International Energy Agency

# Energy Efficiency 2019

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# INTERNATIONAL ENERGY AGENCY

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# Foreword

The IEA views energy efficiency as the "first fuel" of all energy transitions. Our Efficient World Strategy, published in last year's edition of this report, provided a blueprint showing how energy efficiency alone could enable energy sector greenhouse gas emissions to peak before 2020, achieving the energy efficiency target in the Sustainable Development Goals. Unfortunately, data from 2018 reveal that the world is veering away from this pathway.

In 2018, global primary energy intensity improved by only 1.2%, the slowest rate since the start of the decade and the third consecutive year that energy intensity improvements have weakened. This trend is worrying in a world where there is a growing disconnect between political statements and global energy-related greenhouse gas emissions, which, in 2018, grew at their fastest rate since 2013.

As *Energy Efficiency 2019* highlights, the rate at which technologies and processes are becoming more energy efficient is slowing, while structural factors are curbing the power of these technological gains to improve energy intensity. If these trends continue, energy efficiency will need to increase much more quickly to achieve a level of energy intensity improvement consistent with meeting global climate change and sustainability goals.

These findings should trigger immediate action by energy efficiency policy makers and investors. We know that the technologies exist to raise the energy intensity improvement rate to 3%, more than double today's level, and that these technologies are commercially available and cost-effective. To drive their uptake, ambitious policies are required to drive a scale-up in investment.

One area where policy makers could start is digitalisation. *Energy Efficiency 2019* shows how a range of digital technologies accompanied by the right policies could improve energy efficiency in industry, buildings and transport. To harness the power of digital technologies to deliver further gains in energy efficiency, energy policy makers will need to engage with a range of challenging issues.

The IEA will be an active partner, helping all countries to meet the challenge of ramping up efficiency and realising the benefits of digitalisation. I am very proud that in the last year alone we have trained almost 500 policy makers from 100 countries, connecting policy makers all over the world to exchange experience and knowledge.

Other responses to the need for urgent action are emerging. In September, 15 leading countries formed the Three Percent Club, signalling their commitment to help ensure that global energy intensity improves by at least 3% per year. In addition, a group of global leaders have been convened to form the Global Commission for Urgent Action on Energy Efficiency to influence policy at the highest levels. They will work together to identify ways to achieve breakthroughs in energy efficiency policy that are commensurate with the scale of urgency. I will be following these initiatives closely and look forward to them bearing fruit in the near future.

**Dr. Fatih Birol**
**Executive Director**
**International Energy Agency**

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The individuals and organisations that contributed to this study are not responsible for any opinions or judgements it contains. Any error or omission is the sole responsibility of the IEA.

For questions and comments, please contact EEfD (energy.efficiency@iea.org).

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# Executive summary

## Energy intensity improvements continued to slow in 2018

**In 2018, primary energy intensity – an important indicator of how much energy is used by the global economy – improved by 1.2%, the slowest rate since 2010.** This was slower than the 1.7% improvement in 2017 and marked the third year in a row the rate has declined.[1] It was also well below the average 3% improvement consistent with the IEA Efficient World Strategy.

**The slowdown represents a lost opportunity.** For example, although the 1.2% improvement in energy intensity meant that the world generated USD 1.6 trillion (United States dollars) more GDP for the amount of energy used compared to 2017, this figure would have been USD 4 trillion, an amount close to the size of the German economy, had energy intensity improved at 3% every year since 2015.

**A range of short-term factors contributed to the slowdown in global energy intensity improvement.** On the demand side, energy-intensive industries in the People's Republic of China ("China") and the United States (amongst others) increased their share of industrial production and pushed up demand for all primary energy fuels. Weather also played a role: In the United States, a cooler winter and a warmer summer drove up energy use for both heating and cooling. In Europe, a milder winter cut gas demand for heating, a major factor behind a 2% improvement in energy intensity, up from 1.4% in 2017. On the supply side, after three years of flat growth or decline, coal power generation increased in 2017 (3%) and 2018 (2.5%) to supply stronger electricity demand growth. More fossil fuel-based electricity generation increases primary intensity because energy is lost when these fuels are converted from primary to final energy.

**Longer-term structural factors are also playing a part in the slowdown.** While technologies and processes are becoming more efficient, structural factors are dampening the impact of these technical efficiency gains on energy demand, and slowing global energy intensity improvements. In industry, the impact of structural change away from energy-intensive industries, has gradually weakened since 2013. In 2018, structural change in industry actually added to energy demand. In transport, despite improvements in vehicle efficiency, energy intensity is worsening because sales of new, more efficient vehicles have slowed, consumers are preferring larger cars, and typical vehicle occupancy rates have fallen. In residential buildings, structural changes, such as increased device ownership and use, and a significant growth in average per capita residential floor area in all economies, have consistently matched or outpaced efficiency gains since 2014.

If these structural trends continue, technical efficiencies will need to increase much more rapidly to achieve a level of energy intensity improvement consistent with meeting global climate change and sustainability goals.

[1] Energy intensity is the amount of primary energy required to produce one unit of gross domestic product (GDP). In this report, energy intensity is said to "improve" when less energy is needed for a given activity. An energy intensity improvement is expressed as a positive number, while a worsening of energy intensity is expressed as a negative number.

# Technical efficiency improved in 2018, but significant potential remains

**The impact of technical efficiency improvements has been slowing down.** The annual impact of technical efficiency improvements on demand has almost halved between 2015 and 2018, from 2.5% of final demand to 1.4% of final demand. Despite this, technical efficiency improvements in the years 2016-18 resulted in energy demand being 4% lower than it would have been without efficiency gains, a slight increase from the period 2013-15.

**Technical efficiency gains continue to deliver cuts in energy-related emissions**. Between 2015 and 2018, technical efficiency improvements reduced energy-related carbon emissions by 3.5 gigatonnes of carbon dioxide ($GtCO_2$), roughly the equivalent of the energy-related emissions of Japan over the same period, helping to bring the world closer to an emissions trajectory consistent with achieving global climate change goals.

**Importing countries reduced their exposure to oil market instability through technical efficiency improvements.** In 2018, efficiency improvements since 2000 reduced oil imports in the world's major economies by over 165 million tonnes of oil-equivalent (mtoe), similar to the combined annual primary oil demand of Germany, Australia and Belgium. This had signifcant financial benefits for oil importers. For example, in 2018 Japan spent USD 20 billion less on imported oil thanks to a 20% reduction oil imports due to efficiency improvements since 2000. China reduced spending on imported oil by a similar amount, as efficiency gains since 2000 cut oil imports equivalent to 10% of total imports.

**IEA members reduced their spending across all fuels thanks to technical efficiency improvements.** Between 2015 and 2018 energy expenditure in IEA member countries was more than USD 100 billion lower thanks to efficiency gains, with cumulative avoided expenditure since 2000 reaching USD 600 billion in 2018.

**Growth in the coverage of mandatory efficiency policies was marginal in 2018, and almost exclusively due to existing policies.** The strength of mandatory policies increased by less than 0.5%, still below the five-year historical average, indicating more can be done to ensure mandatory policies are effective. The coverage and strength of energy efficiency obligation programmes remained largely unchanged.

**Levels of investment targeting efficiency have remained largely unchanged since 2014.** At USD 240 billion, incremental efficiency investments across the buildings, transport and industry sectors were less than 1% higher in 2018 than in 2017, still well below the levels required to capture the cost-effective opportunities available.

# Digitalisation can unlock greater efficiency if barriers are removed

**Digitalisation is modernising energy efficiency and increasing its value**. By increasing the connectivity of the world's buildings, appliances and equipment and transport systems, digitalisation provides energy efficiency gains beyond those possible when energy end-uses remained disconnected. At a time of deep change in the energy system, with larger shares of intermittent generation being added to electricity systems, digitalisation is also making demand-side energy efficiency a more valuable resource than in the past. This is because in addition to providing gains in end-use efficiency, many digital technologies also provide other services, such as flexible load, that increase the efficiency of the entire system. While end-use efficiency has always had system benefits, digitalisation allows for these benefits to be measured and valued more quickly and more accurately.

**Digital technologies could benefit all sectors and end-uses, but uncertainty about the scale of the benefits remains**. Digitalisation could reduce global buildings sector demand by up to 10% between 2017 and 2040. Digitalisation could also increase demand response capacity more than ten-fold, by unlocking new sources of flexible load in the buildings and transport sectors. However, the exact scale of these impacts is uncertain, and depends on policy responses, which also need to consider the risk of increased energy demand from the growth of digital devices. More evidence is needed on how digital technologies could combine to deliver system-wide improvements, and how rebound effects might curtail their benefits if the spread of digital devices increases energy use.

**Digitalisation is often not driven by energy efficiency, but can be harnessed for this purpose**. Digital technologies are becoming ubiquitous for a number of reasons, but not always for efficiency or energy management. The industry sector has been faster than other sectors to adopt digital technologies, as businesses often have several motives for digitalising their operations: from increasing productivity, to improving safety. Similarly, in buildings and transport, digital technologies have been adopted for reasons such as commercial gain, or convenience. However, these technologies present a largely untapped opportunity for increasing energy efficiency in all sectors, and business models that recognise this are starting to emerge.

**Policy could accelerate the adoption of digital technologies for energy efficiency but policy focused on digital technologies for efficiency is still rare**. Policies targeting digital technologies for efficiency are only just starting to emerge. The IEA has identified a set of critical policy considerations within its new Readiness for Digital Energy Efficiency policy framework. The framework is designed to ensure the benefits of digital energy efficiency are realised through policies that address a range of issues: from balancing data accessibility with data privacy, to helping remove regulatory barriers to innovation.

**The slowdown in global energy efficiency improvement, despite the potential for cost-effective savings, underscores the need for urgent policy action**. New ways of policy thinking that move beyond traditional approaches are required, particularly to maximise the potential efficiency gains from digitalisation. The Global Commission for Urgent Action on Energy Efficiency brings together national leaders, ministers, top business executives and global thought leaders to consider how to accelerate global progress on energy efficiency. The Commission will publish its recommendations in mid-2020, which will be explored in next year's edition of this report.

# I. Demand and energy intensity

## Highlights

- Global primary energy demand rose by 2.3% in 2018, driven in large part by the People's Republic of China ("China"), India and the United States, which were responsible for 70% of demand growth. In the United States, primary demand increased for the first time since 2014.
- Primary energy intensity – an important indicator of how much energy is used by the global economy – improved by 1.2% in 2018, the slowest rate since 2010. This was slower than the 1.7% improvement in 2017 and marked the third year in a row the rate has declined. It was also well below the average 3% improvement that would be consistent with the IEA Efficient World Strategy.
- Primary intensity improvements varied by region. In China and India, primary intensity improved by almost 3%, a slight drop on 2017 levels. In Europe, it improved by 2%, up from 1.4% in 2017. In the United States, primary intensity worsened for the first time in over 25 years.
- In 2018 final demand (total final consumption) grew by 2.2%, continuing an increasing trend since 2015, driven by strong growth in energy-intensive industries. In addition, exceptional weather led to higher gas and electricity use in buildings in many parts of the world.

