annual investment in heating pump technologies increases almost 15-fold, even with a near-40% reduction in estimated costs by 2050 as significant economies of scale encourage lower prices. Appliances and lighting investment increases by around 35%, compared with 2017, as economies of scale (supported by more stringent MEPS) and longer product lifetimes (especially for LED lighting) mean the net costs of delivering more efficient products does not come at a substantial cost, even with considerable growth in appliance ownership.

Overall, cumulative additional costs for energy-efficient and low-carbon investment for buildings in the Faster Transition Scenario are just over USD 14 trillion higher than in the New Policies Scenario – around three-times current annual world spending on buildings, but only around 10% higher (cumulatively) than what would have been spent otherwise (Figure 2.20).

Figure 2.20. Cumulative investment in buildings in the Faster Transition Scenario relative to the New Policies Scenario, 2018-50



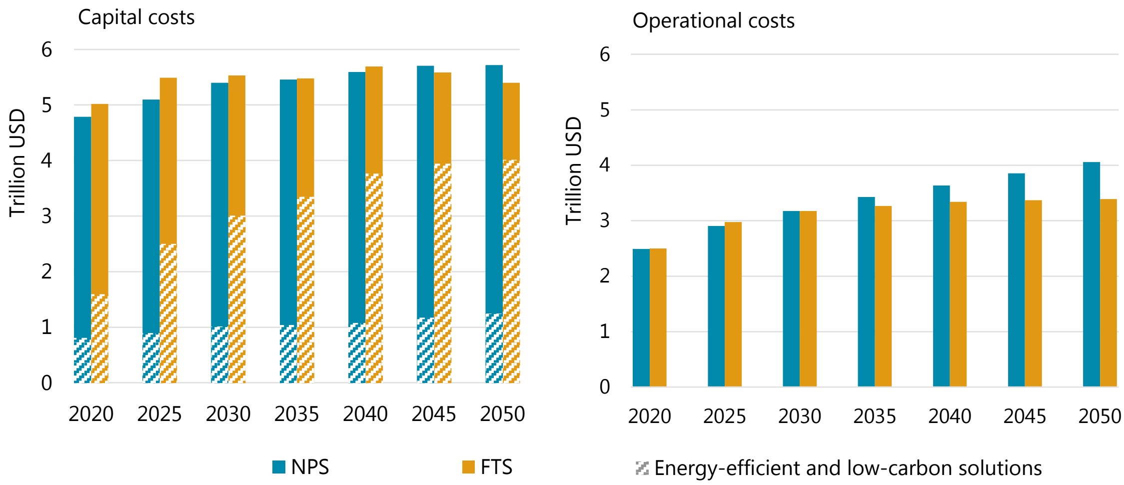
Notes: Investment is shown in 2017 USD.Capital costs represent the annual investments made in building envelope measures and equipment. Additional spending represents investments in energy-efficient and low-carbon buildings solutions above and beyond what would have been spent in the New Policies Scenario (NPS). Savings represents reductions in the overall cumulative investments due to improved lifetimes of investments in the Faster Transition Scenario (FTS), notably due to improved buildings construction and extended lifetime of building envelopes through deep renovation measures.

While capital investments increase over the coming decade in the Faster Transition Scenario, long-term savings in energy spending globally lead to net positive returns by 2050.

The overall increase is relatively marginal, thanks to economies of scale (supported by assertive policies and improved market frameworks) that bring high-performance solutions such as near-zero energy construction towards typical market prices. The additional investment is partially offset by longer lifetimes for buildings and equipment, where high- performance (and generally higher quality) buildings and products tend to last longer. For example, LEDs have lifetimes of around 30 000 hours, compared to around 10-15 000 hours for CFLs. Building energy renovations also help to extend the lifetime of buildings, resulting in greater upfront costs but long-term reductions in overall spending on construction (e.g. avoiding demolition and reconstruction before 2050 of stock built in the 2020s in emerging economies). Collectively, this leads to net cumulative investments to 2050 in the Faster Transition Scenario that only around 3.6 trillion USD (or roughly 2%) more than the New Policies Scenario.

The net additional costs in the Faster Transition Scenario are not spread even across the period to 2050, particularly as rapid deployment of energy-efficient and low-carbon solutions in the 2020s mean that global investments are between 5% and 10% higher (Figure 2.21). The higher upfront costs in the coming decade are reflected by a much higher share of energy-efficient and low-carbon technologies in total spending in the Faster Transition Scenario, which rapidly jumps from around 15% of spending today to nearly 50% by 2025. By 2050, those solutions account for more than three-quarters of total spending on buildings. Assertive policies, better market frameworks and resulting economies of scale help to bring these solutions towards average market prices by the 2030s. As a result, global investment is only around 1-2% higher spending in the 2030s, and by the 2040s moderates to 3-5% less than in the New Policies Scenario projections, particularly as improved buildings construction and renovation extend the lifetimes of buildings.

Figure 2.21. Annual capital expenditure and energy spending in the Faster Transition and New Policies scenarios, 2020-50



Notes: Investment is shown in 2017 USD trillion. Capital cost represents the annual investments made in building envelope measures and equipment; operational costs are the annual spending on energy in buildings. Costs are in constant 2017 USD.

While capital investments increase over the coming decade in the Faster Transition Scenario, long-term savings in energy spending globally lead to net positive returns by 2050.

The high-performance and low-carbon measures for the buildings sector in the Faster Transition Scenario result in global cost of operating buildings that falls compared to the New

Policies Scenario, where significant energy efficiency improvements lead to lower energy bills compared, even as the cost of clean electricity in the Faster Transition Scenario increases in some markets. Overall, global spending on energy in buildings in the Faster Transition Scenario grows to around USD 1.2 trillion per year in 2050, about 20% higher than in 2017 but about 20% less than in the New Policies Scenario in 2050. Over the entire period to 2050, spending on energy consumption is around USD 4.8 trillion lower than the New Policies Scenario in the Faster Transition Scenario – offsetting the net investment to 2050 and leading to total savings in capital and operational spending of USD 1.1 trillion. In a context of renewed interest to address growth of household energy expenditures, energy demand reductions in the buildings sector in the Faster Transition Scenario would equally allow global energy spending per household to remain approximately constant on the long-term, while delivering enhanced building energy services.

The majority of capital costs in the Faster Transition Scenario relate to building envelope measures. Long-term return on the investment depends on energy prices and the subsequent savings from lower spending on heating and cooling. In countries with low electricity or natural gas prices, achieving high-performance building envelope investments – even through appropriate economies of scale – will be challenging in terms of payback from savings in energy costs over the lifetime of those investments. For example, household natural gas prices in Canada and the United States (due to projected increased production and falling demand) remain relatively low in the Faster Transition Scenario to 2050. This means that deep energy renovation (e.g. a 30-50% improvement or better in building envelope performance) could have a payback period of 15-20 years or more, even at reasonable costs (e.g. 15-20% of the original building value).

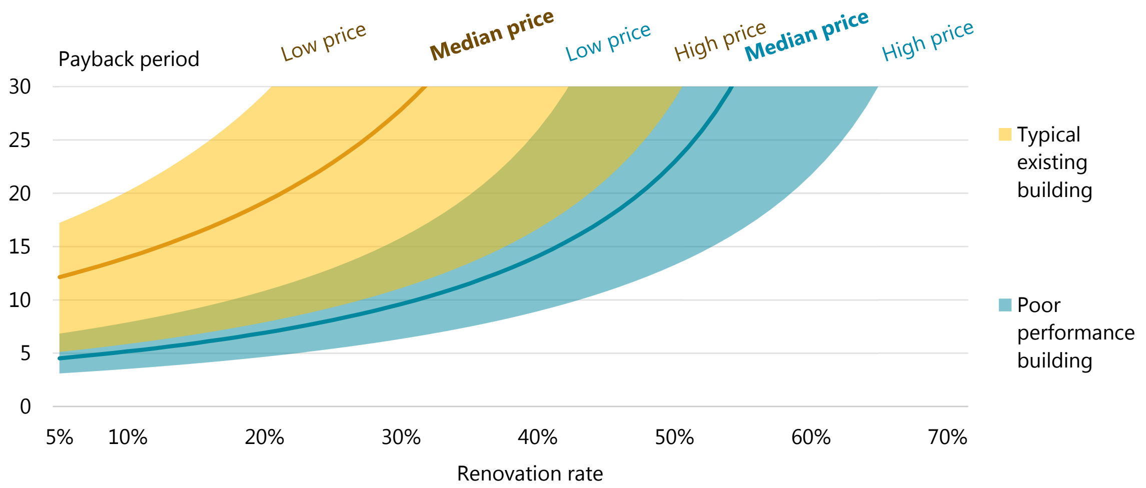
The macro-economic assessment of building energy efficiency and low-carbon investment needs to consider broader benefits than those quantified here. Thermal comfort, health and well-being, improved local air quality and other co-benefits can all bring economic value, for instance directly affecting productivity, medical expenses or building maintenance needs. Green buildings also offer indirect economic benefits such as higher property value, lower tenant turnover and the ability to attract grants or subsidies.

The interface between energy performance and energy prices will be a big challenge in the clean energy transition in some major heating markets (e.g. North America and Europe). Without measures to seriously reduce natural gas demand, prices will likely rise, improving the business case for building renovations. Yet, the significant building envelope improvements projected in the Faster Transition Scenario broadly stabilise natural gas demand, resulting in relatively constant (or even lower) prices in some markets. That paradox will require careful consideration and an assertive policy framework to ensure the right level of energy performance improvements.

- For poor performance buildings, such as single-family households with average annual heating intensity of 200-300 kWh/m^2 cost-effective interventions may range from 30-60% building envelope improvement, depending on natural gas prices and with a payback period of 15-20 years (Figure 2.22).
- For many existing buildings, with heating intensities between 120-200 kWh/m^2, cost-effective interventions at low natural gas prices may only be around 15-20% improvement. At higher natural gas prices, typically around USD 0.12 per kWh, renovation rates could reach 45% or more cost effectively, depending on the expected payback period.

The level of energy performance improvements depends on a number of additional factors beyond energy prices, including to what extent building envelope measures standardised or customised, how short the expected payback period is, and the type of heating equipment used. For example, the Passivhaus programme, which encourages passive house design, applies both building envelope measures and heating equipment replacement to achieve overall energy improvement rates up to 85% or more using cost-effective measures (Passipedia, 2019). Arguably, the return on investment could take into account other social and economic co-benefits of the energy and carbon intensity improvements. The complex interaction of various influences on the decision-making process for building investments illustrates that policy frameworks to enable the clean energy transition may require a strong push to get over the hurdle of low energy prices.

Figure 2.22. Payback period for envelope renovations in buildings using natural gas for space heating



Notes: A "typical building" represents a residential building energy performance of around 120-200 kWh/m² per year for space heating needs. A "poor performance building" represents an energy-intensive residential building using around 200-300 kWh/m² per year for space heating. A 5% discount rate is applied. Payback periods depend on other parameters, such as expected return on investment (resulting in different discount rates), type of heating equipment (where spending reductions would typically be larger for buildings using electric resistance heaters today, as electricity prices are generally higher), economies of scale (where renovation programmes could decrease market costs) and inclusion of co-benefits (e.g. thermal comfort, productivity, health, reduced needs for grid investment upgrades).

Envelope renovations could improve building energy intensity by 30-60% for poor performance buildings and 10-45% for typical residential buildings with a 20-year payback period.

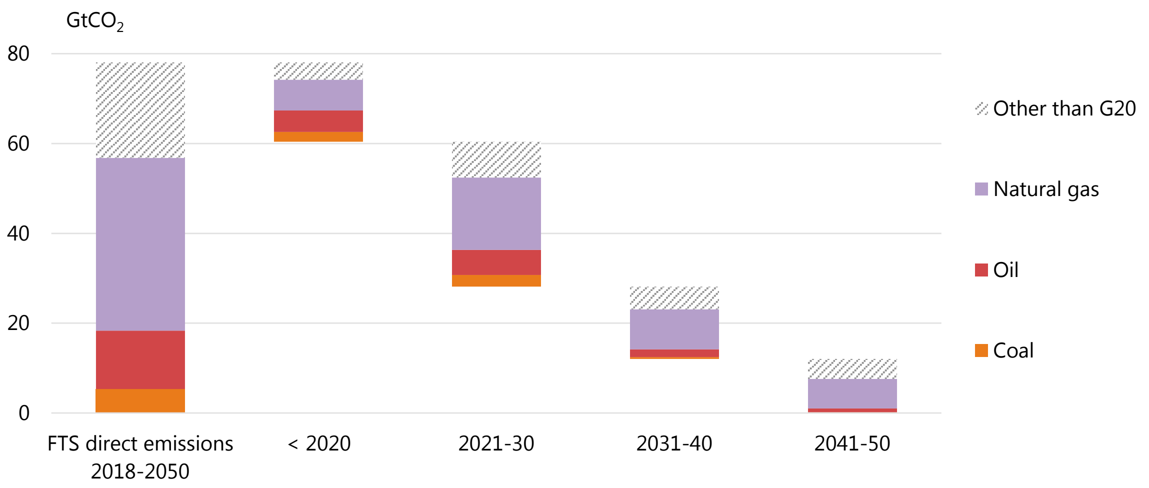
Action is needed to avoid lock-in of capital and operational costs

The next decade is critical to achieve cost-effective implementation of long-term sustainable development ambitions in the buildings sector. In the aggressive Faster Transition Scenario, investment made before 2030 in new fossil fuel assets in buildings would lead to lifetime emissions of around 50 $GtCO_2$ – more than two thirds of direct emissions by buildings to 2050 (Figure 2.23). This illustrates the "lock-in" effect of long-lived buildings sector investments, where decisions in the coming decade could hamper clean energy progress in the years ahead by emitting CO_2 over a lengthy period (or requiring costly early retirement of the assets).

This lock-in effect is even more important for investment in the stock of buildings. New residential buildings account for 80% of global floor area additions to 2050 and more than 60% of buildings-related CO_2 emissions in the Faster Transition Scenario. In emerging economies, where the majority of those floor area additions will occur, residential buildings can last as much as 30-50 years. Non-residential buildings generally have shorter lifetimes, but they nonetheless can stand for 30 to 60 years or more. Implementation and enforcement of building construction standards and mandatory building energy codes will therefore be critical to ensure the additions are energy-efficient and low-carbon. Better building construction could also extend typical building lifetimes to as much as 70 years or more, avoiding energy and emissions to renovate (or demolish and rebuild) those buildings in the coming decades.