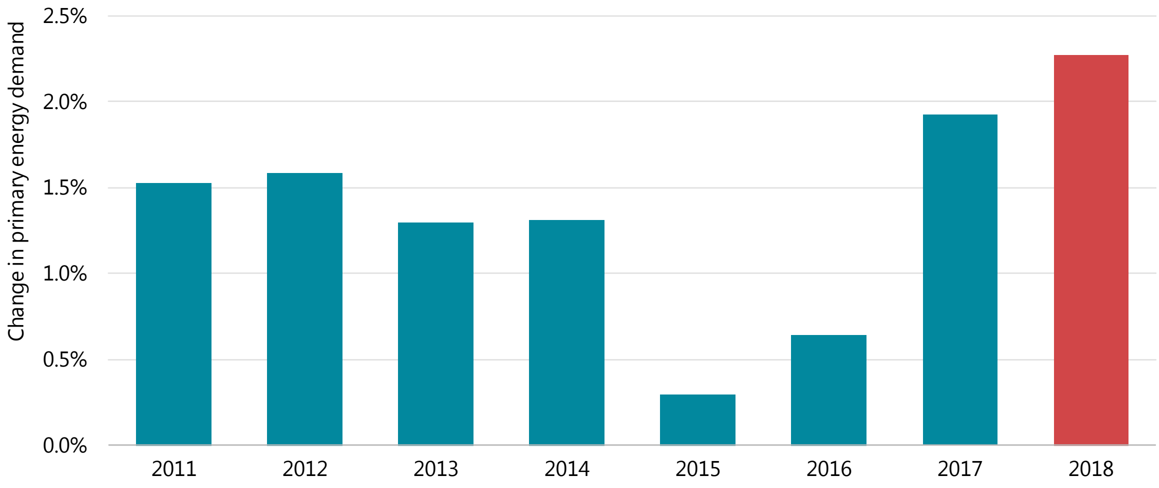
## Primary demand

Global total primary energy demand[1] grew by 2.3% in 2018 (Figure 1.1), the largest increase since 2010. The People's Republic of Chin ("China"), the United States and India together accounted for 70% of the rise in energy demand, up from 43% in 2017. Twenty-five percent of global demand growth occurred in the United States, a significant deviation from recent trends. United States primary demand increased by more than 3.5%, the highest growth in decades following three years of declining demand, while Chinese and Indian primary demand grew at 3.5% and 4% respectively, slightly above 2017 levels.

[1] *Primary energy demand* refers to total primary energy supply (TPES). TPES is made up of energy production plus energy imports, minus energy exports, minus international marine bunkers, minus international aviation bunkers, then plus or minus stock changes. For the world total, international marine bunkers and international aviation bunkers are not subtracted from TPES.

In total, fossil fuels accounted for 70% of the growth in primary demand, with gas comprising 46%, oil 15%, and coal 9%, outweighing the 24% increase from renewables in primary demand. Nuclear made up around 7% of the growth in primary demand (IEA, 2019b).

**Figure 1.1. Changes in global primary energy demand, 2011-18**

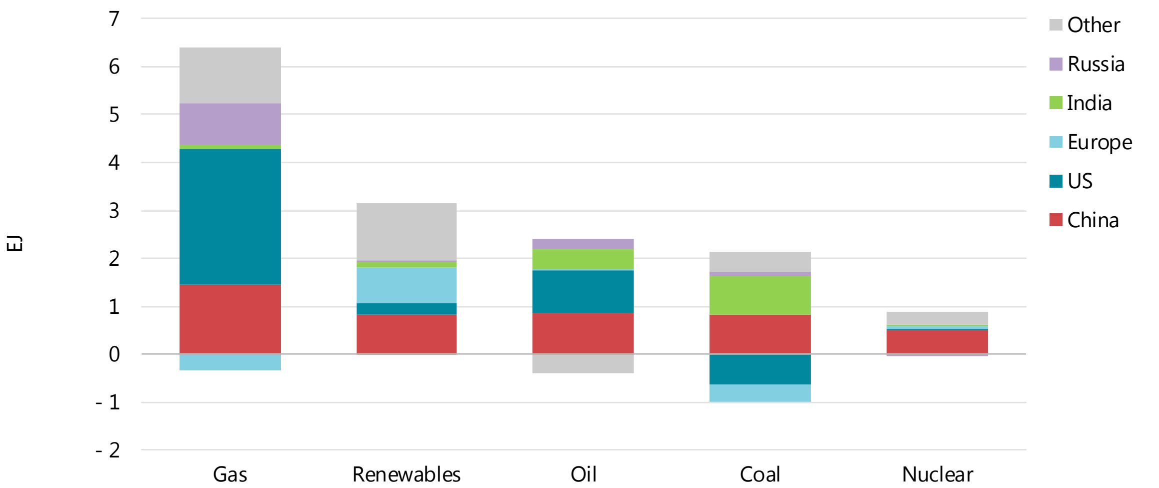





Sources: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database).

Global gas demand expanded at its fastest rate since 2010, with year-on-year growth of 6 exajoules (EJ), 4.6% higher than 2017 levels (Figure 1.2). Nearly half of the increase in gas consumption in 2018 occurred in the United States, where demand expanded by 2.8 EJ (10.5% higher than 2017 levels), particularly for use in electricity generation: the share of gas in generation rose from 31% to 35%. Similarly, the United States and China also dominated the 2018 growth in oil demand, together accounting for around 80% of increased oil use.

**Figure 1.2. Global primary energy demand growth by fuel and leading regions, 2017-18**






Note: Russia = Russian Federation.
Source: IEA (forthcoming), *World Energy Outlook 2019*.

Coal demand increased by 0.7%, or around 1.1 EJ. Although the increase was small, 2018 was the second consecutive year in which coal demand grew, after two years of decline. Growth in primary coal demand was largely confined to emerging economies, particularly in Asia. In other major markets, coal use continued to decline.

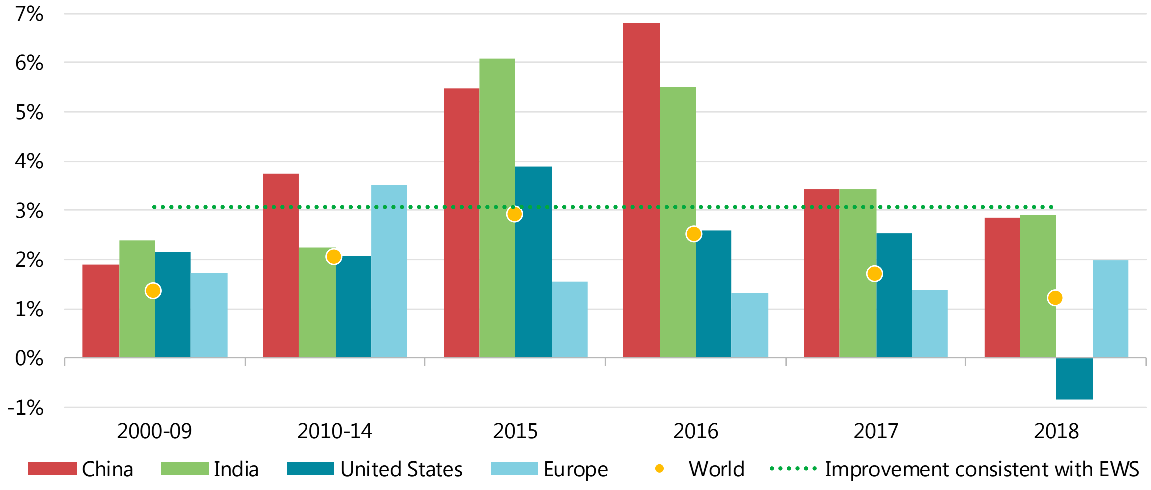
Around a quarter of the increase in primary demand was from renewable energy sources, with China and Europe responsible for around half of this increase.

The increase in primary energy demand – and the high proportion of fossil fuels in the energy mix – led to an increase in energy sector greenhouse gas emissions, which reached an historic high of over 33 billion tonnes of carbon dioxide (IEA, 2019b).

# Primary energy intensity

Despite the large increase in energy demand, primary energy intensity[2] continued to improve in 2018, with the global economy requiring an average of 1.2% less energy to produce each unit of GDP than in 2017. However, this 1.2% improvement continued a falling trend in the annual energy intensity improvement rate (Figure 1.3). This level of improvement is just over one-third of what could be realised through the actions described in the IEA Efficient World Strategy (EWS), as presented in the *Energy Efficiency 2018* report.

**Figure 1.3. Primary energy intensity improvement**






Source: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database).

Primary intensity improvement rates varied from region to region in 2018. In China and India, primary intensity improved by just under 3%, a slight drop on 2017 levels (Figure 1.3). In Europe, primary intensity improved by 2%, up from 1.4% the previous year. One noticeable exception was the United States, where primary intensity worsened by 0.8%, driven by exceptional weather and

[2] *Primary energy intensity* is primary demand per billion USD (United States dollars) of GDP (2018 USD), adjusted for purchasing power parity). In this report, energy intensity is said to "improve" when less energy is needed for a given activity. An energy intensity improvement is expressed as a positive number, while a worsening of energy intensity is expressed as a negative number.

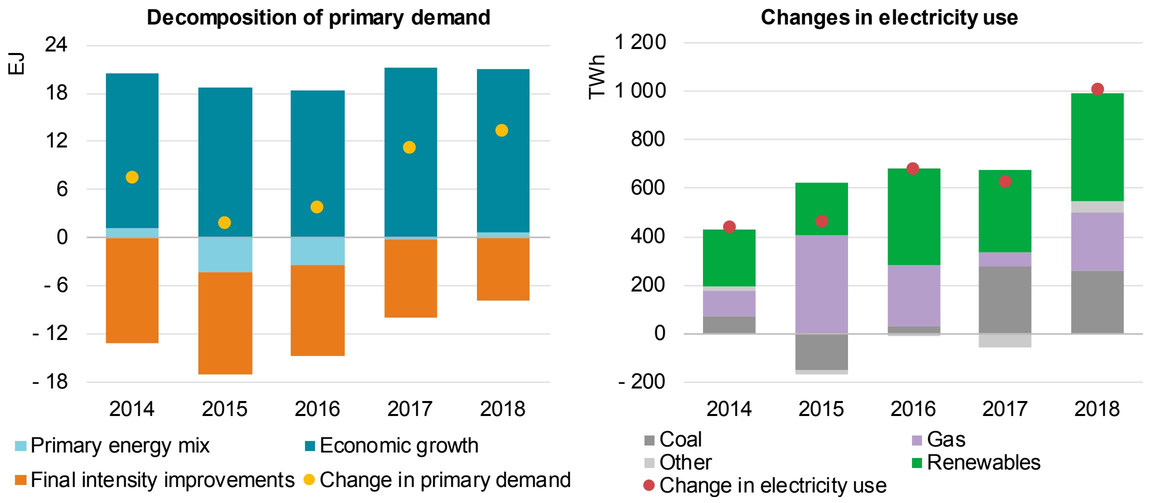
an expansion in energy-intensive industries, especially those using gas for heat production, such as the petrochemicals industry. This was the first time this century that US primary energy intensity has worsened.

The primary energy intensity improvement rate includes the impacts of both changes in energy demand and supply. For example, a larger share of non-combusted renewable energy in primary energy supply will improve primary energy intensity, because from a statistical perspective converting sunlight and wind into electricity is considered 100% efficient.[3] Conversely, fuels like coal, gas and nuclear experience conversion losses when used to generate electricity, so using relatively more of these fuels for electricity slows down primary energy intensity improvements.

In 2015 and 2016, the primary energy fuel mix became less energy-intensive, owing to more renewables and a move away from coal, which helped to reduce primary demand. However, these impacts were not observed in 2017 and 2018, leaving improvements in the final energy demand required to produce a unit of GDP (final intensity) as the only factor helping to reduce primary energy demand (Figure 1.4, left).