The Faster Transition Scenario hinges around extension and improvement of building energy codes across all countries to achieve high-energy performance buildings construction in the coming decades. In the next ten years, around 77 billion m^2 of floor space will be built, more than the current floor area of buildings in China. The additions will mostly be in rapidly emerging economies such as India, Indonesia and Brazil, where building envelopes will play a critical role to reduce thermal loads and beneficially influence energy use for space cooling. Another 20 billion m^2 or so will be renovated, mostly in cold climates where envelope performance is central to heating loads.

Figure 2.23. Lifetime CO_2 emissions "locked in" by buildings equipment by period in G20 countries



Note: Emissions illustrate the lifetime impact of direct CO_2 emissions from building equipment during the period in which it is installed, and not when the CO_2 emissions are actually released into the atmosphere.

Investment needs to shift away from fossil fuels in the 2020s to avoid locking in CO_2 emissions to 2050 from long-lived buildings sector assets.

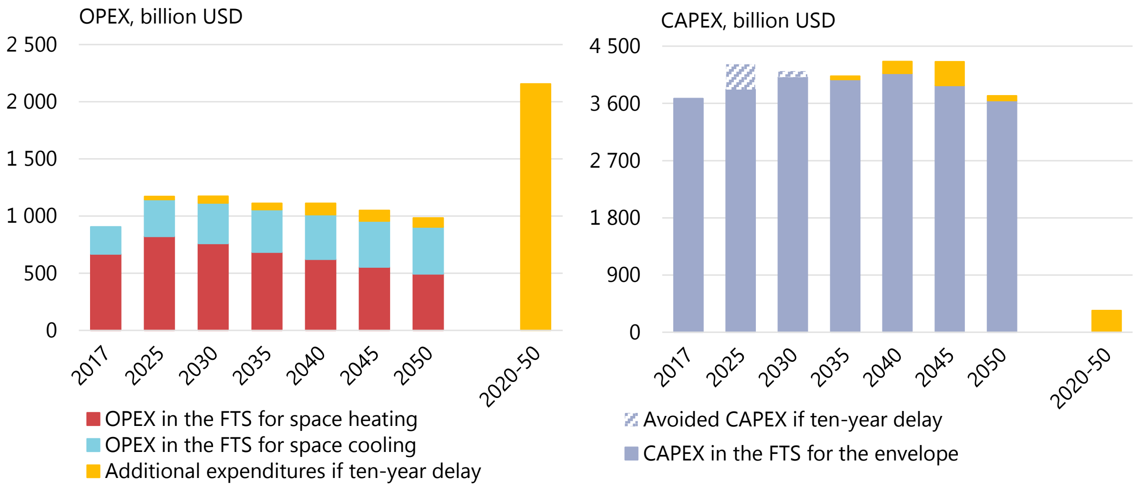
Delaying implementation of the high-energy performance envelope measures projected in the Faster Transition Scenario by another ten years would have major implications, for example leading to as much as 3 500 Mtoe of additional energy demand in the buildings sector to 2050, more than twice the energy demand for total global heating and cooling in buildings in 2017. Delaying action would also lead to substantial increases in capital and operational costs to 2050, particularly as renovating 77 billion m^2 of new construction in subsequent years will face similar challenges as do existing buildings today. When total spending to 2050 is considered, a ten-year delay could cost as much as USD 2.5 trillion more than projected in the Faster Transition Scenario (Figure 2.24).

There are multiple reasons why acting sooner is more economical, including:

- Economies of scale narrow the cost differential between code-compliant and near-zero energy construction in the coming decade.
- Advanced renovation practices make energy retrofits easier, cheaper, scalable and more attractive through innovative models (e.g. pairing with non-energy retrofits).
- Lower heating and cooling operational expenditures in the future, as a ten-year delay affects the thermal performance of the building stock well into the future.
- Reduced capital expenditures for new construction in the long-term, as high-energy performance buildings are more efficient and typically have longer lifetimes.

Delaying envelope measures by ten years also would affect other sectors. For example, higher energy consumption would increase the need for additional power generation and transmission capacities, where peak electricity demand is often associated with heating and cooling loads in buildings that may not occur when renewable production is highest (e.g. during a cold evening in winter or hot night in summer). Shorter building lifetimes would also increase the need for cement, steel and glass, which would place higher demand on the industry sector.

Figure 2.24. Increased expenditure with a ten-year delay in achieving building envelope measures



Notes: Investment is shown in 2017 USD billion. CAPEX = capital expenditures. OPEX = operational expenditures. Cumulative OPEX is largely higher in the ten-year delay due to higher heating and cooling demand. Cumulative CAPEX is slightly higher in the ten-year delay, partly because of increased need for deep energy renovations to make up for inaction in the next decade.

Delaying building envelope measures by ten years would increase expenditures by USD 2.5 trillion to 2050, which is more than 2.5 times operational expenditures for heating and cooling in 2017.

Sustainable buildings will bring multiple benefits

The importance of energy-efficient and low-carbon measures in buildings is broadly recognised. Yet, consumers and policy makers often encounter difficulties in placing the value of needed investment in the spectrum of broad social and economic factors that influence their decision. Frequently, consumer choices are driven by upfront costs with inadequate consideration given to operating cost over the life of the asset. This can engender little engagement with more sustainable measures, even if they have a positive return on investment over the lifetime of the measures.

To address such issues, the concept of monetising the value of co-benefits in assessing investment risk is emerging, intended as any positive impact on economic and social growth, which accompany the primary objective of building energy improvements and carbon abatement. This includes the definition and estimation of additional benefits beyond energy and emission savings, including those that affect the broader community. Co-benefits can be both direct (e.g. reduced energy costs) or indirect, such as reduced number of deaths, job creation and improved health and productivity. As an example, it is estimated that access to clean cooking can reduce premature deaths from household air pollution by 1.9 million in 2040 (IEA, 2018c).

More research attention is being given to the monetisation of co-benefits. Their economic quantification may re-define the impacts of building measures and consequently may shift business models to prefer low-carbon and more efficient energy solutions. For instance, market data that high-energy performance building construction has greater resale value can encourage banks to use more favourable lending conditions for related investment. Various evaluation techniques are available to assess the impact of energy measures in buildings in a comprehensive way (Bisello et al., 2017) and which monetised the co-benefits (Table 2.4).

Monetary values of co-benefits are extremely site dependent and cannot be generalised. Among the multiple factors affecting their values, the physical conditions of the buildings, territorial context, climate and the socio-economic characteristics of investors affect their relevance. Yet, encouraging methodologies with standardised metrics will help include benefits in valuation processes, improving investor perception of building performance measures.

Table 2.4. Selected co-benefits related to building energy performance measures

Beneficiary	Low uncertainty in monetisation	High uncertainty in monetisation
Society and environment	Reduced CO_2 emissions Reduced air pollution Increased urban vegetation Increased renewable quota	Fuel poverty alleviation Benefits to disadvantaged social groups Construction and demolition waste reduction Improved health conditions (BPIE, 2018) Improved comfort
Public finance and public authority	Enhanced tax revenues*	Creation of new green jobs*** (Janssen and Staniaszek, 2012; Grimes et al., 2011) Improved energy security Reduced hospitalisation (Grimes et al., 2011) Lower absence from work/school (BPIE, 2018) Improved productivity (BPIE, 2018) New business opportunities (Grimes et al., 2011)
Energy utility	Reduced generation costs Reduced ancillary service costs	Reduced congestion costs Utility insurance savings The improved public image of the utility
Investors	Reduced global cost** Revenue from sale of on-site electricity production Reduced noise	Increased real estate value (Dell'Anna et al., 2018; Bottero et al., 2018) Improved quality of life Reduced mortality and improved health conditions (Ferreira, Ameida and Rodrigues, 2017) Lower exposure to energy price fluctuation Improved indoor comfort and/or air quality (Buso et al., 2017)

* Tax revenues may equally be reduced, depending on the type of measures. ** Investment, operations and maintenance and replacement over the lifetime of the building. *** Jobs in the construction and energy industries with new skills.

Source: Adapted from Buso,2017; Ferreira et al, 2017; Dell'Anna et al, 2018.

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3. Enabling the transition to sustainable buildings

- Current policies fall short of delivering a clean energy transition for the buildings sector. It is off-track because of continued use of less efficient technologies, which reflects lack of major policy progress and absence of clear market signals. This influences investment. In 2017, only 9% of the USD 4.9 trillion (United States dollars) spent on buildings was on energy-efficient products and services.
- Governments should set clear, ambitious commitments to ensure long-term market signals. Such commitments should put forward specific policy measures, such as building energy codes and mandatory performance standards for equipment. This will enable and encourage uptake of key energy technology solutions for buildings and help to speed up and lower the cost of the clean energy transition for the sector.
- Immediate action is needed to expand and strengthen mandatory building energy codes. In the next three decades, an estimated 225 billion square metres (m^2) of floor space will be built in emerging economies, of which 80% will only be partially covered by building energy codes, if any at all. Governments around the world can work together to share experiences and transfer knowledge to ensure that all new construction is covered by mandatory energy policies.
- Energy efficiency improvements are affordable when supported by effective policies. Government support for product improvements and technology innovation can facilitate economies of scale and industry learning rates to deliver cost-effective efficiency measures. Paired with market signals, including energy performance requirements, the efficiency gains can be achieved with little increase in manufacturing costs or consumer prices, while generally paying for themselves through lower energy bills.
- Finance, market mechanisms and innovative business models can accelerate the transition. Around USD 14 trillion of upfront capital investment to 2050 is needed beyond expected levels to enable sustainable buildings. Governments can enable this through policy intervention that shapes market rules to improve access to finance, de-risk clean energy investment and broaden availability of market-based instruments that lower the barriers for a clean energy transition.
- Comprehensive policy packages can bring solutions under one umbrella. Pairing of traditional policy tools such as mandatory performance standards with more ambitious regulatory and financial incentives to engage the private sector can help bring together multiple technical and market-based solutions for buildings, such as "one-stop shops" and energy service companies. This will foster an across-the-board framework that delivers cost-effective action tailored to specific building needs and using the most effective technology opportunities.
- Governments can collaborate to make sustainable buildings a reality. There needs to be a ramp-up of institutional capacity and global co-operation to enable the clean energy transition. Governments can co-operate to share knowledge, best practices and solutions through multiple initiatives, such as the IEA Technology Collaboration Programmes and the Global Alliance for Buildings and Construction.

Introduction

Achieving the global clean energy transition requires an ambitious combination of low-carbon energy and more energy-efficient buildings, industry and transport sectors. Decarbonising the power sector is a fundamental step to reduce energy-related carbon dioxide (CO_2) emissions. It must be complemented by significant efficiency improvements in buildings, particularly given the impact of rising demand from space cooling, appliances and other electrical devices.

The energy and CO_2 emissions savings potential in the buildings sector has not been fully harvested as signalled by the continued use of less efficient technologies, insufficient policy progress, weak market signals and insufficient investment. Total spending on energy-efficient products and services in buildings was only around USD 425 billion in 2017 – 9% of the USD 4.9 trillion spent on buildings and construction (IEA, 2018a). In fact, incremental energy efficiency investment only increased by 4.7% in 2017 (3% adjusted for inflation), the lowest rate of increase in recent years.[17] If this trend persists, trillions of dollars in less efficient and carbon-intensive investment risk being locked in for decades to come as building infrastructure and equipment are generally long lasting.

Forging a pathway to a sustainable (i.e. low-carbon and high energy efficiency) buildings sector in line with the Faster Transition Scenario requires swift and assertive policy action to innovate and move markets to low-carbon, high efficiency technologies and best building practices. The good news is that global dialogue is helping to sound the bell on a clean, affordable and energy-efficient buildings sector. The toolkit needed to realise that potential includes a suite of policies, technologies and financing tools with proven track records, along with new and innovative approaches that are helping bring to market clean energy solutions for the buildings sector.

This chapter outlines some of the key policy elements to progress the clean energy transition in the buildings sector. The transition can deliver multiple social and economic benefits, ranging from job creation and increased productivity to reductions in local air pollution and more affordable energy bills for businesses and households. However, to do so, better co-ordination among the various stakeholders in the buildings and construction value chain will be necessary. It should build on three central pillars that are well known but often fragmented or poorly co-ordinated in the buildings sector. The following sections focus on the three pillars as part of an integrated policy framework, including:

- **Setting clear ambitions for sustainable buildings** and committing to specific targets that send long-term signals to market actors.
- **Implementing and enforcing assertive policies to transform markets** using traditional, yet effective policy tools along with ambitious strategies that encourage new and transformative solutions.
- **Strengthening institutional effectiveness**, including education and awareness tools together with training and capacity building, in order to plan, implement, monitor, verify and evaluate the long-term transformation of the buildings sector.

These pillars are of equal importance to unlocking the massive energy savings and carbon abatement potential in the buildings sector. Ambitious targets without effective policies risk

[17] Incremental energy efficiency investment includes only the cost of energy-efficient products and services rather than the total spending. For example, the incremental investment for new or renovated buildings is the change in cost for services (e.g. design, delivery and installation) and products (e.g. equipment and materials) that achieve increased energy performance beyond the investment that would have been made otherwise or that is required for the minimum performance legally allowed.

achieving sufficient market appetite for clean energy solutions. Assertive policies without institutional capacity may beget poor compliance. In short, driving the clean energy transition in the buildings sector requires a transparent, consistent and operational policy framework to give as much certainty as possible to investors, industry and other stakeholders over the direction, strength and timing of the expected buildings sector transformation.

Setting clear ambitions for sustainable buildings

Many buildings today do not apply existing efficient and low-carbon technologies to the degree that life-cycle cost minimisation warrants (let alone to levels that are required to deliver the energy transition). Among the barriers to unlocking that potential are higher upfront costs, lack of consumer awareness of technologies and their potential, split incentives (e.g. landlord-tenant) and that the true costs of CO_2 emissions are not reflected in market prices. Overcoming these barriers requires comprehensive policy packages to overcome the barriers with effective policy and enforcement measures.