An important reason for this trend is the growth in global electricity demand, which rose by around 4% in 2018, the highest rate since 2010. Electricity demand continues to exceed the growth of renewable electricity generation in absolute terms (Figure 1.4, right). In 2018, growth in renewable electricity generation was estimated to be slightly less than half the growth in total electricity demand. While this is greater than its share in the global electricity mix, it meant that fossil fuel-based sources of power generation, which have greater thermal losses, were required to satisfy the majority of electricity demand growth, contributing to the lack of change in the primary energy mix. For example, coal-fired generation has grown by over 250 TWh in both 2017 and 2018, after three years of slow growth or decline (Figure 1.4, right).

**Figure 1.4. Decomposition of changes in global primary energy demand (left) and changes in global electricity use by generation source (right), 2014-18**





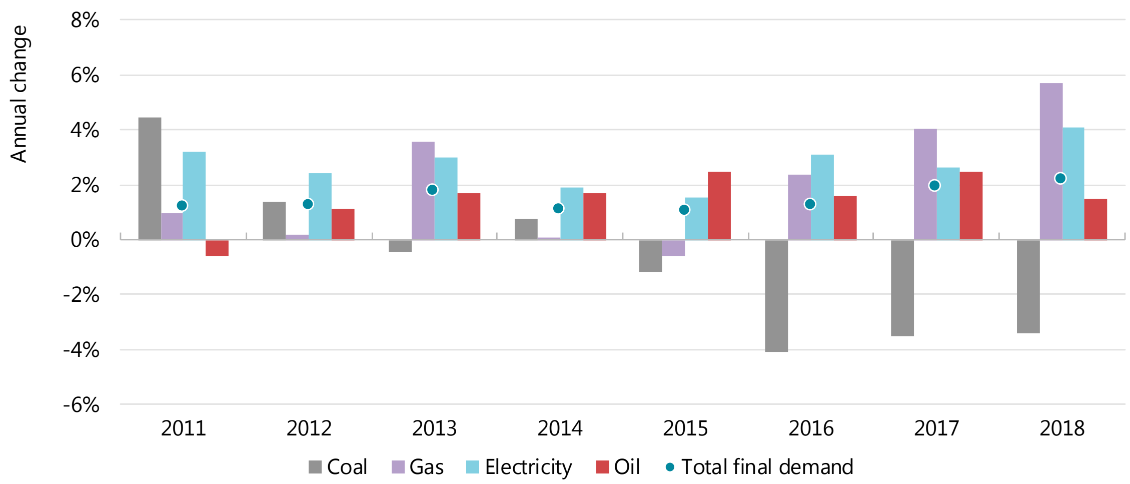

Source: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database).

[3] Although technically these processes are not 100% efficient since energy is lost during the conversion process, such losses are omitted from the IEA energy balances as these sources of renewable energy are free and unlimited.

# Final demand

To isolate the impacts of energy efficiency in the buildings, transport and industry sectors from the impacts of changes in energy supply, it is necessary to examine *final* energy demand[4] and intensity. Like primary energy demand, final energy demand also increased in 2018, by 2.2% (Figure 1.5).

**Figure 1.5. Change in global final demand, by fuel, 2011-18**






Source: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database).

Of the increase in final demand in 2018, growth was strongest in gas (5.7%) and electricity (4.1%). Gas demand growth was driven by its use in industry and buildings for heating. China continued to implement policies designed to shift households and businesses from coal to gas boilers, mainly for air quality reasons (Box 3.5). Electricity demand growth came mostly from the buildings sector as more people gained access to modern energy services and exceptional weather drove demand for heating and cooling.

Oil comprised the largest share of final demand, at around 41%, but demand growth slowed to 1.5% in 2018, a trend that has continued since 2015 when demand grew by 2.5%. In 2018, higher oil prices helped dampen demand for road transport fuels.

In 2018, demand for coal continued to decline (by 3.5%), partly due to switches from coal to gas, noted above, although since 2016, the annual rate of decline has slowed.

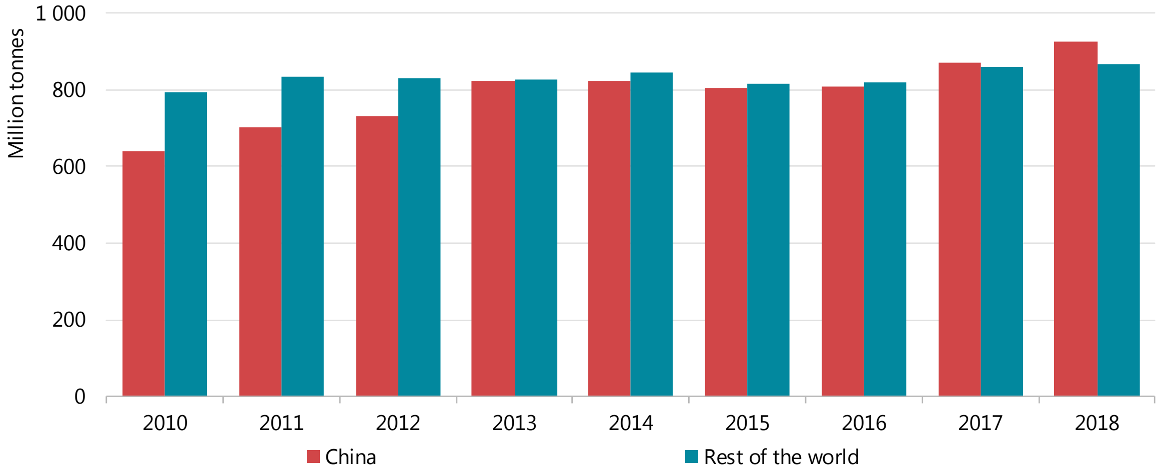
A key factor behind increased final demand was strong growth in energy-intensive industries, such as steel in China and petrochemicals in the United States.

[4] *Final demand* refers to total final consumption (TFC). TFC is the sum of consumption by the different end-use sectors and also includes non-energy use. Final demand is smaller than primary demand due to losses during the conversion of primary to final energy.

Chinese steel production continued to rebound in 2018, underpinning an increase in global production of over 3% (Figure 1.6). Chinese crude steel production increased nearly 8% in 2017 and 6% in 2018, up from -2% in 2015 and 0.5% in 2016 (World Steel, 2019).

Despite improvements in technical energy efficiency, Chinese steel production remains energy intensive, representing around 4% of global final energy use. Energy-intensive primary production routes, specifically those involving a coal-based basic oxygen furnace, are used in well over 80% of Chinese crude steel production. The use of electric arc furnaces – which are much less energy-intensive and are fed by scrap metal – is on the rise. However, demand for steel in China far outweighs the availability of scrap metal, so higher steel demand leads to higher blast furnace use and higher coal use.

**Figure 1.6. Global production of crude steel, 2010-18**

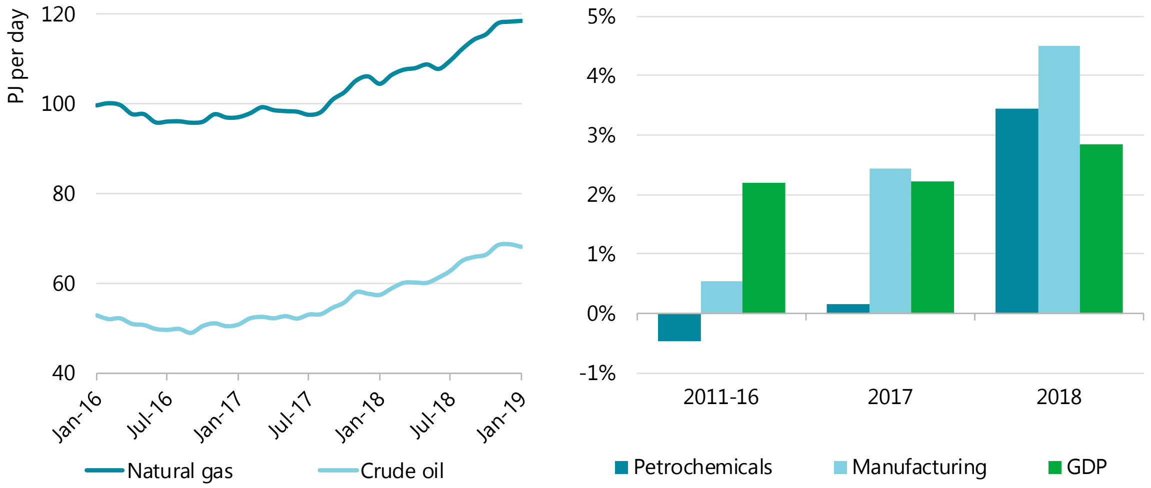



Notes: Iron and steel includes energy used in blast furnaces and coke ovens.
Sources: Adapted from World Steel (2019), *Total Production of Crude Steel*

## Rising gas demand underpins growth in the US petrochemicals sector

Increased final demand in the United States in 2018 was partly the result of greater activity in the petrochemicals sector. Between July 2017 and December 2018, average daily US natural gas extraction grew by 21% and crude oil extraction by 30%. Increased extraction flows through to oil refining and gas processing activity, which, in combination with higher oil prices, led to a nearly 3.5% rise in gross value added (GVA) in the US petrochemicals sector in 2018. This was the largest single year increase since 2013 (Figure 1.7) and contributed over 20% to the growth in US manufacturing GVA of nearly 4.5% in 2018, the fastest single year rise this decade.

**Figure 1.7. Average daily US natural gas and crude oil extraction, 2016-18 (left) and growth in US petrochemicals and manufacturing gross value added, 2011-18 (right).**

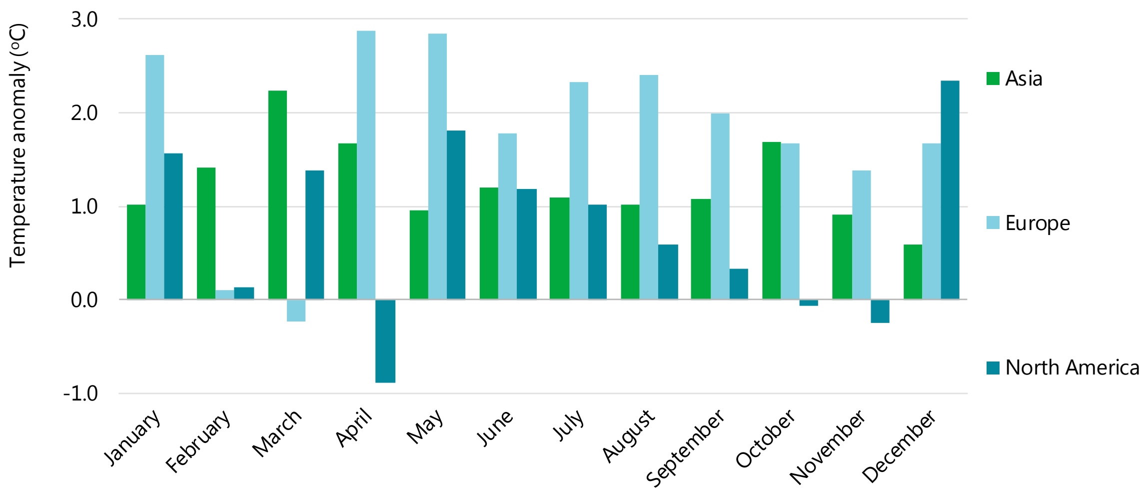



Notes: Petrochemicals includes petroleum and coal, chemical, plastics and rubber product manufacturing. Gross value added comparison based on real industry value added USD in millions of chained (2012) USD.
Source: EIA (2019a), Monthly Crude Oil and Natural Gas Production; BEA (2019), Gross Domestic Product by Industry.