Setting clear and consistent signals for consumers, building operators, asset managers and the broader buildings and construction industry is critical to foster best practices and maximise investments in clean and energy-efficient technologies. Clear-cut ambitions and long-term strategies for sustainable buildings boost confidence among stakeholders, where commitments provide clarity and predictability to decision makers. This reduces investment risks (e.g. costly changes to building assets in the future), which is essential given the long life of most buildings.

Setting clear ambitions for sustainable buildings can include broad objectives, such as energy performance or carbon abatement targets, as well as specific commitments such as elimination of fuel subsidies and requirements for building energy certification schemes. For example, Mexico announced plans in 2018 to eliminate an electricity subsidy that discourages investment in energy-efficient technologies (IEA-UN, 2018). In France, national stakeholders developed an action plan that will boost energy performance in existing buildings (Fédération CINOV, 2018).

Additional signals include commitments to increase spending on research and development (R&D) programmes and to create financing tools that support market deployment of low-carbon and energy-efficient options for buildings. For example, the Government of Canada created the Low-Carbon Economy Fund that provides funding to sub-national jurisdictions to leverage investments in projects that will reduce greenhouse gases (GHG) and help achieve its climate commitments (Government of Canada, 2018). In Ireland, the 2017 National Mitigation Plan committed EUR 21 million (euros) to support the Deep Retrofit pilot programme, which will provide funding in addition to existing incentive programmes for building renovations (SEAI, 2018).

Ensuring that all available options to achieve sustainable buildings are tapped will require unprecedented effort and co-ordination. An important first step is for governments to outline what the buildings sector should look like in the future, including intersections with other economic sector clean energy strategies such as decarbonisation in the power generation. The strategic vision can encourage stakeholders – ranging from builders, manufacturers, equipment installers and financial institutions to businesses and household consumers – to identify, plan and implement appropriate solutions. Clear ambitions will equally help to bring forward challenges, for example, lack of product availability in a market or a need to harmonise standards. This informs the design of specific policy measures to drive forward market transformation.

Establish specific measures to promote energy efficiency in buildings

Limited policy coverage and lack of clear-cut measures to address the performance and carbon intensity of buildings and related energy technologies is an important reason why the buildings sector continues to be off-track to meet stated objectives. To put the sector on a better path, policy frameworks need to signal to public and private investors specific measures that will foster the clean energy transition. This includes expanding mandatory measures such as energy-related building codes and boosting the stringency of measures over time to drive the uptake of energy-efficient and low-carbon solutions.

Countries have a clear opportunity to state their intentions in updates to their Nationally Determined Contributions (NDCs).[18] These can factor in specifics around the key energy technology recommendations for the buildings sector described in this report.

The buildings sector is addressed in more than three-quarters of the strategies to curb emissions in country NDCs. For instance, El Salvador confirmed its ambition to promote enhanced building envelopes for energy efficiency and thermal comfort in its 2017 NDC submission. Lesotho similarly released an updated NDC in December 2017, which committed to decarbonising the buildings sector through the phase-out of incandescent lighting, deployment of efficient stoves, incentives for retrofits and regulations for construction (IEA-UN, 2018).

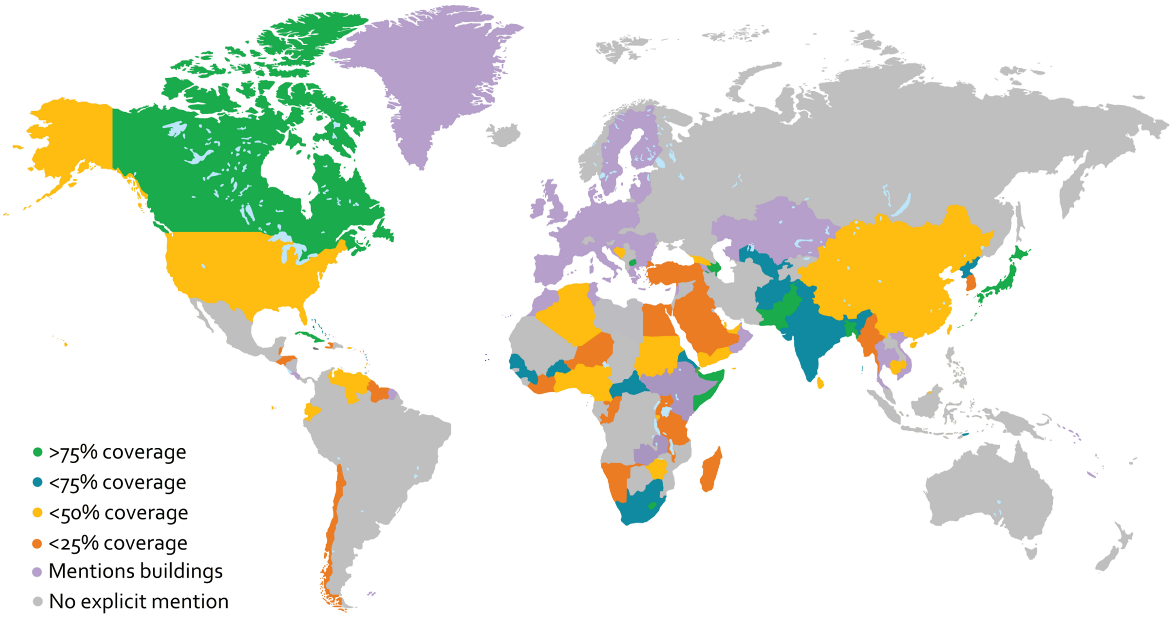
Nonetheless, most NDCs do not include explicit actions in the buildings sector (Figure 3.1). This means that the potential coverage of buildings-related CO_2 emissions is far from the call to address sustainable buildings in country commitments. In fact, of the 136 countries with NDCs mentioning buildings, 48 do not provide any specific indications as to how they will address energy use in buildings and its related emissions. Potential action by another 32 would only cover 25% or less of buildings-related CO_2 emissions if those actions were implemented and enforced as policy. Only nine countries mention specific actions that would address more than 75% of their buildings sector CO_2 emissions.

Countries should establish specific policy measures, such as building energy codes and minimum energy performance standards (MEPS) for equipment, which support and promote the uptake of energy-efficient and low-carbon solutions for buildings. For example, the European Union has committed to fully decarbonise its buildings sector by 2050. To that end, the Energy Performance of Buildings Directive was revised and came into force in July 2018 to strengthen action to achieve a highly efficient and decarbonised building stock. The directive lists a series of specific measures that will enable citizens, owners and tenants to live in better buildings in terms of energy performance, comfort and well-being. It includes actions to stimulate deep renovation, identification of trigger points for renovation, policies and actions to target the worst performing segments of the buildings stock, and an outline of initiatives to contribute to the alleviation of energy poverty. Member states have to provide indicative milestones for 2030 and 2040 as well as measurable indicators (e.g. renovation rates or a cap on energy consumption per m^2) to track and measure progress.

[18] The Paris Agreement (Article 4, paragraph 2) requires each country (Party) to prepare, communicate and maintain successive nationally determined contributions, which embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. For more information, see: https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry.

Another type of measure can be detailed market targets, which send clear signals to investors and also can also be used to monitor progress and identify market gaps and barriers. Examples include targets for energy-efficient technology deployment, such as the number of heat pumps or solar thermal units deployed by 2030, and specific energy performance targets, such as achieving near- or net-zero building energy for new construction over the next decade. Such targets can be paired with signals of eventual mandatory policies, such as forthcoming MEPS. For these types of measures, clear timelines and stakeholder engagement are critical to ensure market acceptance, especially given the long life of many buildings sector investments.

Figure 3.1. Potential share of CO_2 emissions from buildings in Nationally Determined Contributions



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Notes: Emissions coverage is estimated using specific mentions of measures related to the buildings sector, building end use or technology with respect to 2017 buildings sector CO_2 emissions. Country NDCs that do not explicitly mention building measures, for example in the case of economy-wide targets in the European Union, have not been counted in the emissions coverage.

Source: Derived from IEA (2018c), World Energy Statistics and Balances 2018, www.iea.org/statistics and IEA (2018b), Energy Technology Perspectives buildings model, www.iea.org/buildings.

Most current NDCs lack specific measures to address buildings sector energy use and CO_2 emissions.

Countries can also send clear signals by committing resources to specific action. This includes leading by example, such as requiring high energy performance construction for new public buildings, supporting deployment through market leverage (e.g. through public procurement of clean energy technologies) and offering financial incentives to enable market uptake of needed solutions. For example, in 2017, the government in Croatia announced an increase in funding for improvements in the energy efficiency of public buildings. Financing of up to EUR 51 million in grants is available for project proposals to renovate public buildings (BGEN, 2018).

Other mechanisms can provide useful signals to building sector markets. For example, the Advancing Net Zero (ANZ) is global project by the World Green Building Council that aims to promote and support the acceleration of net-zero carbon buildings to 100% by 2050. A key part of the ANZ project is the commitment phase, which calls on businesses, organisations, cities, states and regions to reach net-zero carbon operating emissions within their portfolios by 2030 and to advocate for all buildings to be net-zero carbon by 2050. That commitment provides a framework for organisations to develop globally ambitious yet locally relevant, flexible and universally viable solutions for their portfolio to both reduce energy demand and achieve net-zero carbon emissions (WGBC, 2019).

Strategies to enable a faster energy transition in buildings

Building structures, technologies, energy needs and occupant behaviour are quite diverse. There is no precise set of options that will work in all instances, building types or climatic conditions. Nonetheless, several key considerations generally hold true (Table 3.1), and policy makers have the opportunity to increase effectiveness using complementary targets, methods and timelines. This includes consistency with the ambitions and targets set forth in the *Global Roadmap for Buildings and Construction* (GlobalABC, 2016) and the IEA Efficient World Scenario (IEA, 2018a).

Many of the technologies needed to transform the global buildings sector are already commercially available and cost-effective in most markets, with payback periods that can be less than five years. Others are more costly and will require government intervention if they are to achieve wide market uptake. Yet, only a small proportion of buildings technologies require major R&D breakthroughs. Many, however, could benefit from a combination of market incentives, policy support and expanded demonstration to achieve the necessary economies of scale and reduce costs. Additional R&D can also help to enhance performance, improve affordability and address technical barriers that may limit technology application (e.g. product size and flexibility).

Immediate priorities and future goals will need to reflect a country's energy supply and buildings sector profile.[19] Nevertheless, several actions are universal. First, rigorous building energy codes need to be implemented in all countries. For new buildings in cold climates, those standards should be subject to progressively tighter regulatory standards, moving towards annual energy consumption of 15-30 kilowatt-hours (kWh) per m^2 for heating purposes. In hot climates, especially in emerging economies, mandatory building energy codes should at a minimum require low-cost reflective technology such as cool roofs and low-emissivity windows. Enforceable codes in emerging economies should be progressively tightened to include high-performance building envelope measures, such as advanced roofs and building-integrated solar. For both advanced and emerging economies, it is recommended that policies be implemented to address not just individual components but also the whole performance of buildings.[20]

In major heating markets, where a considerable share of buildings to 2050 are already standing, establishing large-scale refurbishment of buildings should be a key policy priority in the coming decade. Greater effort needs to be focused on compiling a comprehensive and sound evidence base of existing technical and economic case studies, as well as pilot programmes that demonstrate actionable results. In particular, this includes validating economic benefits and associated cost-effectiveness of measures that can be achieved without the need for financial incentives. In parallel, countries should introduce regulatory normative measures such as building energy labelling schemes and codes for renovations that set either minimum technical requirements or minimum energy performance levels.

[19] Specific technology and policy recommendations for the key global regions can be found in the IEA report *Transition to Sustainable Buildings* (IEA, 2013c), available at www.iea.org/etp/buildings/.

[20] A preferred approach is a combination of minimum prescriptive requirements for individual elements (e.g. windows), along with total building energy performance criteria that are more stringent than the culmination of the individual minimum criteria. This will ensure a maximum level of efficiency and that all components are improved to at least a minimum threshold.

Table 3.1. Key policy actions by end-use

Action area	Near-term actions to 2025	Long-term ambitions to 2050
Whole buildings	Implement and enforce mandatory building energy codes, striving for near-zero energy and net-zero emissions in new construction in the coming decade. Work with stakeholders to set clear energy performance targets for existing buildings.	Establish advanced building energy codes with mandatory performance standards (e.g. near-zero energy or better). Set minimum energy performance levels for existing buildings and work with industry to increase availability of energy-efficient and low-carbon measures at affordable prices.
Building envelopes	Require high energy performance envelope components and measures, including air sealing, insulation, insulating and low-emissivity windows and cool roofs. Provide incentives for deep energy renovation of existing building shells.	Achieve high efficiency building envelopes at negative life-cycle cost and mandate energy performance standards for envelope components. Work with industry to deliver non-invasive and whole-building retrofit packages.
Space heating	Provide incentives for solar thermal and heat pump technologies. Improve heat distribution and controls. Mandate minimally condensing boiler technology for fossil fuel equipment. Set targets for MEPS above 100%. Support development of integrated, high efficiency district systems.	Mandate MEPS above 150% for stand-alone heating equipment in new construction. Prohibit the use of electric resistance heaters as main heat source. Prevent expansion of fossil fuel heating and pursue strategy to shift demand to high efficiency and integrated energy solutions with net-zero emissions.
Space cooling	Set MEPS of 350% efficiency or higher. Improve thermal distribution and controls. Work with air conditioning manufacturers to identify R&D needs to deliver higher efficiencies. Promote the use of waste heat from cooling for heating and hot water demand.	Pursue low-cost solar cooling technologies and set MEPS above 400%. Pursue high efficiency and renewable district cooling where appropriate. Mandate use of waste heat from large-scale cooling for heating and hot water use on-site or via district systems.
Water heating	Encourage heat pump water heaters. Continue R&D on low-cost solar thermal. Support adoption of demand-side response measures.	Mandate MEPS of 150% efficiency for electric equipment. Achieve affordable thermal storage and low-cost solar thermal systems.
Appliances	Expand and update MEPS to cover all major appliances and set energy performance requirements for networked devices.	Set MEPS above or higher than current best-available technologies and enact MEPS for small plug-loads.
Lighting	Ban incandescent and halogen light bulbs. Establish MEPS above 65 lm/W lighting by 2025 and encourage the uptake of LED technology.	Implement MEPS above 120 lm/W for all new lighting. Work with manufacturers to ensure product reliability and higher efficiencies.
Building controls	Encourage smart sensors and intelligent building energy management systems. Work with industry to enable demand-side response solutions.	Require energy management systems for all large commercial buildings, and intelligent controls for all major heating and cooling equipment in buildings.

Standards and labelling for equipment, appliances and lighting products need to be pursued, strengthened and implemented in all countries. In the very near term, countries without standards and labelling programmes should implement those policies to ensure that consumers are aware of choices and are encouraged to select efficient technologies. Standards should progressively eliminate the least efficient products from the marketplace, including putting forward policies that prohibit the sale of energy- and carbon-intensive technologies, such as coal and oil boilers. This can be supported by complementary policy actions that reinforce shifts to high-performance and low-carbon solutions, such as removal of fossil fuel subsidies and the use of carbon pricing.

Across the key global regions (including within regions and countries), technology and policy strategies will likely differ in terms of major priority areas to address buildings sector growth, energy consumption and carbon footprint (Table 3.2).

Fortunately, countries are not alone in putting forward strategies to enable a fast transition to sustainable buildings. Numerous initiatives exist at the local, regional, national and global scale, including the Global Alliance for Buildings and Construction, which brings together 26 countries and 84 non-state organisations from all over the world. Additional resources to support the development of strategies and supporting policy frameworks for buildings include:

- Global Roadmap: Towards Low-GHG and Resilient Buildings (GlobalABC, 2016).
- Science-based targets for buildings: a framework for carbon emissions management along the building and construction value chain (WBCSD, 2018).
- Technology Roadmap: Energy-Efficient Building Envelopes (IEA, 2013b).
- Policy Pathway: Modernising Building Energy Codes (IEA, 2013a).
- Policy Pathway: Energy Performance Certification of Buildings (IEA, 2010).
- Super Low Energy Building Technology Roadmap (Singapore BCA, 2018).
- Nearly (Net) Zero Energy Building Roadmap (APEC, 2018).
- Zero Energy Building Pathway to 2035 (National Grid, 2016).
- A Guide to Developing Strategies for Building Energy Renovations (BPIE, 2013).
- A Carbon Positive Roadmap for the Built Environment (Green Building Council Australia, 2018).
- Roadmap for Implementation of Energy Efficiency in Public Buildings of Kyrgyz Republic (World Bank, 2019).
- A Roadmap for Retrofits in Canada (Canada Green Building Council, 2017).
- Aligning District Energy and Building Energy Efficiency (BPIE, 2018a).

Table 3.2. Technology and policy priorities in selected regions

	China (People's Republic of)	India	Southeast Asia	Brazil	Latin America	Africa	Middle East & Eurasia	Europe	North America
Technology priorities									
Advanced envelopes (highly insulated windows, air sealing and building insulation)	○ (red)						○ (red)	○ (red)	○ (red)
Reduced cooling loads (reflective technologies and high-performance cooling equipment with low GWP refrigerant*)	○ (gold)	○ (red)	○ (red)	○ (red)	○ (red)	○ (dark blue)			○ (dark blue)
Heat pumps (water heating and/or space heating/cooling)	○ (gold)						○ (gold)	○ (gold)	○ (gold)
Solar thermal (water and/or space heating)		○ (gold)	○ (gold)	○ (gold)	○ (gold)	○ (gold)		○ (gold)	
More efficient use of biomass (leading to modern biofuels or electricity)			○ (gold)		○ (gold)	○ (red)	○ (gold)		
Policy Priorities									
Building codes with supporting measures (education, products ratings, and implementation for holistic approach with advanced envelopes)		○ (red)	○ (red)	○ (red)	○ (red)	○ (red)	○ (gold)		
Appliance and equipment MEPS (complemented by labelling, and support programmes to promote advanced appliances, lighting, heat pumps, efficient cooling equipment and plug-loads)	○ (red)	○ (gold)	○ (gold)	○ (gold)	○ (gold)	○ (gold)		○ (gold)	○ (gold)
Deep renovation of existing buildings (systems approach with advanced envelopes and high-performance equipment)	○ (gold)						○ (red)	○ (red)	○ (red)
Zero-energy new buildings (advanced holistic building design with integrated renewables)	○ (gold)			○ (gold)				○ (gold)	○ (gold)
Energy subsidy reform		○ (gold)	○ (gold)		○ (gold)	○ (red)	○ (gold)		

* Low GWP= low global warming potential.

Notes: Red circles ○ indicate immediate priority; gold circles ○ indicate second priority. This is not an exhaustive list, but shows the immediate priorities for technology and policy, along with two secondary goals, to help highlight which technologies and policies will have the largest impact in the country or region. Most technology and policy categories are applicable to all countries.

Source: IEA (2019).

Importance of long-term signals to enable investment

Most buildings last for decades – some for centuries – and building owners often only do one major energy renovation in their lifetime, if that. This has significant implications for policy makers, as the very low turnover rate of the buildings sector is a critical constraint and risks locking in investments for decades to come. Long-term signals on the intention of government policy direction therefore are very important. They provide greater certainty, and importantly, they allow governments and other actors to plan for future actions and investment.

There are various types of long-term targets and signals used by governments to enable strategic investment in energy improvements in the buildings sector. They include measures such as targets or energy performance requirements for building energy intensity, or absolute energy consumption. Requirements can be incentive driven. For example, in the United Kingdom only buildings with an energy performance rating of D or better are eligible for a higher feed-in tariff for renewable electricity (BEIS, 2018). Alternatively, they can be prescriptive, for example, to require an energy performance below a certain threshold in order to sell or rent a building. They can also be tied to financial tools, such as, providing preferential finance rates for buildings below a certain energy performance level or including energy performance in the calculation of property taxes. Signals can be specific to components (e.g. banning the sale beyond 2030 of buildings with installed coal boilers).

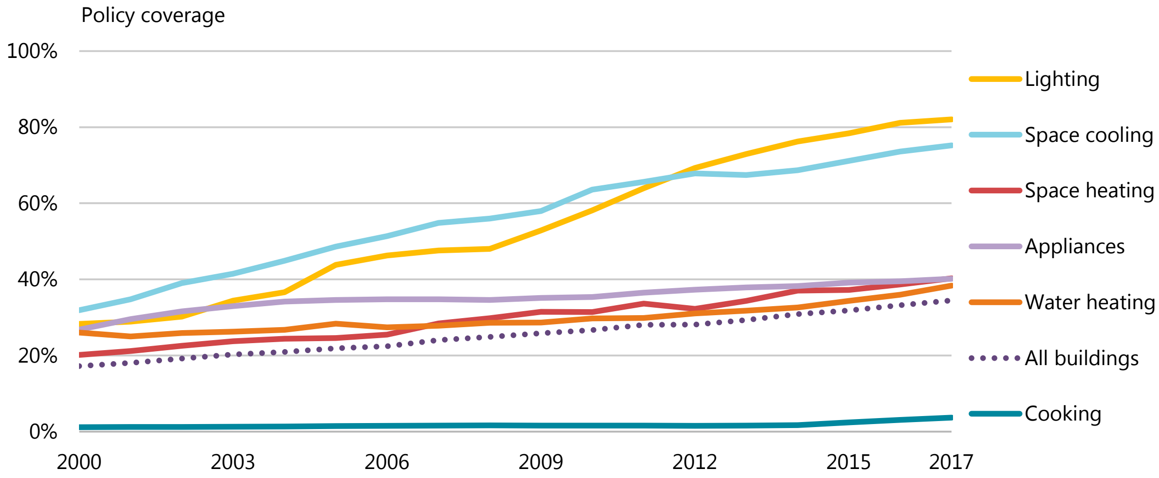
Whatever the measures taken, targets and policy signals should be transparent and include realistic timelines to give investors and other buildings sector stakeholders sufficient time to plan and implement. Long-term signals should ideally be complemented by roadmaps that provide evidence and insights on how to meet the targets and what elements should be considered. This provides better clarity and predictability on the potential measures to take, for instance, adding insulation or replacing windows when doing non-energy renovations, to avoid additional costs in the future.

Strategies also need to address potential barriers to adoption or implementation, which may require additional measures to avoid negative impacts or onerous market effects. For example, some of the least efficient energy performance in buildings is often in low-income households. Setting long-term energy performance targets in and of themselves are unlikely to address the economic barriers to achieving building energy renovations and likely will require financial support or other appropriate market mechanisms such as third-party financing. One example is a recent French law that makes it possible to create a new category of stakeholders that offer technical and financial services to renovate private housing (IEA-UN, 2018). These third-party actors will help achieve France's broad strategy to renovate as many as 500 000 buildings per year to 2030, without placing the direct onus on low-income households. Similar programmes exist in other countries.

Buildings sector policy insights

While buildings sector mandatory policy coverage continues to improve globally, the annual rate of increased coverage has diminished, from roughly 5-8% annual improvement in the 2000s to 2-3% in recent years (Figure 3.2). Mandatory policy coverage does not indicate how effective policies are or whether codes and other measures have been updated and reinforced. For example, lighting policies that were instituted to phase out incandescent lamps in many countries have not been updated in the past decade. As a result, many lighting markets continue to be dominated by sales of halogen and compact fluorescent lamps, despite major improvements in the cost and quality of light-emitting diode (LED) lamps.

Figure 3.2. Global mandatory policy coverage by end use, 2000-17



Notes: Policy coverage includes residential and non-residential buildings. Coverage is for policies with mandatory performance requirements, such as buildings codes and minimum energy performance standards.
Source: IEA (2018a), *Energy Efficiency 2018*, https://www.iea.org/efficiency2018/.

Mandatory policy coverage of energy use in buildings has improved for some end uses like lighting and cooling, but this does not imply their stringency has improved in tandem.

The lack of significant stringency improvement globally influences energy efficiency investment in buildings, which has slowed down in recent years. This is particularly evident when looking at the low rate of incremental investment for energy efficiency, which only considers measures that go beyond the investment required for the minimum energy performance legally allowed (or that that go beyond what would have otherwise been spent for countries without energy efficiency requirements, which in some cases is no spending at all).

To realise the investment required to put the buildings sector in line with the Faster Transition Scenario, countries need to quickly and assertively expand, and improve the use of effective traditional policy measures to address buildings sector energy demand and CO_2 emissions. These need to be complemented by other measures, including more ambitious and innovative policy tools, market-based incentives and business models, and strengthened institutional capacity to monitor, verify and enforce the transition to sustainable buildings.

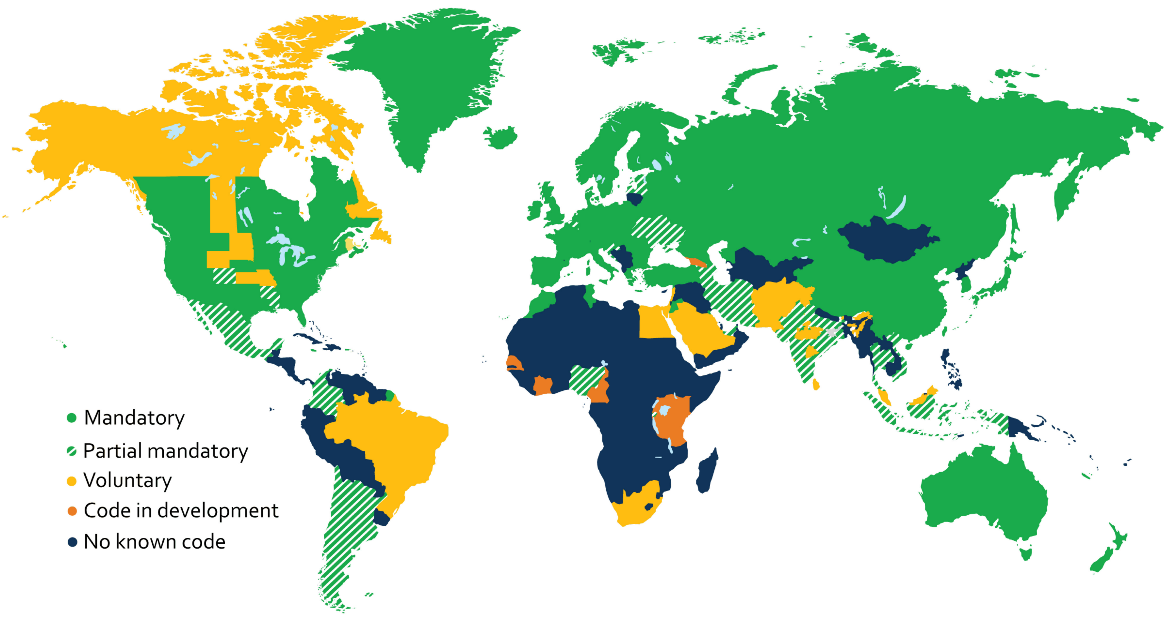
Traditional, yet effective policy measures

Building energy codes and certifications

Building energy codes or standards are requirements that focus on reducing the energy used for a specific end use, building component or an entire building. In 2018, 69 countries had building energy codes in place (either voluntary or mandatory) and 8 countries were developing codes. This is an increase from 54 countries with codes in place in 2010, but at the same time is still short two-thirds of the world's countries that do not have building energy codes today. In 16% of countries, the codes are only voluntary. In 28% (19 countries), the codes are mandatory for only particular segments of the sector (typically commercial buildings). Most changes to codes and standards in 2017-18 were updates to existing codes.

The global status of building energy codes is bleak when looking at country coverage relative to projected growth in floor area (Figure 3.3). Over the next 30 years, as much as 225 billion m^2 in floor area additions could be built in emerging economies, more than doubling total floor area in those countries today. Two-thirds of that growth will be in countries that currently do not have any mandatory building energy codes. When countries with only partial mandatory building energy codes are included, that numbers rises to a notable 80%, or 180 billion m^2 of building additions to 2050, equivalent to 2.5 times the current floor area in the People's Republic of China (China) that will be only partially covered by building energy codes. Wider adoption and coverage, and improvement in building energy codes are vital to putting the buildings sector on a sustainable, clean energy path. Countries and sub-national jurisdictions need to enact new and update existing policies to ensure that the world "builds it right" and avoids locking in poor energy performance in buildings for decades to come. This will help to avoid expensive (and potentially technically challenging) deep energy retrofits of buildings in the future – something many advanced economies are wrestling with today.