## Exceptional weather drove up demand for space cooling and heating

Exceptional weather events, as seen in temperature anomalies in many parts of the world, spurred additional demand for both space cooling and heating. In Europe, average daily temperatures in 2018 were 1.8 °C above average, with temperatures in April, May, July and August all more than 2°C above average. Higher than average temperatures were also observed in Asia. In North America, while summer months were hotter than average, there were periods of the year when weather conditions were either close to or below historic averages, which were much lower than preceding years when higher than average temperatures were observed.

**Figure 1.8. Monthly temperature anomalies (compared with 1910-2000), by region, 2018**



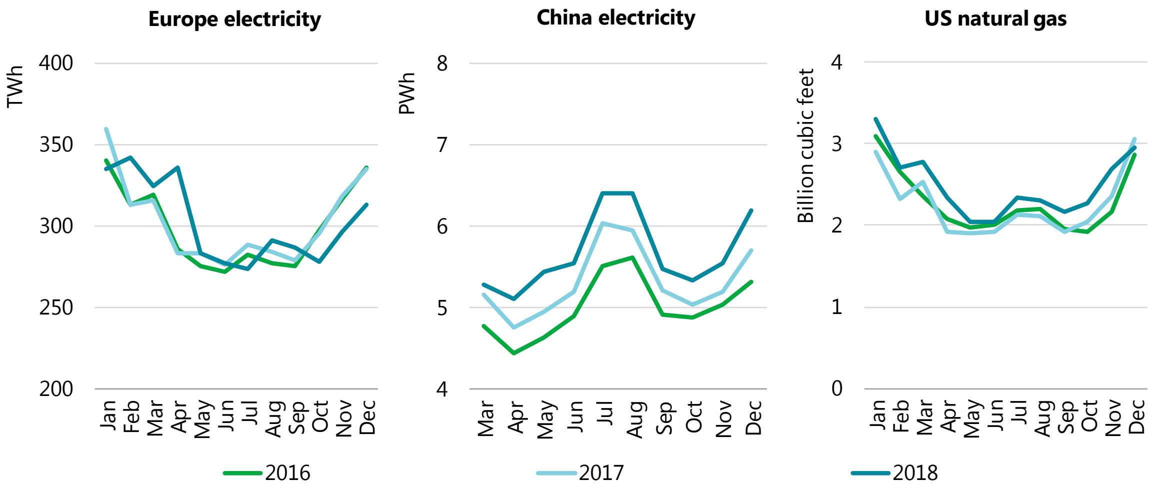

Source: NOAA (2019), *Climate at a Glance: Global Time Series*.

The weather events in 2018 were reflected in spikes in monthly electricity and gas consumption. In April 2018, temperatures in Europe were nearly 3°C higher than average, the highest ever recorded for that month. As a result, electricity consumption was nearly 20% higher than in April 2016 and 2017 (Figure 1.9). A smaller, but still noticeable, spike in electricity use was also observed in August, when temperatures were more than 2°C above average. However, the milder start to the European winter, when temperatures were around 1.5°C above average, correlated to a 7% drop in electricity consumption in October to December, compared with 2016 and 2017, with gas consumption in December nearly 10% lower than preceding years (Eurostat, 2019).

As electricity use in China is growing, reflecting increased living standards and demands for energy services, changes in energy use correlating to weather anomalies are not as readily identifiable as in Europe or North America. However, a spike was observed in May 2018, when temperatures were 1°C above average across the wider Asian continent.

In North America, temperatures below the long-term average were observed in April, October and November. While not as extreme as the above-average temperature anomalies, this weather was colder than the milder weather in these months in preceding years. Gas consumption in the United States rose 20% in April, 12% in October and 14% in November, compared with 2017, reflecting increased demand for space heating in the buildings sector.

**Figure 1.9. Europe and China monthly electricity consumption and US monthly gas consumption, 2016-18**




Source: ENTSO-E (2019), *Monthly Domestic Values*; CEC (2019), *Data/Statistics: Monthly Statistics of China Power Industry*; EIA (2019b), *Natural Gas Monthly*.

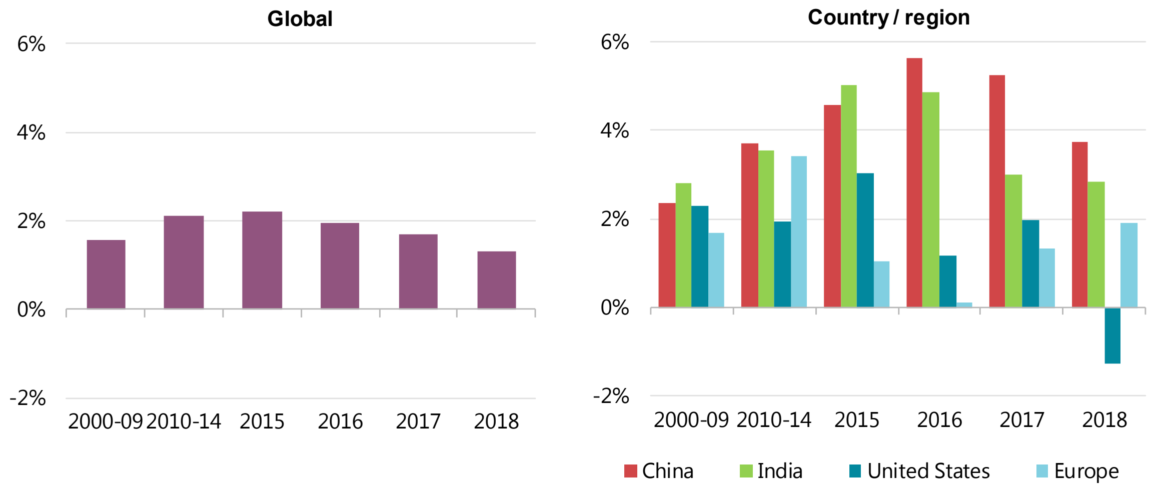
# Final energy intensity

Final intensity[5] improved by 1.3% in 2018, the lowest rate since 2010, continuing the slowing trend since 2015. However, regional differences were notable. Europe's rate of final intensity improvement increased to nearly 2%, the highest rate of improvement since 2014, up from 1.3% the previous year. Chinese final energy intensity improved by around around 3.7%, down from

[5] *Final intensity* is final energy demand per billion US dollars of GDP (2018 dollars, adjusted for purchasing power parity).

5.3% the previous year. This was nearly a third higher than the primary intensity improvement rate, indicating that much of the increase in Chinese primary demand was driven by supply-side factors, such as more coal-based electricity production. In the United States, final intensity worsened by 1.3%, which, due to the reasons discussed above under *Primary energy intensity*, was the first worsening of energy intensity since 2013.

**Figure 1.10. Final energy intensity improvement**






Source: IEA (forthcoming), *World Energy Outlook 2019*; IEA (2019a), *World Energy Balances 2019* (database).

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# II. Why are energy intensity improvements slowing?

## Highlights

- Between 2015 and 2018, the amount of energy demand required to produce a unit of GDP – global primary energy intensity – continued to improve, but the annual rate of improvement steadily declined from 2.9% to 1.2%, the lowest level since 2010.

- Factors behind the recent slowdown in energy intensity improvement include supply-side changes, such as an increase in the use for electricity generation of energy-intensive primary fuels, which experience losses when converted to final energy. For example, coal-fired generation increased by 3% in 2017 and 2.5% in 2018, after three years in which growth was either flat or negative.

- On the demand side, recent shifts in the composition of economic output towards energy-intensive industries in some of the world's largest economies (particularly the People's Republic of China ["China"] and the United States), have increased global energy intensity. In 2018, exceptional weather also drove up demand for gas and electricity used for space cooling and heating.

- Longer-term trends compounded these short-term changes. While technical efficiency has improved in all sectors of the economy, structural factors are blunting its impact.

- In industry, the impact of structural change away from energy-intensive industries, which helps to reduce energy intensity, has gradually slowed since 2013. In 2018, structural change in industry actually added to energy demand.

- In residential buildings, structural impacts have increased energy demand by 1.4% on average per year since 2014, while technical efficiency improvements reduced demand by only 0.9% on average per year over the same period. These structural impacts are partly driven by people gaining access to modern energy services for the first time and partly by changing consumer preferences and behaviours.

- The impact on energy intensity from the growth in digital devices is still unclear and the sector is changing quickly. While digital devices, networks and servers now consume around 800 TWh per year, their impact on global energy demand has been offset by technical efficiency improvements. As a result, energy demand from these devices has remained steady in recent years.

# Introduction

As detailed in Chapter 1, global primary energy intensity improved by 1.2%, the slowest rate since 2010 and a steady decrease since 2015. Understanding the causes of the recent slowdown in improvement may help identify ways in which technical energy effiecincy, amongst other measures, can help to reverse the trend.

The slowdown in primary energy intensity improvement between 2015 and 2018 can be attributed to a combination of supply- and demand-side factors. On the supply side, the last two years have seen a small but significant rebound in the use of energy-intensive fossil fuels, such as coal for electricity generation (see Chapter 1, "Primary energy intensity" section).

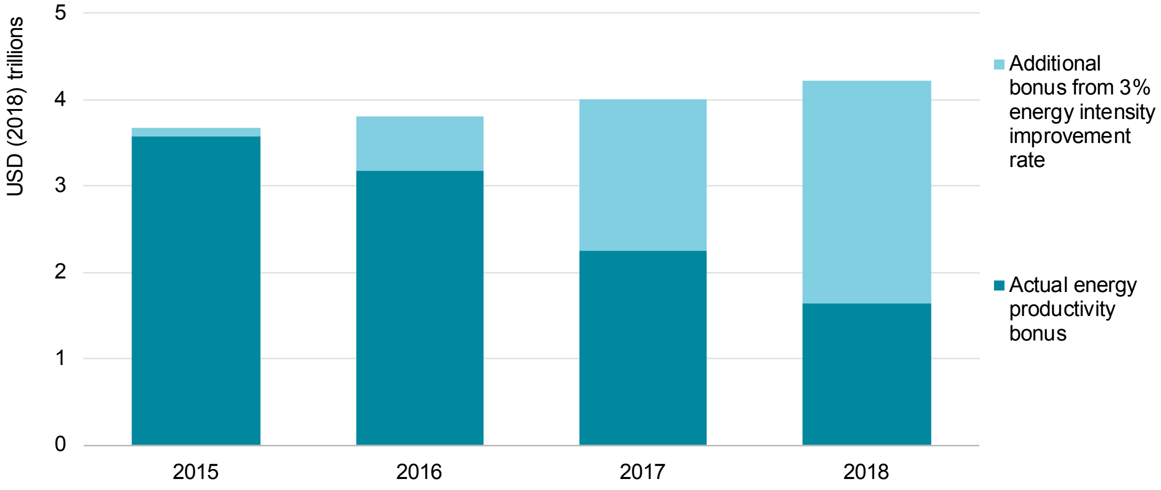
On the demand side (on which the remainder of this chapter is focused), a combination of short-term factors and longer-term trends contributed to the slowdown. Short-term factors include changes in the composition of the global economy in 2017 and 2018, and exceptional weather in 2018 (see Chapter 1, "Final demand" section).

In the longer term, while technical efficiency has improved in recent years, it has not improved fast enough to offset the impact of structural factors. In industry, structural factors include a slowdown in the shift away from energy-intensive production, which had been helping to decrease energy intensity in the previous ten years. In the residential buildings and transport sectors, structural factors, including purchasing decisions and energy users' behaviour, are slowing the rate of energy intensity improvement.