Figure 3.3. Building energy codes by jurisdiction in 2018 relative to projected growth in floor space



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Region	2017 floor area (billion m^2)	% mandatory policy coverage, 2017	2050 floor area (billion m^2)	% growth without mandatory coverage
North America	37	83%	54	30%
European Union	29	97%	40	3%
Other advanced economies	13	96%	19	8%
China	58	100%	81	0%
India	21	9%	84	91%
Africa	21	8%	58	95%
Latin America	12	1%	26	98%
Other emerging economies	44	26%	99	84%
World	**235**	**61%**	**461**	**71%**

Notes: Policy coverage includes residential and non-residential buildings.
Source: IEA (2018b), *Energy Technology Perspectives buildings model*, www.iea.org/buildings.

Substantial growth in floor area is projected in emerging economies, and about 80% will be in countries that lack mandatory building energy codes for the entire sector.

Fortunately, some progress is evident, and lessons can be learned from countries that are establishing new building energy codes. Argentina's national government recently developed a national standard for thermal envelope performance that applies to social housing – the first national standard for building energy performance (IEA-UN, 2018). The federal government in Mexico established a national model code, the Energy Conservation Code, which has references to various existing building standards and brings them together in one document that can be adopted as legal language for residential and non-residential building energy codes in states and local jurisdictions (CASEDI, 2016; CONAVI, 2017). India took a step forward in 2018 with the development of its draft Energy Conservation Building Code for Residential Buildings, which has been developed to enable simple enforcement while also improving occupant thermal comfort and supporting the use of passive systems (BEE, 2018; BEEP India, 2018).

Building energy certifications are another tool to encourage high energy performance in buildings and construction. Certifications evaluate the performance of a building and its energy service systems. They may focus on rating operational energy use or the expected (or notional) energy use of a building. Eighty-five countries have adopted building certification programmes and their adoption is growing. Voluntary certification programmes are common in many countries. There are good examples of mandatory certification programmes, such as in the European Union, where energy performance certificates must be presented when a building is sold or rented as well as when it is advertised (European Commission, 2019a).

There are some major differences in programme approaches for energy certifications. Some programmes explicitly consider building energy performance, while others include a variety of considerations, ranging from energy efficiency to other environmental criteria. The energy efficiency and environmental approaches both seek to promote the construction and purchase of more sustainable buildings, but this can lead to buildings that have high environmental quality but mediocre energy performance, something that certification schemes have been trying to address in recent years. Compliance and subsequent disclosure with certifications are also known issues in some markets, although this is improving. As with building energy codes, a balance is required between rigour and accessibility to avoid high entry costs. Above all, consistency and repeatability of performance ratings is of considerable importance (IEA, 2017b).

There are a number of well-established certification programmes. The "Passivhaus Programme" has grown considerably since its creation in 1990, with estimates of more than 60 000 passive houses built worldwide in 2017 (Passipedia, 2018). The programme has very stringent building envelope requirements, focusing on minimising energy needs for space heating, cooling and ventilation. Other programmes include sustainability labels such as the "Leadership in Energy and Environmental Design Programme" (LEED), the "Building Research Establishment Environmental Assessment Method" (BREEAM) and the International Finance Corporation's "Excellence in Design for Greater Efficiencies".[21]

Country specific certification programmes also exist. For example, Canada launched its "ENERGY STAR" certification programme for commercial and institutional buildings in 2018 (NRCAN, 2018). In France, some 500 000 housing units and 2 000 non-residential buildings are certified "Haute Qualité Environnementale" (HQE). More than 800 000 housing units and 120 million m^2 of non-residential buildings in France are also "Effinergie" certified, and 50 000 new dwellings each year are certified "NF habitat HQE", representing around 15% of the new residential construction market (IEA-UN, 2018).

[21] For more information see: http://leed.usgbc.org/; www.breeam.com/; www.edgebuildings.com/.

Other examples include the "Active House" certification scheme in Europe, which combines energy aspects with other drivers for energy efficiency investment, such thermal comfort, indoor air quality and access to natural daylight (ActiveHouse, 2019). As part of the European Union Circular Economy Action plan, the European Commission has launched "Level(s)", a voluntary reporting framework for the buildings sector that encourages life-cycle thinking at a whole building level. Using existing standards, Level(s) provides a common approach to the assessment of environmental performance in the built environment. Level(s) focuses on six key areas: GHG emissions, resources, water, health, resilience and cost. The World Green Building Council Europe is working with the European Commission to support the testing phase of Level(s) and to develop an implementation strategy. The final version is to be released in March 2020 (European Commission, 2019b).

In the coming decade, governments can take the lead on driving market familiarity, acceptance and compliance with building energy codes and certification programmes, particularly when they are first introduced or are voluntary. It is not uncommon for government agencies to adopt voluntary codes or certifications as mandatory measures for public buildings. Leading by example can not only help establish good will in a market; it can also create appropriate scales of demand to overcome potential entry costs, where government owned, controlled or supported buildings (e.g. public or subsidised housing) are often a significant portion of the buildings stock. For instance, the implementation strategy for the new European Union Level(s) framework states that it will be first introduced via green public procurement.

Standards and labelling for energy-using equipment, appliances and lighting

Most of the energy used in buildings is from end-use equipment, such as refrigerators, lighting and space conditioning equipment. These are usually installed or plugged in after the building has been constructed and may be replaced several times during the lifetime of a building. At the time of installation or purchase, the available equipment can represent a considerable range of efficiencies. However, for a range of reasons, the most efficient – even the most cost-efficient models – are not typically purchased and installed. Well-known reasons for sub-optimal efficiency include:

- Lack of consistent and comparative information.
- Split incentives, where the person purchasing the equipment does not pay the energy bill (e.g. landlords and tenants).
- Upfront costs for the most efficient equipment, despite savings over the lifetime of the investment.

To overcome such market failures and boost adoption of energy-efficient equipment and building measures, many governments use consumer information labels and energy performance requirements. One of the most successful programmes is the ENERGY STAR label, which was created in the United States in 1992 to provide simple and credible information on highly efficient products. This voluntary label is now used in several countries and across multiple products, which represent annual spending of more than USD 100 billion, equivalent to nearly a quarter of global energy efficiency spending in the buildings sector (ENERGY STAR, 2018).

Labelling programmes provide information to the public and other actors when making purchasing decisions, which can instil greater confidence in energy-efficient products and improve their attractiveness. Labels are implemented in a number of formats, including the most common approach that uses a comparative scale or ranking to depict energy performance on a relative ranking, compared to the range of products available in a market. Examples include the A to G scale used in the European Union and the 1 to 5 tiered scale in China. Another type is an endorsement or award label, which is usually voluntary in nature. This can highlight products that achieve a specified level of performance (e.g. ENERGY STAR).

Energy labels are useful in a number of ways to support efficiency objectives. For example, government procurement practices can require the purchase of high efficiency products and services, as in the United States where the federal government procurement rules require purchase of ENERGY STAR equipment. Regulators can mandate that low-efficiency products not be sold in their market. This pairing of labelling and MEPS can help to raise the threshold of energy performance; progressively raising MEPS as the market shifts towards higher performance products.

Over 80 countries have MEPS and labelling programmes, and more countries are planning to introduce them. For example, Chile recently announced MEPS and labels for refrigerators (IEA, 2018a). Not only do those policies improve energy efficiency, they also have a number of other co-benefits. A meta-review by the IEA Technology Collaboration Programme (TCP) on Energy-Efficient End-Use Equipment (4E) listed multiple benefits of MEPS and labelling programmes, such as the 800 000 jobs created since 1990 through the European Union eco-design and labelling programmes (4E TCP, 2019).

The most effective MEPS and labelling programmes tend to have these characteristics:

- They are based on sound underlying testing standards, ideally internationally developed and recognised. The tests themselves should be representative (i.e. they are sufficiently representative of actual conditions of use), and they should be repeatable (if undertaken by the same laboratory a number of times) and replicable (by different testing laboratories). For the basis of a robust programme, the laboratories should be independently accredited.
- Performance requirements are technology neutral (e.g. there should not be different requirements for fixed speed and variable speed air conditioners).
- Products should be required to register before market entry. This is an important step to enable more effective compliance programmes by regulators and is the basis for publically available databases to allow consumer access to comparable information.
- Performance levels for MEPS and energy label thresholds are upgraded regularly as technology and markets evolve.

Compliance systems, including monitoring, verification and enforcement, are necessary for an effective standards and labelling programme. Australia illustrates good practice in monitoring in which a mandatory product registration database is coupled with market sales to provide very detailed data tracking on different aspects of the market (Energy Rating, 2019). There can be temptation for equipment manufacturers to "game the rules" (legally, depending on how the standard and testing procedures are written) or breach regulations. Regular market surveillance is important. An example of how to tackle this is the United Kingdom's national independent market surveillance programme, with ring-fenced funding (OPSS, 2019). More recently, the European Union's Anti-Circumvention of Standards for Better Market Survey project was setup to understand better issues of gaming test procedures (Anticss, 2019).

Standards and labels do not have to result in any significant additional costs to consumers. Historical evidence from multiple standards and labelling programmes shows that energy-efficient products and technologies can be delivered at little to no increase in purchase prices (Box 3.1). Thanks to the number of regional and internationally recognised and certified programmes, standard and labels can be implemented without major costs to governments (certainly not large when compared to the benefits of such programmes). Countries using similar or the same labelling schemes with the same testing metrics can share costs (or benchmark using other country's standards). Perhaps the best example is electric motors, where different types of motors across the world can now be ranked on a single efficiency scale: IE1 to IE4 (EMSA 2019). Other programmes, such as the Association of Southeast Asian Nations (ASEAN) Standard Harmonization Initiative for Energy Efficiency (SHINE) programme, help to harmonise standards across countries, lowering the costs of energy-efficient products (and related monitoring, verification and enforcement) (SHINE, 2091).

Box 3.1. Effective policy can enable energy efficiency improvement without additional cost

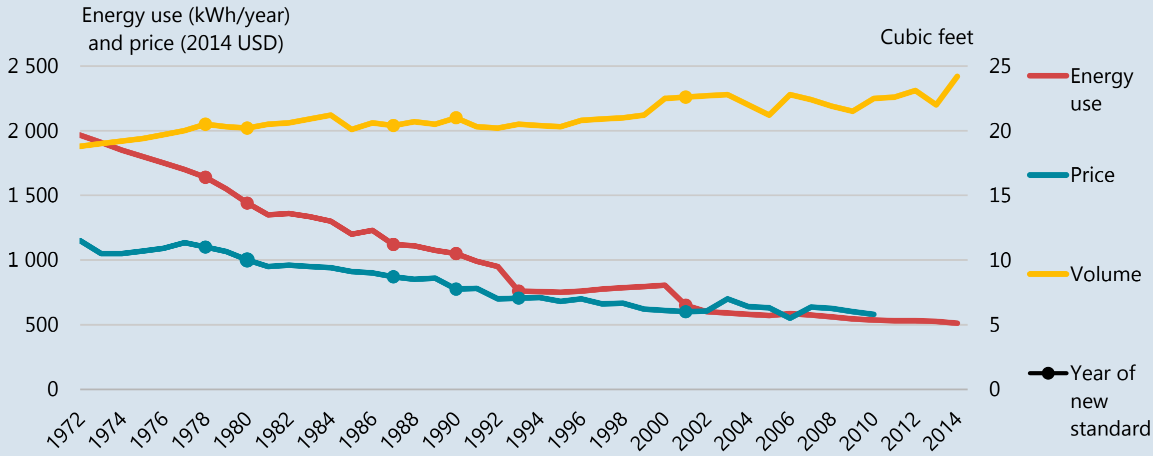
In many markets, there is usually a correlation between purchase price and energy efficiency. However, using current market price as an indication of the future cost of efficiency improvement can be misleading for a number of reasons. These include manufacturers bundling efficiency with other features (e.g. mosquito repellent in efficient air conditioners), where premium products (at higher prices) are often more efficient than basic "stripped-down" units. This is compounded by consumers who are willing to pay more for energy-efficient or "green" products, which can lead to efficient products being seen as a high-end good.

With appropriate policy intervention, energy efficiency improvements can be obtained with little increase in manufacturing cost or consumer purchase prices, especially when MEPS are set using engineering analyses rather than just observed market prices. Such analysis generally requires detailed technical understanding of options to improve product efficiency, and standards usually are set to offer the least life-cycle cost to consumers. By using this approach, the increase in the average purchase price for policy-driven efficiency improvements over time is often limited. In essence, performance thresholds are set in a way that leads to marginal additional costs, if any.

This effect can be seen in many countries for products such as household refrigerators, where establishment of more stringent MEPS have not led to higher purchase prices. For example, the average energy consumption of refrigerators in the United States has declined by more than 70% since the 1970s, even with tightening performance requirements and expanding refrigerator volumes over the period (Figure 3.4). Similar long-term trends are observed in Australia and the European Union. In some cases, purchase prices fell even faster after the introduction of MEPS (van Buskirk et al., 2014).

While this may seem counter-intuitive, it is largely explained by economies of scale and related learning rates for manufacturing industries. Mass-produced equipment, such as refrigerators, plays an important role in achieving higher efficiencies without significant additional costs. This should be kept in mind for other energy-efficient and low-carbon technologies needed for the clean energy transition and transformation of the buildings sector.

Figure 3.4. Purchase price and energy use of new refrigerator sold in the United States, 1972-2014



Source: ACEEE (2014), https://aceee.org/blog/2014/09/how-your-refrigerator-has-kept-its-co.

Multiple evolutions in energy performance standards for refrigerators in the United States have led to lower prices for consumers, despite typical refrigerator volumes also increasing.

Ambitious and innovative policies to transform markets

Building energy codes, certifications, standards and labelling all work best when they are part of a wide market transformation strategy. A key part to the long-term transition of the buildings sector is the use of innovative policy and market schemes to enable change where traditional policies have not always delivered widespread results. For example, rebates and procurement policies can be employed at different points of the value chain to support energy efficiency deployment. Yet, enabling swift and disruptive change in markets requires more co-ordinated and wide reaching approaches to market transformation. R&D and technical innovation are also needed to bring to market highly efficient and low-carbon solutions that are cost competitive and that can be adapted to various building energy types and conditions.

In cold climates countries, such as in Europe and part of North America, refurbishment of the existing buildings stock is likely to be one of the most challenging pieces to the clean energy transition. Technology measures such as insulation may not be expensive, but installation costs and other building disruptions (e.g. need to open walls) are big barriers to the uptake of deep energy retrofits – barriers that certification and energy performance requirements are unlikely to address on their own. The World Green Building Council's Build Upon project demonstrated that such non-technical barriers were spread across the supply chain and that a number of initiatives and programmes were needed to overcome them (Build Upon, 2019).

More innovative approaches are needed to put the buildings sector on a clean energy path, as is information and best practice sharing among countries. For example, the Building Policy Innovation Exchange (BPIE) is documenting ways to improve policy for deep renovation of buildings in Europe. Some of its findings are:

- Extension of buildings codes to include mandatory performance requirements for existing buildings can raise awareness to address poor performance buildings. In England and

Wales, regulations for privately rented property established a minimum level of energy efficiency in 2015, which as of 2018 required landlords to ensure that their properties reached an Energy Performance Certificate rating of E or better for new leases. Those requirements will apply to all privately rented properties in England and Wales – even where there has been no change in tenancy – as of 2020 for residential properties and 2023 for non-residential properties (UK Government, 2019). The aspiration is to raise this requirement to level C over time.

- In Denmark, "Better Home" is a one-stop shop renovation service, initially set up by the companies Rockwool, Velux and Grundfos. It was made possible by a government decision to make building energy data publicly available (with certain constraints) (BPIE, 2018b). Building regulations introduced two renovation classes, from which owners can choose the level of renovation. A feature is that the methodology follows the approach for new buildings, where renewable energy is included and owners get benchmarks to new and existing buildings. The highest renovation level sets requirements for indoor comfort levels to the new building code level (IEA-UN, 2018).
- France set a requirement in 2017 to undertake energy performance improvements when a major renovation occurs. This requires increased insulation when renovating 50% or more of an exterior surface with the aim of a no-regret approach through optimised costs in the renovation process (République Française, 2018). The French Energy Transition Law sets a requirement for users and owners of tertiary buildings (i.e. commercial and public service buildings) to reduce energy consumption by 40% in 2030 (compared to 2010), 50% in 2040 and 60% in 2050.
- In the European Union, the revised Energy Performance of Buildings Directive provides a framework for member states to introduce optional programmes for building renovation passports to stimulate cost-effective deep energy retrofits. Building passports record information on components and operations of a building over its lifetime. Existing initiatives include the "Individual Renovation Roadmap" in Germany and the "Energy Efficiency Passport" in France (BPIE, 2018b).

Innovative regulatory changes such as these help to foster updated approaches and new business models to address building energy renovations (knowing there will be market demand, due to the performance requirements). For example, the United Kingdom energy regulator Ofgem has the "Innovation Link" as a "one-stop shop" offering support to businesses looking to launch new products, services or business models for buildings. Where regulations prevent the launch of a product or service that could benefit consumers, Ofgem can grant a regulatory "sandbox" to allow a trial test of new products, services or business models without some of the usual rules applying (Ofgem, 2018). This approach builds from experience in the financial sector and could influence further policy development, depending of the results of the trial.

For end-use equipment, regulators have explored setting MEPS at more stringent levels than the minimum life-cycle cost and more ambitious requirements may be possible. Technology Forcing Standards (TFS) could be considered to drive further innovation (Lane et al., 2013). TFS have been used in environmental regulations to ban certain processes or substances. TFS have led to technology innovation, such as the catalytic converter resulting from the 1970 Clean Air Act in the United States. TFS for products in the buildings sector could set more ambitious targets for MEPS beyond current products. Of course, there are potential risks and challenges in pursuing this type of approach, but there are examples of countries already doing this. For example, the United States Department of Energy includes learning rates in the engineering cost assessments when setting MEPS (Desroches et al., 2013). This results in performance requirements that are stricter than they would have been otherwise.

The use of traditional policy tools for efficiency improvements can be combined with other policy measures for synergistic benefits. For example, the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (entered into force on 1 January 2019) aims to phase out harmful refrigerant gases in refrigerators and air conditioners and recognises that energy efficiency has a key role to play in minimising the use of the potent GHGs. In Columbia, the "Return and Save Programme" aims to replace 1 million refrigerators within five years by reducing the value-added tax on the most efficient refrigerators from 19% to 5%, while also recycling old refrigerators and disposing of their refrigerants. The policy is projected to deliver revenue for the government as the tax cut is offset by a reduction in energy subsidies, as well as the creation of 2 000 direct and 10 000 indirect jobs (MINMINAS, 2018).

Support for R&D will help deliver innovative products and solutions. This includes government-sponsored research that will reduce the risk of investing in cutting-edge and innovative technologies. For example, the majority of private sector equipment and building material manufacturers have very low research investment ratios (percent of revenue spent on R&D). This reflects many factors, including the commodity-based nature of building materials and products, the long cycle to change to new products, the fragmented nature of the buildings material market and low profit margins for many manufacturers. Government support of R&D can spur innovations in the private sector to deliver solutions and best practices that ultimately will make their way into the wider market (Box 3.2). Governments can equally support industry looking to bring more efficient and innovative solutions to market, for instance, by providing tax incentives, grants and loan guarantees to set up shop in a new market. Such mechanisms are usually only applicable to very large activities and are designed to reduce financial risk so that private sector investors will be willing to participate. A strategic policy in this regard can be highly effective in appropriate circumstances.

Box 3.2. Strategies and innovative practices for material efficiency

Establishing and enforcing building energy codes and construction standards to ensure high-performance and low-carbon solutions will require standards and policies aiming to improve building material components (e.g. for efficient building envelopes).

There are various strategies to achieve these objectives, ranging from the design stage to operations and end-of-life. Regulatory and financial incentives can address known issues in the buildings and construction value chain. Public procurement is one means to steer innovation, as this sets an example by demonstrating the feasibility of high-performance and low-carbon buildings solutions. New material requirements can also facilitate shifts towards low-carbon and high-performance materials. Performance-based specifications may be preferable to prescriptive requirements, as they allow investors and contractors to choose among a wide range of material efficiency strategies. At the same time, building material policies should re-think product classifications from a life-cycle perspective, to guide decision-making processes towards solutions that have long-term value. For instance, the carbon footprint of concrete could be used to differentiate concrete classes, while a set of standards relative to exposure, resistance and durability would be complementary.

Material use policies also need to take into account known issues in the buildings value chain. An example is the perverse incentive created by indexing of engineering, architecture or design services to the overall cost of construction, which leads to decisions to use low quality or fewer materials in construction. This could be discouraged through building code requirements that value material efficiency strategies. Setting high-level resource efficiency targets can also push actors to implement strategies for material efficiencies, including quantified material demand and waste reduction targets. The promotion of informative tools (such as buildings passports) can facilitate material efficiency, while other monitoring tools could simplify data gathering and project management. From an administrative perspective, measures could include things like requirements in supplier contracts to buy back unused materials or used materials for recycling.

New and innovative buildings sector policies can influence strategic thinking on such material efficiency strategies. For instance, the Australian government made changes to building codes in 2018 that recognise massive timber as a viable, code-compliant construction material for mid-rise buildings. Previously, the use of timber in construction of buildings was limited to around three stories (ABCB, 2016). In France, a national reference database is being compiled with nearly 1 100 declarations on environmental profiles for more than 70 000 products for buildings equipment and services. The life-cycle inventories will be used to promote high-quality eco-design of buildings through assessment of environmental and health impact (IEA, 2019).

Market incentives and business models for sustainable buildings

The role of financial policy for sustainable buildings solutions

In the buildings sector, self-financing is the main avenue for funding efficiency improvements (IEA, 2014). This is likely to be insufficient (or politically difficult) to achieve the increase in upfront investment needed to enable the clean energy transition. To do so, improved financial policies, market-based instruments and innovative business models will be needed to deliver the Faster Transition Scenario ambitions.

Government and government-regulated spending on programmes, policies and incentives related to energy efficiency in buildings was about USD 67 billion in 2017 (IEA, 2018a). This sets an enabling environment for investment by consumers and companies, resulting in total energy efficiency expenditure that was more than six-times the government and government-regulated spending in 2017. It also enables more efficient products and services to have lower costs, compared to a market without government-supported initiatives.

Governments can influence the deployment of finance for sustainable buildings through direct policy intervention. These avenues include seven common categories: administrative costs, tax exemptions, public procurement, grants, loans (and loan guarantees), auctions and obligations. The choice of policy intervention to support deployment of energy-efficient and low-carbon buildings solutions depends on the country context, organisational capacity and available financing. Support of administrative costs can be a straightforward and important intervention. This is particularly relevant for nascent markets where administrative overhead (e.g. monitoring actual energy savings) can offset prospective savings. Government funding can also be used to leverage technology advances (e.g. smart meters and connected devices) to reduce administrative costs via improved data. This equally can be used to build the business case for expanded efficiency initiatives.

Tax exemptions (or credits) and public procurement are useful policy tools to increase investment in building energy measures, introducing or bringing to scale energy-efficient and low-carbon solutions. Tax credits, where consumers have access to tax breaks for the purchase of energy-efficient products, are generally used to introduce high-performing products that have very limited market presence. They can also be used to encourage investment in building energy performance measures, for example tax credits up to a certain deductible value for building insulation or replacement windows. Related financing tools, such as low or zero interest loans, can be used to encourage these measures.

The provision of grants to support building energy efficiency measures is the most direct form of financial support that can be provided by governments. Grants represent a reduction in the capital cost of energy efficiency measures, as the money provided by the government does not have to be repaid (unlike debt or loan finance). For example, France has a programme for low-income households that insulates attics for EUR 1 and in 2019 initiated one to replace boilers in low-income dwellings with a heat pump for EUR 1. In Mexico, the government provides a social housing subsidy, where improvements in the energy and water performance represent up to 15% (approximately USD 550) of the total subsidy. This incentive has proven important for the creation of market demand for sustainable technologies and has enabled creation of local green jobs (IEA-UN, 2018).

Similar initiatives pair disincentives with government financing. For example, up to Swiss francs (CHF) 450 million per year is available in Switzerland for building energy refurbishments using funds raised through a CO_2 tax on stationary fuels for heating and industry (Programme Bâtiments, 2018).

Green banks, established by national or regional governments, provide finance and leverage private investment for projects that are commercially viable but struggle to attract finance (Coalition for Green Capital, 2019). Those banks can be public, quasi-public or private institutions with a mandate from a public authority to ensure the scope of their activities. Most green banks invest public funds in projects, along with private capital. Globally, green bank energy efficiency investment was about USD 430 million in 2017, of which the buildings sector received about 80%. Australia's Clean Energy Finance Corporation represented nearly half of the investments (IEA, 2018a).

The majority of green finance has been in the form of loans to small- and medium-enterprises for building and equipment upgrades as well as new construction of energy-efficient single-family homes. The share of energy efficiency financing in their portfolios is increasing and was the largest sector for new green bank investment in the first quarter of 2018 (because of a significant investment made by Australia's Clean Energy Finance Corporation). Globally, green banks represent only a small portion of investment in energy efficiency. Lack of tools for properly defining efficiency in green finance also makes it difficult to measure how much of green bank investments are in energy efficiency.

Other financial institutions, such as the European Bank for Reconstruction and Development (EBRD) and the European Investment Bank (EIB), have remits for clean energy and energy efficiency investments. For example, the German investment bank KfW plays a leading role in energy efficiency investment in residential buildings. It increased the share of programme spending dedicated to energy efficiency from 49% to 59% in 2017, which resulted in overall increased incremental investment (KfW, 2018).

Beyond providing direct finance, governments can improve the business case for investment in low-carbon and energy-efficient buildings. This includes working with the finance sector, banks and investors, among others, to create a common taxonomy and a solid evidence base for such investment. For example, in 2018 the European Commission launched the "Action Plan for Sustainable Finance", which led to the creation of a technical expert group (TEG) on sustainable finance (European Commission, 2019c). The TEG is exploring the development of a European-wide classification to determine whether economic activity is environmentally sustainable. Although it is in the early stages of development, this taxonomy will define what financial activities can be labelled as green or sustainable, and therefore is hugely important for the buildings sector. In terms of developing an evidence base, the European Commission's "De-risking Energy Efficiency Platform" (DEEP) is an initiative to provide detailed analysis and market-based evidence on the performance of energy efficiency investments to support the assessment of the financial benefits and risks.[22]

Recent developments suggest that with appropriate dialogue between governments and financial institutions, there are significant opportunities for financial institutions to support the clean energy transition. At the 2018 Global Conference on Energy Efficiency, the IEA and the EIB launched the "Efficient World Financing Forum" (EWFF). The EWFF aims to facilitate technical co-operation between international financial institutions (IFIs) to overcome the barriers to accelerate energy efficiency at scale. To this end, a core group of IFIs (EIB, World Bank, EBRD) in partnership with the IEA are working to establish an annual global forum that will focus on better understanding the existing gaps in financing and share best practice and approaches on policy and financial measures to bridge them.