## The slowdown in energy intensity improvement represents missed opportunities

The impact of primary energy intensity improvements can be represented by the additional GDP generated from global energy demand. In 2018, the 1.2% improvement in primary energy intensity represented just over USD 1.6 trillion (United States dollars) of additional GDP generated from global energy demand, referred to in previous versions of this report as an "energy productivity bonus".

**Figure 2.1 Additional economic value from energy intensity improvements**






Sources: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database).

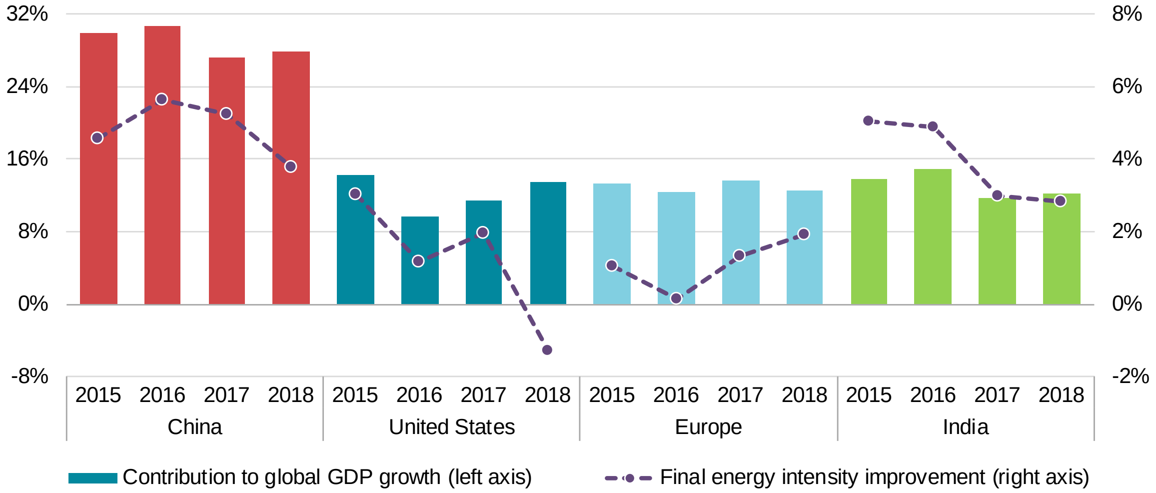
The slowdown in energy intensity improvement represents a lost opportunity to have generated more economic value from global energy demand, shrinking the energy productivity bonus. A primary energy intensity improvement of 3% in each year from 2015 onwards could have seen the energy productivity bonus in 2018 exceed USD 4 trillion, an amount close to the size of the German economy (Figure 2.1).

## Large economies determine the dynamics of the slowdown

Today, just four of the world's largest economies account for more than 60% of global GDP: China, Europe, India and the United States. As a result, changes in these economies have tended to influence strongly the direction of global energy intensity in recent years.

For example, in 2017, China's share of global GDP growth declined significantly, from 31% to 27%. This meant that a larger share of global economic output in that year came from countries whose energy intensity was improving more slowly than was China's 5.3% (Figure 2.1). The US share of global economic growth increased from 10% in 2016 to 11% in 2017, while its energy intensity improved by only 2%. Europe's contribution to economic growth increased by over a percentage point to reach 14% in 2017 while energy intensity improved by only 1.3% (Figure 2.1). The net result was that global energy intensity slowed down.

**Figure 2.2 Contribution to global economic growth and final energy intensity improvement**






Source: IEA (forthcoming), *World Energy Outlook* 2019; IEA (2019a), *World Energy Balances 2019* (database); IMF (2019), *IMF DataMapper*, www.imf.org/external/datamapper/PPPSH@WEO/OEMDC/ADVEC.

In 2018, China's contribution to economic growth grew by 1 percentage point but, owing to a greater share of energy-intensive production, its final energy intensity improved by only 3.8%, a large drop from 5.3% in 2017 (Figure 2.1). At the same time, the US contribution to global economic growth expanded by over 2 percentage points to 13.5%, while its energy intensity worsened for the first time since 2013. These dynamics, combined with minimal changes elsewhere in the global economy, played a key role in lowering global energy intensity improvements below 2017 levels.

# Recent changes in industry and exceptional weather compounded longer-term trends

As noted in Chapter 1 (see "Final demand" section), recent changes influencing global demand, and therefore intensity, include the following:

- A higher share of industrial output from energy-intensive heavy manufacturing. Chinese steel output has rebounded strongly (8% in 2017 and 6% in 2018) after contracting by -2% in 2015 and growing by only 0.5% in 2016. The Chinese steel sector is a significant driver of yearly changes in energy intensity. Manufacturing in the United States also expanded over the last two years, particularly in energy-intensive sectors such as petrochemicals. A shift toward energy-intensive industry in the United States and China – the world's largest and second-largest economies – tends to translate into a higher share of energy-intensive economic output globally.
- Exceptional weather events in 2018 increased demand for heating and cooling at different times of the year (see Chapter 1, "Final demand" section). Hotter than average months increased air conditioning use, while cooler winter weather returned to several northern hemisphere countries, following milder winters during the previous few years that had reduced heating demand.

These recent changes, which affected energy intensity in the world's largest economies, compounded underlying trends that continued to contribute to a slower rate of energy intensity improvement.

# The impacts of improved technical efficiency are being blunted by other factors

Longer-term trends have also played a role in influencing year-on-year changes in energy intensity improvement, specifically:

- Improvements in technical efficiency have been underpinned by progress in the industry and service sectors, however there are signs the pace of improvement is slowing.
- The impact on energy use from structural shifts away energy-intensive industry to less energy-intensive services is slowing down.
- In the transport and residential buildings sectors, structural factors are reducing the impact of technical efficiency improvements.

These factors are explained in more detail below.Between 2015 and 2018, final demand in the world's largest economies[1] grew by over 4%, a slight increase on the growth between 2012 and 2015 (Figure 2.2). Factors contributing to changes in final demand can be broken into:

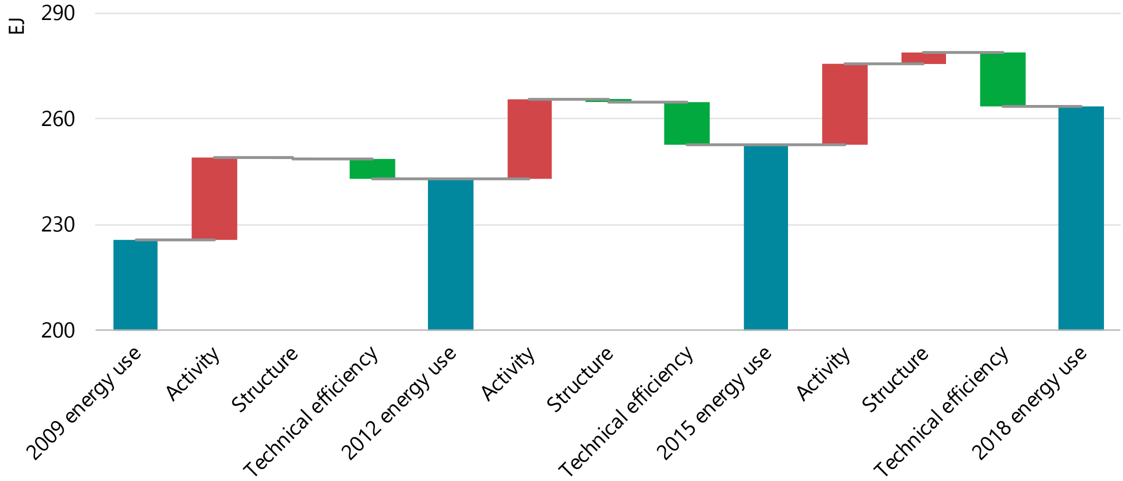
- Activity effects: changes in energy-using activities, such as industry value-added, tonne or passenger kilometres travelled, climate and population. Between 2015 and 2018, increasing activity levels in the world's major economies created over 9% more energy use, similar to growth in the other three-year periods since 2009 (Figure 2.2).

[1] Major economies are IEA member countries plus Argentina, Brazil, China, India, Indonesia, Russian Federation and South Africa.

- Structural effects: changes in the type of energy-using activities, such as the share of activity across various economic sectors, appliance ownership, number of buildings and floor area, and the share of different transport modes. Between 2015 and 2018, structural effects led to nearly 1.5% more energy use.
- Technical efficiency effects: changes in the amount of the energy used per unit of activity. Between 2015 and 2018, technical efficiency improvements avoided around 6% more energy use, a slight increase on the previous three years (around 5%).

An increase in energy-using activities drives up energy use, changes in structure can either increase or decrease energy use, while improved technical efficiency avoids energy use.

**Figure 2.3 Decomposition of final energy use in the world's major economies, 2009-18**






Note: Y-axis starts at 200 EJ. Major economies are IEA members plus Argentina, Brazil, China, India, Indonesia, Russian Federation ("Russia") and South Africa. "Energy use" covers the residential, industry and services, passenger and freight transport sectors. It excludes non-energy use (i.e. feedstocks) and energy supply. Similar to the analysis presented in *Energy Efficiency 2018*, the data for road freight tonne-kilometres and energy consumption in the United States have been revised for 2008-11 and 2000-15 respectively, leading to a change in the intensity of road freight compared with the previous values for the same years, impacting energy savings from this sector. The data have therefore been excluded from this analysis.

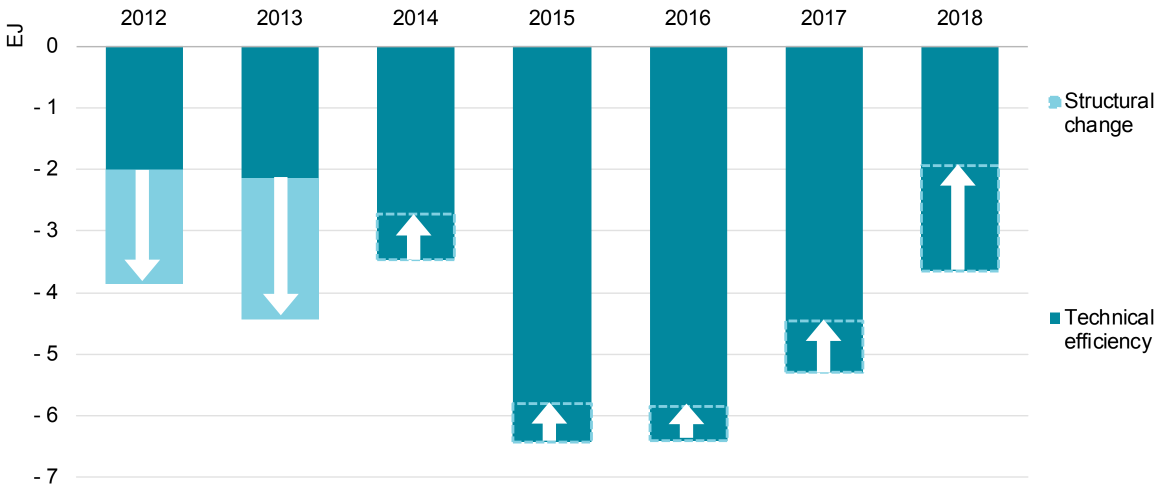
Sources: Adapted from IEA (2019b), *Energy Efficiency Indicators 2019* (database); IEA (2019a), *World Energy Balances 2019* (database); IEA (2019c), *Energy Technology Perspectives* (buildings model); IEA (2019d), *Mobility Model* (database); Timmers et al. (2015), *World Input Output Database* (database); IBGE (2019), *Quarterly National Accounts* (database); ADB (2019a), *People's Republic of China: Input-Output Economic Indicators* (database); ADB (2019b), *India: Input-Output Economic Indicators* (database); ADB (2019c), *Indonesia: Input-Output Economic Indicators* (database); StatsSA (2019), *Gross Domestic Product (GDP), 4th Quarter 2018* (database); Quantec (2018), *Industry Service – RSA Standard Industry – Input Structure at basic prices* (database); INDEC, Republica Argentina (2019), *Macroeconomic aggregates (GDP)* (database); World KLEMS Data (2019), *Russia* (database).