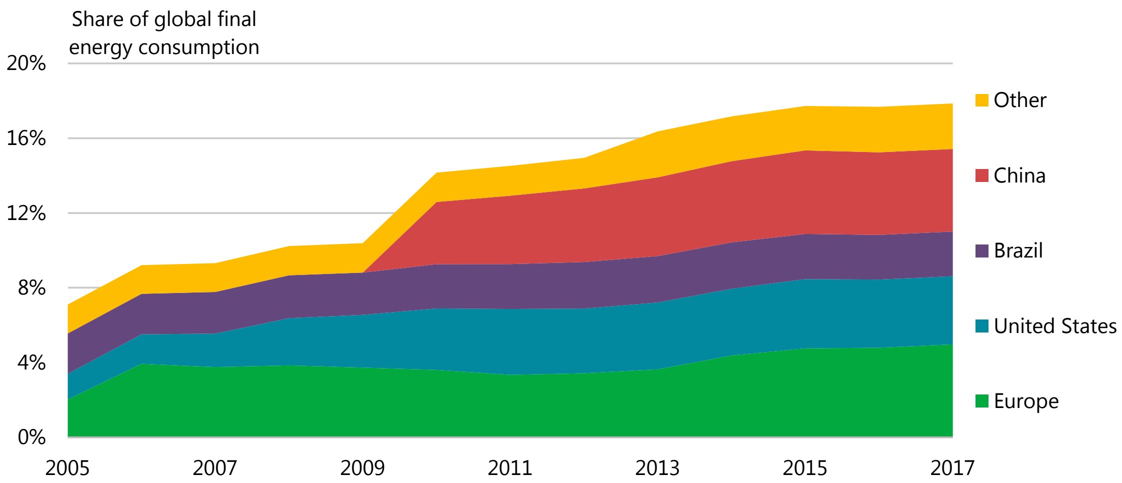
Market-based instruments

Market-based instruments for energy efficiency set a policy framework specifying the outcome (e.g. energy savings or cost-effectiveness of products) to be delivered by market actors, without prescribing a delivery route (IEA, 2017a). Generally, these are categorised as obligations and auctions. Obligations may be imposed on the main energy market actors (e.g. energy retailers or distributors) and require specific efficiency outcomes, which may include the use of white certificate programmes or energy efficiency resource standards. Auctions, including tendering programmes, invite bids (usually from a wider range of market actors) to deliver specified efficiency outcomes.

Obligation schemes are increasingly common and cover about 18% of total final energy consumption globally (Figure 3.5). At the end of 2017, there were over 50 obligation type programmes in 21 countries in Africa, Asia, Australia, Europe and the Americas. The European Union requires member states to have such programmes and many have been in place since the 1990s (e.g. the United Kingdom's Energy Efficiency Standards of Performance). Obligation schemes address such critical barriers as access to credit for measures where utilities or energy retailers have better access to capital and bundle risks than can individuals. Decision makers for obligation schemes (or auctions) are more likely to have stronger familiarity with the technical options to achieve the energy performance improvements (as the financial success of the scheme depends on the cost-effectiveness of the measures).

[22] For more information, see: https://deep.eefig.eu/.

Figure 3.5. Global final energy covered by supplier obligations, 2005-17



Source: IEA (2018a), *Energy Efficiency 2018*, https://www.iea.org/efficiency2018/.

Market-based mechanisms such as obligations cover an increasing share of final energy consumption.

Broadly speaking, market-based mechanisms are helping to increase investment in building energy performance measures and low-carbon solutions. However, there are potential risks and barriers to the use of market-based mechanisms such as supplier obligations. One risk is that the responsible parties will capture the low-hanging fruit to deliver energy performance improvements leaving more expensive measures (but potentially critical ones) for the future. Market conditions (e.g. energy prices) may mean that actors are unwilling to take on some of the high-performance measures needed to deliver on Faster Transition Scenario ambitions. These types of risks and barriers are surmountable (e.g. through clear long-term ambitions in finance agreements). They may require additional financial policies, complimented by regulatory frameworks and other market tools, to attract a larger portfolio of market-based mechanisms to deliver on sustainable buildings and construction. Governments need to evaluate their market-based instruments on a regular basis to ensure they are in line with policy targets to deliver the needed energy improvements.

Business models and market mechanisms

If sufficient finance is to be available to fund the clean energy transition, new and existing business models and innovative market mechanisms will need to be introduced and developed. One such example of increasingly used business model is an energy service company (ESCO). ESCos design, install and can even finance energy efficiency projects through contractual agreements with customers, typically in the form of an energy performance contract. Given the increasing need to increase finance for energy efficiency, attention to ESCO financing models is increasing and is likely to be a key enabler of large-scale financing. The global ESCO market was nearly USD 30 billion in 2017, with the majority of that going into buildings (IEA, 2018a).

The use of ESCOs has been taken up by large players such as the "Ujala" initiative in India, which managed to substantially reduce the cost of energy-saving LED lamps in the past decade. Energy Efficiency Services Limited (EESL), a state-owned "super" ESCO in India, led the initiative and is now translating the experience to a range of other energy-efficient equipment (IEA, 2018a). The initiative seeks the successful use of bulk procurement to deliver energy efficiency at much lower costs. For example, LEDs now cost less than USD 1 (around Indian

Rupee [INR] 60), which is 80% lower than the previous market price, thanks to bulk purchase of nearly 330 million LEDs since 2015. In 2017, EESL issued its first procurement for energy-efficient air conditioners that will help to save 30-40% on electricity demand for cooling, but at a cost only slightly higher than that of the cheapest air conditioners on the market.

Accounting principles heavily influence the development of national ESCO markets. The attractiveness of an energy performance contract as a way to enable investment depends strongly on accounting rules, which vary between countries and regions. Accounting rules impact how the contracts can be structured, specifically whether a public or private sector entity can record it as an on- or off-balance sheet asset. This can increase the debt or liability held by the ESCO, reducing the attractiveness of an energy performance contract.

Mortgages for energy-efficient buildings are another growing finance mechanism and are increasingly being offered in Europe and North America. They typically provide preferential interest rates or funds for energy-efficient improvements. For example, the Energy-Efficient Mortgages Action Plan is a project co-ordinated by the European Mortgage Federation, which has received funding under the European Union's research and innovation "Horizon 2020" programme to create a private-bank financing mechanism to increase energy-efficient investment in residential buildings.[23] The project will define a standardised approach for mortgage lenders in the European Union to offer households the option of a preferential interest rate and/or additional funds in return for measurable energy efficiency improvements. Currently, more than 40 banks are involved in the initiative (EeMAP, 2019).

These initiatives are important as they send signals to investors and the finance community that government-led or government-sponsored financing considers energy-efficient and low-carbon buildings solutions a priority. When paired with appropriate, finance-based information on the performance of energy-efficient and low-carbon investments, they can provide a strong evidence base for the broader finance community to see those investments favourably.[24]

Small-scale energy efficiency projects pose a significant challenge for investors. In recent years, there has been an increasing trend to bundle small projects (mostly lighting) to reduce investor risk and increase available financing for building energy performance measures. On-tax financing is another form of energy efficiency financing to address small-scale energy efficiency projects. It is a repayment programme operated by public-backed bodies or utilities. The best-known example is the "Property Assessed Clean Energy" (PACE) programme in the United States, through which property owners can obtain funds for energy efficiency financing and repay funds through charges to property tax bills. This supports the deployment of a range of low-carbon, energy-efficient and water-conservation projects. As the funding is repaid, it is re-integrated into the PACE funding pool to support additional investments. This model now is used in other regions, including Australia, Canada and Spain (PACENation, 2018).

Other programmes, mostly managed by utilities, similarly use energy bills as the repayment mechanism, referred to as on-bill financing. This assists a variety of households, including low-income ones, to overcome the upfront financial barriers to fund efficiency improvements in situations where customers can accept a tariff that allows the utility or energy provider to invest in cost-effective building measures and they recoup the cost through the energy billing. As the

[23] For more information, see: https://ec.europa.eu/programmes/horizon2020/what-horizon-2020.

[24] The Energy-Efficient Mortgages Action Plan is complemented by the Energy Efficiency Data Protocol and Portal (EeDaPP), which aims to design and deliver a market-led protocol to record data related to energy-efficient mortgage assets. It will be accessible via a common data portal (EeDAPP, 2019).

utility investment is specific to a particular location, if a customer leaves, the cost recovery is typically passed on to the new consumer. This can create a challenge for on-bill financing: although the new consumer benefits from the upgrade, they are often required to continue paying the charge on the utility bill, while the previous owner in fact may have benefitted from a more favourable sale (due to the efficiency improvement).

The issuance of green bonds (bonds created specifically for low-carbon and energy-efficient projects) is another growing market. These can provide investors with greater certainty and transparency that their investment will contribute towards the clean energy transition. Green bonds can also provide a lower cost source of financing, or refinancing, than traditional bank loans, thereby helping to reduce the cost of capital for projects, including building energy efficiency measures. For example, the value of green bonds issued primarily for energy efficiency projects tripled in the United States, from USD 16 billion in 2016 to USD 47 billion in 2017, outpacing green bonds dedicated to renewable and other energy sources for the first time (IEA, 2018a). Fannie Mae's green mortgage-backed securities accounted for nearly 60% of green bonds issued primarily for energy efficiency in 2017 (Fannie Mae, 2018).

While finance models for sustainable building measures are improving, additional efforts are needed to increase the likelihood of broad development of these types of business models and market mechanisms globally. This includes a solid evidence base of the financial value of high-performance and low-carbon buildings, as well as increased integration of quantifiable co-benefits. For instance, research shows considerable benefits from green building certification standards in six countries (Brazil, China, Germany, India, Turkey and United States) valued at an estimated USD 5.8 billion in health benefits from reduced air pollution and USD 7.5 billion in energy savings (using LEED) (MacNaughton et al., 2018). Governments can integrate these multiple benefits in financial regulations. The European Union, for example, requires multiple benefits to be taken into account, such that renovation strategies are now to include "an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality" (European Parliament, 2018).

Comprehensive policy packages to address market barriers

The complex nature of the buildings sector – including building type, location, ownership, customer preferences, equipment costs, energy prices and overall convenience, among others – affect investment decisions and the transition to sustainable buildings. Ambitious policy packages (including well known, highly effective traditional policy measures), along with innovative market design, financial packages and new business models are all needed to deliver on the clean energy transition of the global buildings sector. More importantly, the measures are needed together in a comprehensive policy packages to address the market barriers to widespread action.

Perhaps one of the most innovative policy packages to address sustainable buildings in recent years is the *Energiesprong* ("energy leap") programme in the Netherlands (Box 3.3). *Energiesprong* brings together multiple policy and market-based initiatives to achieve deep energy renovations in existing buildings (public housing), working with multiple stakeholders from the buildings and construction value chain, housing authorities, financial institutions, industry and energy utilities. The programme has led to zero-energy renovations for more than

5 000 homes in the Netherlands since 2013 and is being tested in other places, including France, United Kingdom and the state of New York in the United States (Energiesprong, 2019).[25]

Box 3.3. Insights from the *Energiesprong* programme and its expanding market

Energiesprong is a market-based programme that is a combination of new building and whole house refurbishment standards with a funding mechanism. Developed in the Netherlands in 2012, the programme seeks to retrofit existing buildings to a high efficiency standard, which usually results in buildings with net-zero energy consumption. Renovations are usually completed within one week, with occupants remaining in the dwelling and the energy performance is guaranteed for 30 years. The refurbishment delivers desirable homes with fully integrated solutions that are commercially financeable and scalable. The renovation is financed by the money that would normally be spent on the energy bills and maintenance (on-bill financing) (Energiesprong, 2019).

This innovative and successful approach is being explored in the European Transition-Zero project. Research aims to expand private sector refurbishments beyond public housing improvements. Social housing pilot projects are being tested in France and the United Kingdom. The pilot programmes are helping to make the business case for the Energiesprong concept and illustrate the importance of setting up comprehensive policy packages to enable their success. This includes ensuring the appropriate economies of scale and renovation value chain to keep costs to a minimum. For instance, initial costs in the Energiesprong demonstration in the United Kingdom were relatively high (around GBP 85 000 [British pounds sterling]), but they are estimated to have dropped by 25% by the end of the first pilot as various logistics and programme mechanics were worked out. The costs could be reduced by another 30% through learning and innovative measures that cut product and labour costs, such as prefabrication and competitive tenders (CIBSE, 2018).

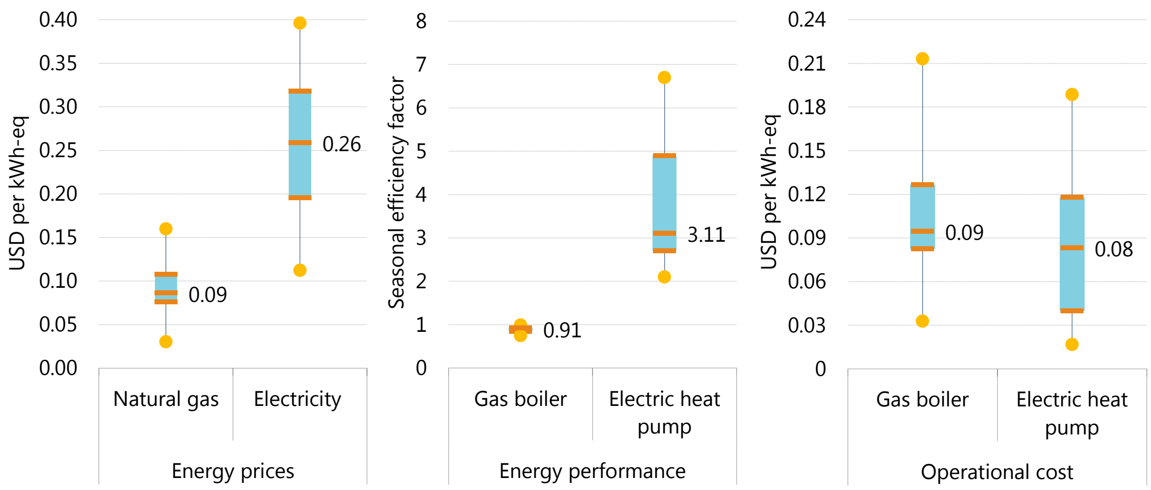
The *Energiesprong* structured finance model uses an innovative approach to collate finance from different sources. These include government-related grants available to all households (such as feed-in tariffs and energy company obligations) and access to low-interest capital (e.g. from pension funds with long-term investments). Bringing financial markets together with housing associations and industry has helped to guarantee retrofit measures (market confidence) as well as provide substantive evidence of the renovation social and energy benefits (raising public interest). Combined with other important measures such as bulk procurement and market tenders, this has helped to improve the cost, speed and quality of the retrofits. In fact, some renovations are done in the course of a few days – an impressive feat for deep energy retrofits.