In the three years since the slowdown in energy intensity improvement began, technical efficiency improvements have reduced demand by a larger amont than the previous three-year period while the impact of structural effects has reversed: from helping to reduce demand to pushing demand up (Figure 2.2).

However, annual data reveal a more nuanced picture, showing that the annual impact of technical efficiency improvements has gradually declined since 2015 (Figure 2.3). This decline is a major reason for the slowdown in energy intensity improvement and reflects limited progress on policy and investment (Chapter 3).

Annual data also reveal that structural factors began adding to energy demand and blunting the impacts of technical efficiency as early as 2014, after two years in which they helped reduce demand (2012 and 2013). This switching may be partly linked to low crude oil prices during the period from 2014 through to mid-2017. Lower crude oil prices flowed through to lower energy prices and influenced energy-using behaviour, particularly in the transport sector, as evidenced by the increased adoption of larger passenger cars and lower occupancy rates.

**Figure 2.4 The combined impacts of technical efficiency improvements and structural effects on demand, annually, 2012-18**




Note: Negative values indicate years where technical efficiency improvements helped reduce final energy demand. The direction of arrows indicates if structural effects led to increases (upwards pointing) or reductions (downwards pointing) in final demand.

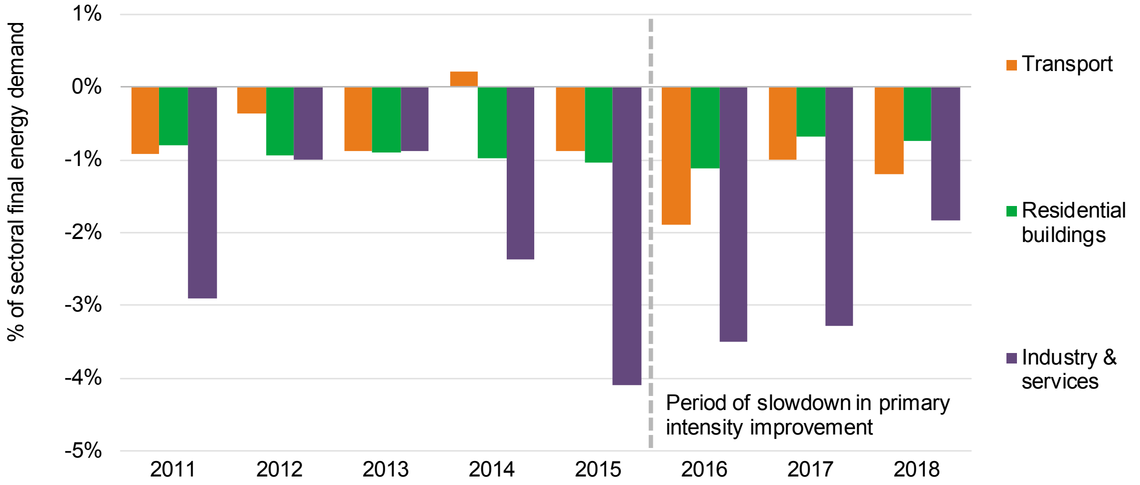
Sources: Adapted from IEA (2019b), *Energy Efficiency Indicators 2019* (database); IEA (2019a), *World Energy Balances 2019* (database); IEA (2019c), *Energy Technology Perspectives* (buildings model); IEA (2019d), *Mobility Model* (database); Timmers et al. (2015), *World Input Output Database* (database); IBGE (2019), *Quarterly National Accounts* (database); ADB (2019a), *People's Republic of China: Input-Output Economic Indicators* (database); ADB (2019b), *India: Input-Output Economic Indicators* (database); ADB (2019c), *Indonesia: Input-Output Economic Indicators* (database); StatsSA (2019), *Gross Domestic Product (GDP), 4th Quarter 2018* (database); Quantec (2018), *Industry Service – RSA Standard Industry – Input Structure at basic prices* (database); INDEC, Republica Argentina (2019), *Macroeconomic aggregates (GDP)* (database); World KLEMS Data (2019), *Russia* (database).

## In industry, technical efficiency is returning to trend while structure is changing

The majority of gains in technical efficiency between 2015 and 2018 have been made in the industry and services sector, thanks in particular to expanded and more efficient heavy industrial production in emerging economies such as China and India. However, in recent years the impact of annual technical efficiency gains in the industry and services sector has fallen from around 4% of final energy demand in those sectors in 2015, to just under 2% in 2018, a return to the trend of previous years (Figure 2.4). Despite this slowdown, these gains resulted in technical efficiency offsetting nearly 70% of the impact on final energy demand from increased activity in the industry and services sector from 2015 to 2018.

Structural factors, notably the shift of economic activity towards less energy-intensive sectors (particularly services) offset another 4% of the impact from increased activity in the industry and service sectors between 2015 and 2018 (Figure 2.5). However, since 2013 this effect has been slowing as energy-intensive manufacturing has increased. By 2017, in the industry and services sector, avoided energy use from structural change was equivalent to just 0.1% of final energy use. In 2018 it is estimated that its impact switched to create additional demand equivalent to 0.1% of final energy use (Figure 2.5).

**Figure 2.5** **The impact of technical efficiency improvements as a share of sectoral final energy demand**

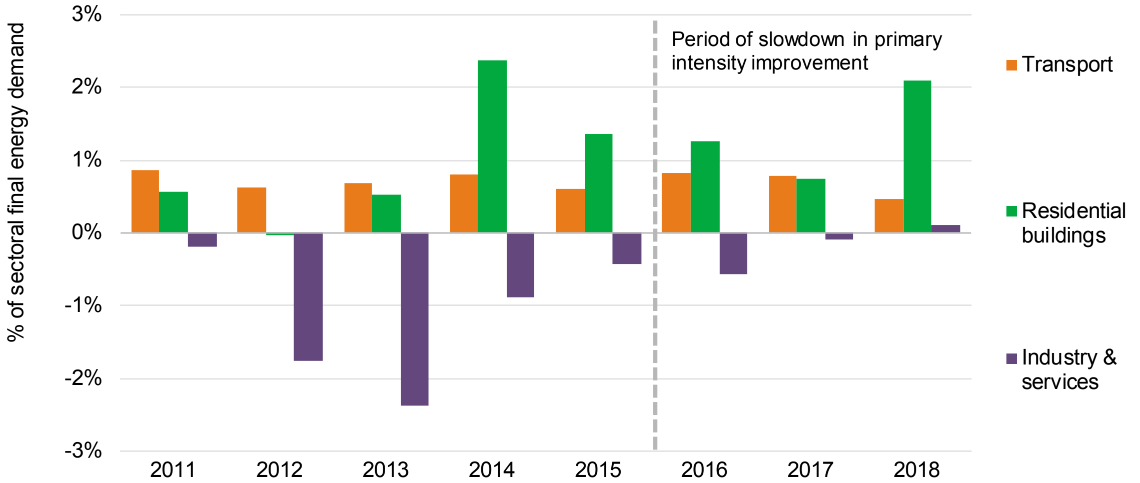





Note: Negative values indicate years where technical efficiency improvements helped reduce final energy demand.

Sources: Adapted from IEA (2019b), *Energy Efficiency Indicators 2019* (database); IEA (2019a),*World Energy Balances 2019* (database); IEA (2019c), *Energy Technology Perspectives* (buildings model); IEA (2019d), *Mobility Model* (database); Timmers et al. (2015), *World Input Output Database* (database); IBGE (2019), *Quarterly National Accounts* (database); ADB (2019a), *People's Republic of China: Input-Output Economic Indicators* (database); ADB (2019b), *India: Input-Output Economic Indicators* (database); ADB (2019c), *Indonesia: Input-Output Economic Indicators* (database); StatsSA (2019), *Gross Domestic Product (GDP), 4th Quarter 2018* (database); Quantec (2018), *Industry Service – RSA Standard Industry – Input Structure at basic prices* (database); INDEC, Republica Argentina (2019), *Macroeconomic aggregates (GDP)* (database); World KLEMS Data (2019), *Russia* (database).

**Figure 2.6** **Structural impacts on demand, as a share of sectoral final energy demand**






Note: Negative values indicate a net energy saving.

Sources: Adapted from IEA (2019b), *Energy Efficiency Indicators 2019* (database); IEA (2019a),*World Energy Balances 2019* (database); IEA (2019c), *Energy Technology Perspectives* (buildings model); IEA (2019d), *Mobility Model* (database); Timmers et al. (2015), *World Input Output Database* (database); IBGE (2019), *Quarterly National Accounts* (database); ADB (2019a), *People's Republic of China: Input-Output Economic Indicators* (database); ADB (2019b), *India: Input-Output Economic Indicators* (database); ADB (2019c), *Indonesia: Input-Output Economic Indicators* (database); StatsSA (2019), *Gross Domestic Product (GDP), 4th Quarter 2018* (database); Quantec (2018), *Industry Service – RSA Standard Industry – Input Structure at basic prices* (database); INDEC, Republica Argentina (2019), *Macroeconomic aggregates (GDP)* (database); World KLEMS Data (2019), *Russia* (database).

## In transport and residential buildings, structural factors are outpacing technical efficiency gains

In the transport and residential buildings sectors, technical efficiency gains have been smaller than in the industry and services sector but are still improving at or above the five-year average. Since 2015, annual technical efficiency gains in the transport sector averaged over 1% of final transport energy demand, with technical efficiency gains in residential buildings averaging just under 1% of residential buildings sector energy demand (Figure 2.4).

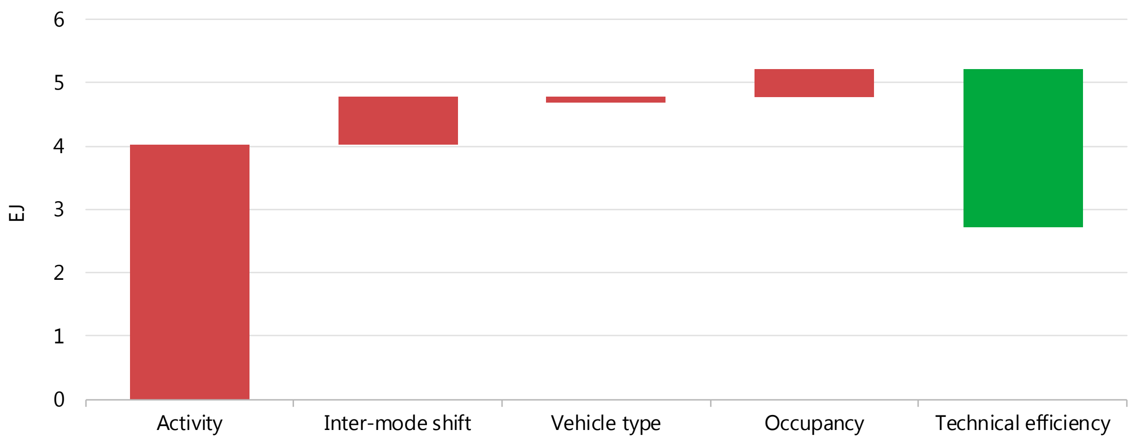
In both transport and residential buildings, savings from technical efficiency gains have been largely offset by structural factors, driven primarily by energy users' purchasing decisions and behaviour (Figure 2.5). For example, while passenger vehicles available in most markets are some of the most technically efficient in history, people are using more energy-intensive modes of transport, buying larger vehicles and travelling with fewer people per vehicle, slowing the rate of efficiency improvement. Since 2015, these structural impacts have led to additional annual increases in energy use equivalent to over 0.5% of total transport final demand.

In residential buildings the impact of structural factors on demand has been even more pronounced. In 2018, structural factors, such as increasing building floor area and appliance ownership, created additional energy demand equivalent to over 2% of final demand (Figure 2.4). These structural factors exceeded the impact of technical efficiency gains, which only avoided energy use equivalent to 0.7% of residential building final energy demand (Figure 2.3).

The following sections explore trends in transport and residential buildings to better understand how energy users' actions in these sectors are contributing to the slowdown in global energy intensity improvement.

# Passenger transport trends

**Figure 2.7 Factors influencing passenger transport energy use, 2015-18**






Notes: *Activity* describes the change in the level of action that creates demand for energy, such as an increase in the distances driven by car owners. *Inter-modal shifts* describe changes in energy use that occur when passengers choose between different modes of transport, such as cycling or driving. *Vehicle type* describes the impact on energy use of people's choice of vehicle within a mode of transport, such as SUVs instead of hatchbacks. *Occupancy* describes the impact on energy use of filling a train, plane, ship or car with more or fewer people. Major economies are IEA members plus Argentina, Brazil, China, India, Indonesia, Russian Federation and South Africa

Sources: Adapted from IEA (2019b) *Energy Efficiency Indicators 2019* (database); IEA (2019d), *Mobility Model* (database).

A shift to more energy-intensive transport modes, an appetite for larger cars, and lower vehicle occupancy all mean that despite improvements in the technical efficiency of motor vehicles, passenger transport remains an energy-intensive sector of the economy (Figure 2.6). While technical efficiency has been improving at a faster rate in recent years, it is not increasing as fast as it could because the global vehicle fleet is ageing, as people are holding onto their cars and vans longer. Another factor affecting technical efficiency in recent years has been the shift away from diesel vehicles, which are mostly being replaced with petrol vehicles.

## Passenger road transport activity is highest in cars and trucks, some of the most energy-intensive modes of transport

Data on the number of passenger kilometres (pkm) travelled by different modes of road transport indicate that cars and trucks remain the preferred choice for many trips. Over the last three years, more than half of the growth in pkm in the world's major economies has been due to cars, much more than that the share due to buses (around 25%) and trains (10%). Cars and trucks are some of the most energy-intensive transport modes (IEA, 2019e), so the strong growth in activity compared with less energy-intensive modes is slowing overall energy intensity improvements in the transport sector.

## Consumers continue to prefer larger vehicles

Although technical efficiency has improved on a per vehicle basis, consumers' adoption of larger cars continues to add to global transport energy demand. The market share of sport-utility vehicles (SUVs) and pick-up trucks has grown rapidly after oil prices began to decline in 2014 in almost all car markets. In 2018 alone, global SUV sales grew by almost 7%, while overall light duty vehicle sales (passenger cars, passenger light trucks and light commercial vehicles) fell by 0.5% (JATO, 2019a). The market share of SUVs and pick-up trucks in the United States reached a record 68%, China's SUV sales surpassed 40% of new registrations and for the first time SUVs took more than one-third of the European market (JATO, 2019b; ACEA, 2019; JATO, 2019a).

## In emerging markets, declining occupancy rates are offsetting efficiency gains from new car sales

Car ownership rates in emerging car markets are sometimes more than 20 times lower than those in advanced car markets, but the gap is closing as per capita income rises (IEA, 2019d). In China, the largest global car market in terms of sales, the car fleet grew by 10% in 2018, although there was a 3% drop in sales, as cars are now staying in use for longer (Sun et al, 2019; IEA, 2019j).

As car ownership in emerging markets rises, the global fleet tends to become more efficient as it comprises a larger share of newer, more efficient vehicles. However, concurrently, the average occupancy rate per car within these markets has continued to fall, offsetting some of the efficiency gains per passenger-kilometre from more efficient new cars (IEA, 2019d; Goldman Sachs, 2017; US DoE, 2018; Darido, 2009). Occupancy rates tend to fall as car ownership rates rise: More cars allow more consumers take trips by themselves, (Fiorello, 2016). For example, the car fleet in Beijing rapidly expanded between 2000 and 2007, while the average number of passengers per car decreased from 1.6 to 1.3 (Darido, 2009).

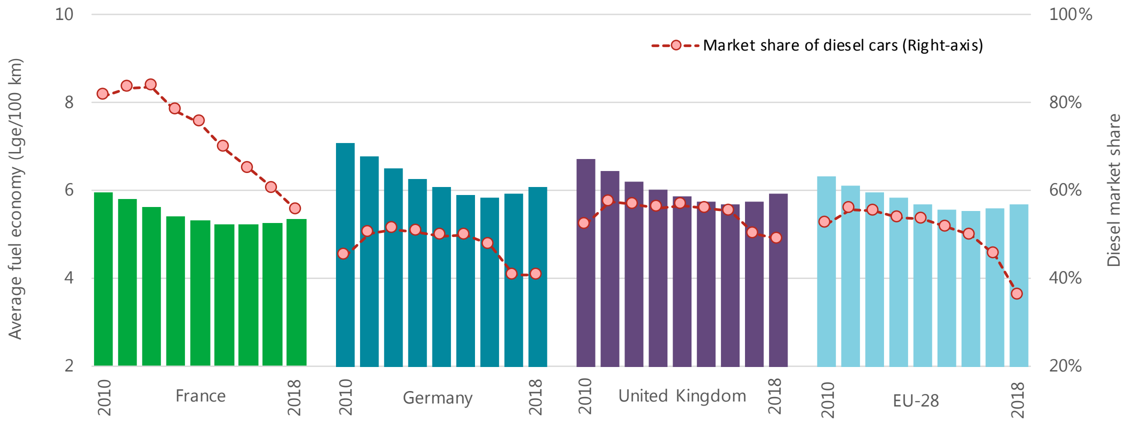
## In established markets, cars and vans are getting older, reducing the overall technical efficiency of the global fleet

Even though vehicle production and new vehicle sales declined in most countries in 2018, the global vehicle fleet[2] continued to grow because households and businesses are keeping their vehicles for longer (OICA, 2019; JATO, 2019a). The retirement age of existing stock is increasing even in developed car markets, such as the European Union. The average age of cars and vans on the road has gone up by 6% in the past five years in Europe (ACEA, 2019), from 10.5 to 11.1 years. The average age of the car stock in the United States grew by one-third from 2007 to 2017, speeding up after the 2008 economic crisis[3] (EIA, 2018; Richter, 2018).

## Diesel cars are being driven out of the market

The political climate affecting diesel vehicles has changed significantly in the past five years after the "Dieselgate" scandal led to a surge in policy measures limiting the use of diesel cars in the short- to medium term (see section *Policy drivers of efficiency*). As a result, diesel car sales have fallen rapidly in several major vehicle markets, especially Europe, which comprises a significant share of this technology (IEA and ICCT, 2019; IEA, 2018a). While the move away from diesel cars benefits local air quality, the shift away from diesel has contributed to a worsening of average fuel consumption since diesel cars tend to be more efficient than the equivalent gasoline vehicles. Despite double-digit growth rates for electric vehicles (EVs), the majority of diesel cars were replaced by gasoline versions. Between 2017 and 2018, more than 20 European vehicle markets experienced a worsening in average fuel consumption while experiencing a steep drop in diesel sales (Figure 2.6) (JATO, 2019c; ACEA, 2019).

**Figure 2.8 Average fuel consumption and diesel market share of newly registered vehicles for selected European car markets, 2010-18**






Note: Average fuel consumption is tested fuel consumption based on the worldwide light-duty test procedure (WLTP).

Source: Analysis based on ACEA (2019), *The automobile industry pocket guide book 2018/2019*; and IHS (2018), *Vehicle Registrations and Other Characteristics at Model Level (database)*.

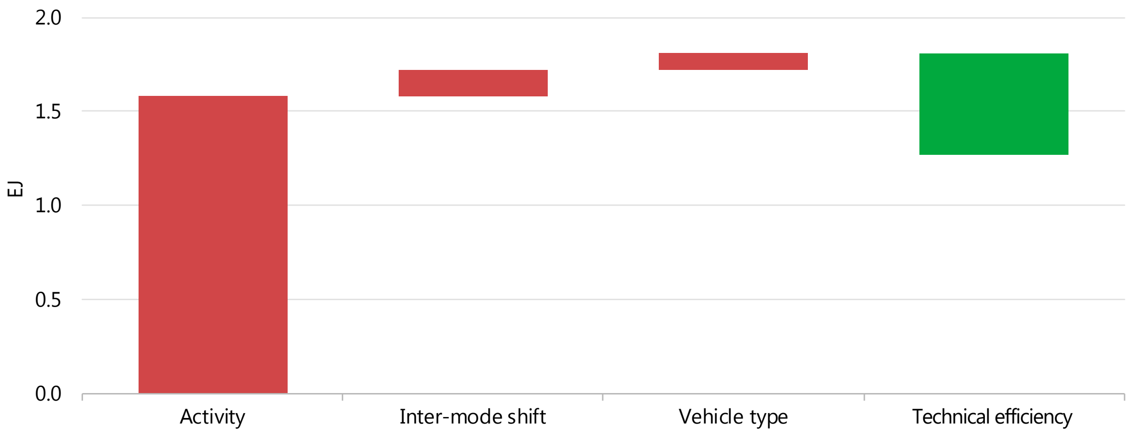
[2] The number of registered vehicles on a given date in a country and licensed to use roads open to public traffic. The vehicle stock changes each year based on new registrations, second-hand imports and exports, and vehicle scrappage.

[3] The economic crisis reduced sales of new vehicles, as consumers shifted towards second-hand vehicles and made more effort to maintain their existing vehicles.

## Freight transport trends

Freight transport also remains energy intensive, as technical efficiency improvements have managed to offset less than a third of the increase in energy use (Figure 2.7). Most truck fuel economy standards did not come into force until the last five years (China, India and the United States) or are being implemented after 2018 (European Union, Korea and Mexico), meaning that technical effects may increase in coming years. Road freight activity has grown faster than shipping or rail, leading to a small increase in energy use from modal shift.

**Figure 2.9 Factors influencing freight transport energy use 2015-18**






Notes: *Activity* describes the change in the level of action that creates demand for energy, such as an increase in the distances travelled by freight ships. *Inter-modal shift* describes changes in energy use driven by transporting goods using different modes of transport, such as moving freight by rail instead of using trucks. *Vehicle type* describes the impact on energy use due to the choice of vehicle within a mode of transport. For example, transporting goods via an electric train instead of a diesel train. Major economies are IEA members plus Argentina, Brazil, China, India, Indonesia, Russian Federation and South Africa. The data for freight road tonne-kilometres and energy consumption in the United States have been revised for years 2008-11 and 2000-15 respectively, leading to a significant increase in the intensity of freight road transport compared with the previous values for the same years and a decrease in energy saving coming from this sector. Therefore, these data have been excluded. Load factors (tonne kilometres per vehicle kilometre) are not available.