Another major challenge for sustainable building measures is low energy prices. Policy packages aimed at addressing energy-efficient and low-carbon buildings measures need to address fossil fuel and electricity subsidies in order to reflect the real costs of energy. In many

[25] For more information on the Energiesprong programme, see: https://energiesprong.org/. Transition-zero is a European programme under Horizon 2020 that is building upon the Energiesprong programme. More information at: http://transition-zero.eu/.

markets (especially in cold climates), the spread between natural gas and electricity prices (driven by power generation efficiencies) will be a particular challenge. That spread is often a factor of 2-3 (i.e. natural gas prices are two- to three-times less the price of electricity in equivalent terms), with some markets having a spread of four or more, depending on taxes or other market costs (Figure 3.6). It is no surprise, that use of technologies such as gas boilers is very common in many of cold climate countries, while higher performance equipment such as heat pumps represents a small portion of heating equipment sales. When the range of energy efficiency (e.g. the seasonal efficiency factor) of gas boilers and heat pumps is taken into account, the real operational costs (in USD per kWh-equivalent of heat demand) are often only marginally different. Taking into account capital costs (gas boilers tend to be less expensive in most countries reflecting a combination of issues such as market scale of heat pump demand), means that higher performance heat pumps may barely break even on a life-cycle basis.

Figure 3.6. Energy prices, performance and operational costs for natural gas and electric heating equipment in IEA countries, 2017



Note: Natural gas and electricity prices are prices to residential consumers, including taxes, in 2017 USD. Ranges shown show the minimum, maximum and typical range of energy prices, equipment performance and operational costs, with the median value displayed.

The ratio between natural gas and electricity prices often means that electric heat pumps are only marginally less expensive to operate when energy performance is considered.

Policies need to address this critical hurdle to shift buildings away from carbon-intensive energy vectors. Comprehensive and integrated policy packages are more likely to succeed (and be accepted) than individual policy tools. A few critical actions governments can take to facilitate dialogue and strategic ambitions for sustainable buildings include:

- Improve policy regulations and market signals related to energy efficiency and CO_2 emissions in the buildings sector.
- Boost effective use of financial tools, such as tax incentives, and link with R&D activities to reduce the cost of heat pumps.
- Use economic tools, such as a carbon tax, to improve pricing dynamics for clean energy solutions.

A marginal increase in natural gas prices (e.g. using a carbon tax) in many markets could provide the incentive for some buildings to switch to better performance heat pump technologies (e.g.

in new construction, where it is easy to install). Paired with the right incentives and ample market demonstration, this could include some vintage building stock (e.g. detached dwellings), which could choose heat pumps if natural gas prices increase slightly. When energy or carbon performance requirements are included, some hard-to-convert buildings (e.g. multi-family units in dense urban centres) could switch to modern district energy solutions where available, or business models such as ESCOs and on-bill financing could implement cost-effective efficiency improvements for them. Others may remain with natural gas-fired equipment but invest in building envelope measures.

Strengthening institutional capacity

If governments and relevant stakeholders around the world are to ramp up efforts for the buildings sector to transform in the clean energy transition, there needs to be a corresponding boost of institutional capacity. This requires training of policy makers and industry professionals, and the strengthening of capacity of governments and relevant institutions to plan, implement, monitor, enforce and evaluate comprehensive policy responses (Box 3.4).

Box 3.4. International Energy Agency Clean Energy Transitions Programme

The Clean Energy Transitions Programme (CETP) leverages IEA energy expertise across all fuels and technologies to accelerate global clean energy transitions, particularly in major emerging economies. The programme includes collaborative analytical work, technical co-operation, training, capacity building and strategic dialogue.

Under the CETP, the Energy Efficiency for Emerging Economies (E4) Programme supports the expansion of energy efficiency activities that generate economy-wide benefits in countries such as Brazil, China, India, Indonesia, Mexico and South Africa, as well as with regional and multilateral platforms including the Association of Southeast Asian Nations (ASEAN) and G20. The E4 Programme works with target country governments based on areas of interest including projecting the potential for energy efficiency to inform national policy, tracking progress and assessing impacts and adapting polices to achieve greater impacts. The programme also works with countries to quantify and communicate the multiple benefits of energy efficiency with the objective of engaging leaders, ministries and other influential stakeholders.

Source: https://www.iea.org/cetp/

Training and capacity building

Robust policy implementation and management requires good policy design and sufficient resources and institutional capacity to achieve cost-effective and desired outcomes. This includes the capacity to design effective policy packages and to monitor their progress relative to targets. Without training and capacity building, policy makers and stakeholders in the buildings sector may not be able to deliver the energy transition effectively. In particular, countries with little experience with building energy codes and energy efficiency policy generally require support to establish and strengthen institutional capacity for all aspects of the policy cycle (design, implementation, monitoring, verification and evaluation). International efforts in this area can help to ensure the rapid transition towards sustainable buildings.

Effort is also needed to share best practice, lessons learned and innovative approaches to deploy energy-efficient and low-carbon solutions in the buildings sector. Good policy design (from formulation of rationale and objectives to appraisal of policy options) can be found across a number of buildings-related platforms, including the Global Alliance for Buildings and Construction, which seeks to mobilise and enable all stakeholders in the buildings and construction value chain to scale up climate actions.

The building sector has a wide array of stakeholders from builders, contractors, designers (e.g. architects, engineers), industry and retail (e.g. material, equipment), property owners (e.g. private, public), service companies (e.g. surveyors, ESCOs, facility managers, developers and lawyers) and finance (e.g. investors, banks, insurance companies). Stakeholder engagement is vital, as it offers opportunities to ensure compliance and gain feedback, and to build trust with those that will be affected or will be able to support the implementation of policies. Making use of appropriate partners who have knowledge and resources is important, whether they be other government departments, industry, consumer organisations or international collaboration. Online tools can increasingly be used to manage policy programmes effectively.

Stakeholder engagement has an additional benefit, which is growth in the number of actors working to promote and ensure high-performance, low-carbon building solutions. Governments can enable market change by "training the trainer", which often has relatively low costs. This can ensure that decision makers are aware of solutions that are in line with policy objectives when making investments. For example, France has a media campaign to promote residential retrofits by private owners. The French government has worked with non-profit organisations to provide free and independent advice to help homeowners choose appropriate solutions for building renovation projects. It is also using renovations in schools to communicate the value of sustainable buildings with teachers, children and parents (IEA-UN, 2018).

Another example is a programme in Mexico to establish a growing market of specialised suppliers and professionals. To ensure that technologies are included in building sustainability programmes, significant efforts and investments have been made in capacity building, including communicating evidence of performance and durability. The government in Mexico has trained about 1 500 architects and engineers in the use of a sustainable housing simulator and it expects to increase this number through related academic programmes.

The World Green Building Council's "Build Upon" project has brought together since 2015 over 2 000 diverse stakeholder organisations at more than 100 workshops across Europe to support the design and implementation of national renovation strategies, as required under the European Union's Energy Performance of Buildings Directive. The project aims to overcome a key barrier to delivering successful renovation policy, the lack of large-scale structured collaboration between stakeholders across the value chain that impedes the impact of policies for renovation in the buildings sector (Build Upon, 2019). The project mapped the key challenges to renovation, including awareness raising, skills and capacity building, financial, economic, policy and regulation, organisational and administrative factors. This led to the development of an online platform, the "RenoWiki", which identified key initiatives to tackle the barriers in each of the 13 countries in the project. The first phase of the project concluded in 2017 with a series of recommendations and actions for how each country can overcome the key barriers to renovation. The second phase of the project will focus on working across multiple level(s) of governance to support the implementation of these recommendations.

The IEA is committed to developing capacity to strengthen energy policy and has trained policy makers from emerging economies since 2015 at multiple training sessions and through online courses (Box 3.5). Other avenues of support for capacity building in emerging economies include financing through the Global Environment Facility, development banks and various international support programmes, including foreign assistance programmes. For example, Viet Nam developed its equipment standards and labelling programmes with financial support from Australian Aid and experienced international experts (AusAid, 2019).

Box 3.5. International Energy Agency energy efficiency training events and online courses

The Energy Efficiency for Emerging Economies (E4) Programme, part of the IEA Clean Energy Transitions Programme, has been organising week-long training session since 2015 dedicated to sharing experience with planning, implementing, monitoring and evaluating energy efficiency policies in emerging economies. These training weeks have brought together more than 1 000 people from 90 countries to foster a community of energy efficiency practitioners. The aim of the training is to equip policy makers with knowledge and skills to be more effective in their roles.

An E4 training week consists of courses on energy efficiency in buildings, appliances and equipment, industry, transport, urban environment, and energy indicators and evaluation. Each course offers a mix of lectures, interactive discussions and practical exercises that allow participants to learn from international good practices and each other. Guest speakers and trainers are invited to provide further insights. The programme also includes collaborative sessions on assessing the potential for energy efficiency, tracking progress, communication campaigns and energy efficiency finance, as well as a special focus on measuring the social and economic benefits of energy efficiency measures.

In addition to the training weeks, the E4 hosts open access, self-paced online training courses in Energy Efficiency Indicators: Fundamentals of Statistics and Essentials for Policy Making. The online courses complement the training weeks by sharing methods and best practices in the development of energy efficiency indicators and their use for implementing policy that is more effective. The courses are being translated into Portuguese, Spanish, Chinese and Bahasa Indonesia languages. For more information, see: https://www.iea.org/topics/energyefficiency/e4/ .

Education and awareness tools

The success of energy efficiency programmes depends not just on implementing the right policies at the right time, but also including the people who have to implement and deliver the programmes. Behavioural and organisational changes can be important in enabling a long-term successful transition. Successful awareness raising programmes can enhance programmes and make them more effective.

One example is the "Energy Efficiency Awareness Program" in Canada (NRCAN, 2019). This successful programme outlines a series of steps, which provide a useful list for good practice.

The Global Alliance for Buildings and Construction also has a working group on awareness and education that is to develop common narratives and key messages around sustainable building and construction, including support for capacity building globally. Topics include the importance of targets, the need to increase the level of ambitions, making the case for finance and policies, bringing out multiple benefits, increasing demand for energy-efficient buildings and training building professionals.

International co-operation

Governments need to work together and with key stakeholders to ensure that markets around the world send effective signals to consumers and manufacturers to maximise efficiency and to limit the cost of future changes. Common targets for implementing building codes and MEPS for equipment and appliances can help market players to plan and deliver cost-effective, high-performance and low-carbon solutions for the buildings sector.

Governments and key stakeholders should collaborate to share best practices and lessons learned. This includes sharing data and information and working together to harmonise standards. Collaboration and dialogue help to avoid actions that "reinvent the wheel" and use scare resources more effectively.

Governments, utilities, industry and researchers should also collaborate on R&D and technology innovation to accelerate learning through shared experiences. The IEA has numerous multilateral technology initiatives that bring together researchers from across the world on a number of buildings-related topics (Box 3.6). Other useful partnerships include collaborations between multilateral organisations and national governments with universities, research organisations and manufacturers.

Box 3.6. International Energy Agency Technology Collaboration Programmes

The Technology Collaboration Programmes (TCPs) are independent, international groups of experts that enable governments and industries from around the world to take part in programmes and projects on a wide range of energy technologies and related issues. Today the TCPs involve more than 6 000 experts worldwide who represent nearly 300 public and private organisations located in 55 countries. To date, participants have examined around 2 000 energy-related topics and carried out projects on socio-economic aspects of technology deployment, research to reduce emissions, advancing demonstration of innovative technologies and contributing to benchmarks and international standards.

Several TCPs look to advance the research, development, demonstration and deployment of energy technology solutions for sustainable buildings. They include TCPs on Buildings and Communities, District Heating and Cooling, Energy-Efficient End-Use Equipment, Energy Storage), Heat Pump Technologies, Solar Heating and Cooling, Demand-side Management and Smart Grids. For more information, see: www.iea.org/tcp.

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

4E	IEA Technology Collaboration Programme on Energy Efficient End-use Equipment
AC	air conditioner (or air conditioning)
ANZ	advancing net zero
ASEAN	Association of Southeast Asian Nations
BPIE	Buildings Performance Institute Europe
CCUS	carbon capture, utilisation and storage
CFL	compact fluorescent lamp
CO_2	carbon dioxide
COP21	21^{st} Conference of Parties
E4	IEA Energy Efficiency in Emerging Economies programme
EBC	IEA Technology Collaboration Programme on Energy in Buildings and Communities
EBRD	European Bank for Reconstruction and Development
ECES	IEA Technology Collaboration Programme on Energy Storage
EEFW	Efficient World Financing Forum
EESL	Energy Efficiency Services Limited (India)
EIB	European Investment Bank
ESCO	energy service company
ETP	IEA *Energy Technology Perspectives*
FTS	Faster Transition Scenario
GHG	greenhouse gas
GlobalABC	Global Alliance for Buildings and Construction
HPT	IEA Technology Collaboration Programme on Heat Pumping Technologies
HVAC	heating, ventilation and air conditioning
ICE	internal combustion engine
IEA	International Energy Agency
IFI	international financial institution
IPCC	International Panel on Climate Change

LED	light-emitting diode
MEPS	minimum energy performance standard
NDC	nationally determine contribution
NPS	New Policies Scenario
PV	solar photovoltaic
R&D	research and development
SDG	sustainable development goal
Shine	Standard Harmonization Initiative for Energy Efficiency
TCEP	IEA Tracking Clean Energy Progress
TEG	technical expert group
TCP	IEA Technology Collaboration Programme
TFS	technology forcing standard
UNFCCC	United Nations Framework Convention on Climate Change

Units of measure

°C	degree Celsius
CHF	Swiss franc
EUR	euro
g	gramme
gCO_2	gramme of CO_2
GBP	British pound
Gt	gigatonne (billion tonnes)
GW	gigawatt (billion watts)
GtCO2	gigatonne of CO_2
INR	Indian rupee
kWh	kilowatt-hour (thousand watt-hours)
lm/W	lumens per Watt
m^2	square metre
Mtoe	megatonne (million tonnes) of oil equivalent
tCO2	tonne of CO_2
TWh	terawatt-hour (10^{12} watt-hours)
USD	United States dollar
W/cm^2	watts per square centimetre

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Typeset in France by IEA – April 2019

Cover design: IEA.