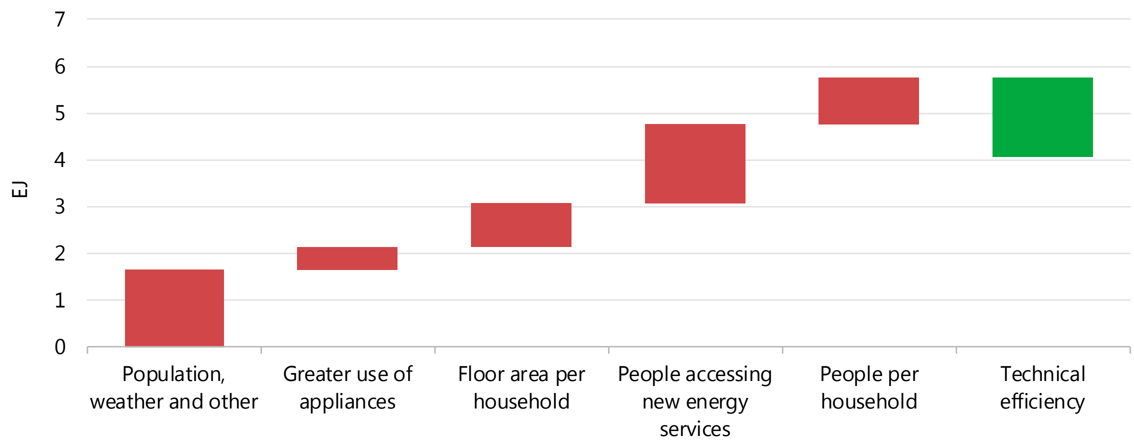
Sources: Adapted from IEA (2019b) *Energy Efficiency Indicators 2019* (database); IEA (2019d), *Mobility Model* (database).

## Residential buildings trends

Despite improvements in building design and construction and the use of more efficient appliances, building energy demand has continue to increase in the last three years, driven by a range of factors including a growing population and an increase in building floor area per household (Figure 2.9).

Energy use is also being driven up by increasing incomes in emerging and developing countries. As these countries become richer, more people are gaining access to better quality dwellings and modern energy services, a trend that is likely to continue as there is still a significant access gap. For example, of the nearly 3 billion people that live in the hottest parts of the world, less than 10% currently have access to air conditioning. The increased adoption of air conditioning, particularly in these regions, could see space cooling electricity demand triple by 2050, accounting for over 20% of potential global electricity demand growth (IEA, 2018b). Increasing incomes have also changed living arrangements, as people move into homes with fewer people under the same roof (Figure 2.8).

**Figure 2.10 Factors influencing residential buildings energy use, 2015-18**






Notes: *Population, weather and other* describes the impact of population growth, changes in heating and cooling use and other factors on demand. *Greater use of appliances* captures the impact of people using the appliances and equipment in buildings more or less (excluding heating and cooling services, which are captured under *weather*). *Floor area per household* corresponds to the impact of increases in building floor area not driven by population growth. *People accessing new energy services* is the combined impact of increased per capita appliance and equipment ownership and people gaining access to energy services for the first time (particularly electrification). *People per household* captures the impact of people choosing to live with more or fewer people in the same dwelling.
Source: Adapted from IEA (2019c) *Energy Technologies Perspectives* (buildings model).

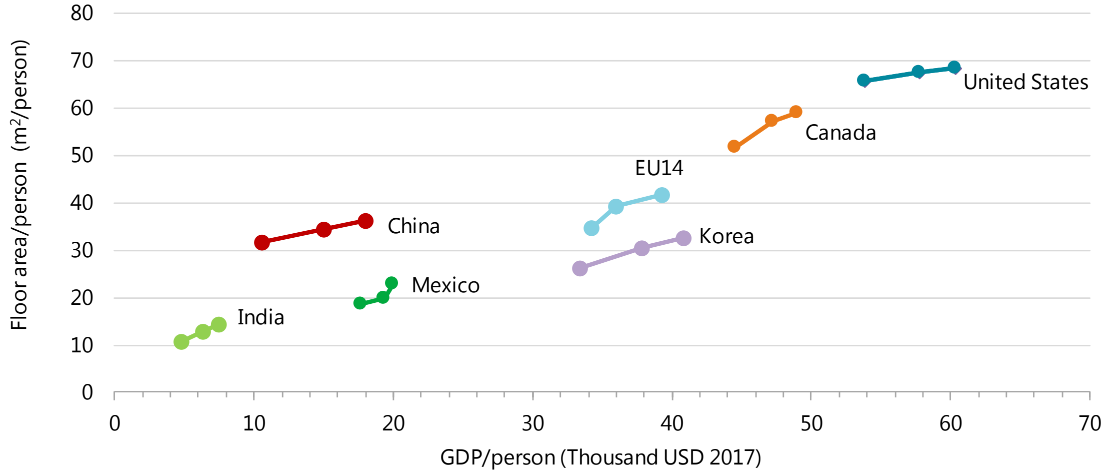
Changes in weather patterns and higher penetration of cooling equipment have resulted in higher energy use for air conditioning, but warmer weather has also helped reduce energy consumption for heating in colder Northern Hemisphere climates. Hence, while extreme weather increased demand in 2018, the overall impact of weather in the last three years has been almost neutral due to energy savings within space heating, which is the largest end-use in buildings. However, between now and 2050, climate change is set to increase demand for space cooling services, particularly in countries with large populations in hot climates, such as India (IEA, 2018b).

## Residential floor area keeps rising while household occupancy rates fall

Average residential floor area per person across all economies is increasing, reflecting ongoing income growth (Figure 2.9). This trend is visible in both emerging and advanced economies. In emerging economies, many people are enjoying substantial increases in income, allowing them to move into more comfortable dwellings. In several advanced economies, demand for additional space also appears to be continuing to rise.

The increased demand for larger homes is also reflected in changes to building occupancy, with the average number of people per building declining. In emerging economies, average household size is continuing to drop steeply as incomes increase, whereas in more developed economies, such as the United States, the decline in occupancy rates is starting to level off (Figure 2.11).

**Figure 2.11 Average residential per capita floor area versus GDP in selected countries, 2010-15-18**

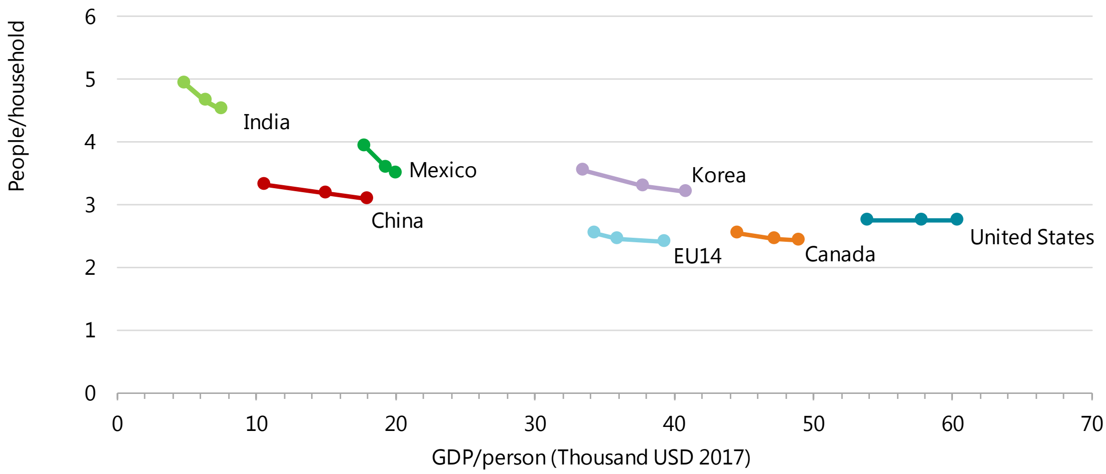





Notes: The country label shows the 2018 value. GDP is based on 2017 USD and purchasing power parity. EU14 refers to Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

Source: Adapted from IEA (2019c), *Energy Technology Perspectives* (buildings model)

**Figure 2.12 Average household size versus GDP in selected countries, 2010-15-18**





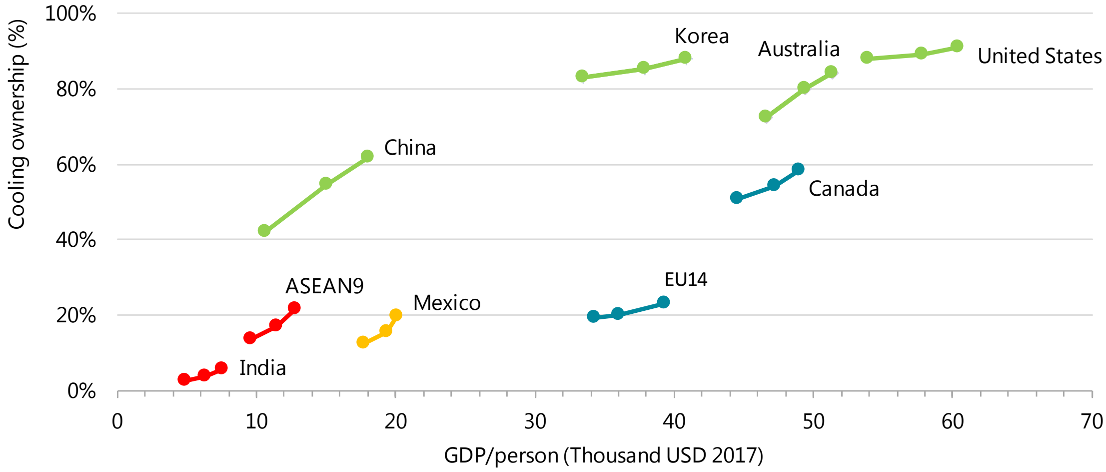

Notes: The country label shows the 2018 value. GDP is based on 2017 USD and purchasing power parity. EU14 refers to Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

Source: Adapted from IEA (2019c), *Energy Technology Perspectives* (buildings model).

## Demand for energy services, such as space cooling and space heating, continues to rise

The use of air conditioning is rising in homes, driven by increasing wealth and the desire for cooling in warmer and warming climates. Ownership rates are highest in wealthier countries with relatively mild climates (Figure 2.11). Ownership is low in the countries with the hottest climates (e.g. India and ASEAN countries), but demand is rising quickly (IEA, 2018b) and is expected to continue to grow as incomes in these countries increase. Since 2000, Chinese demand for residential cooling has grown by 13% annually, and now consumes around 1 400 petajoules (PJ) a year (IEA, 2019f). However, recent policy developments may help to temper demand (Chapter 3).

**Figure 2.13 Ownership of cooling devices and GDP per capita in selected countries, 2010-15-18**






Notes: Blue = cold (<75 days above 20C), green = mild (75-199), orange = hot (200-299), red = very hot (>300). GDP is based on 2017 USD and purchasing power parity. *Ownership* means household ownership of at least one cooling device. EU14 refers to Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

Source: Adapted from IEA (2019c) *Energy Technology Perspectives* (buildings model).

Energy demand for heating services is falling in some countries as buildings and equipment become more efficient. In emerging economies with cold climates, however, rising incomes are leading to higher heating demand. In China, where energy demand for residential space heating has increased by 10% since 2010, over 4 000 PJ are now used annually.

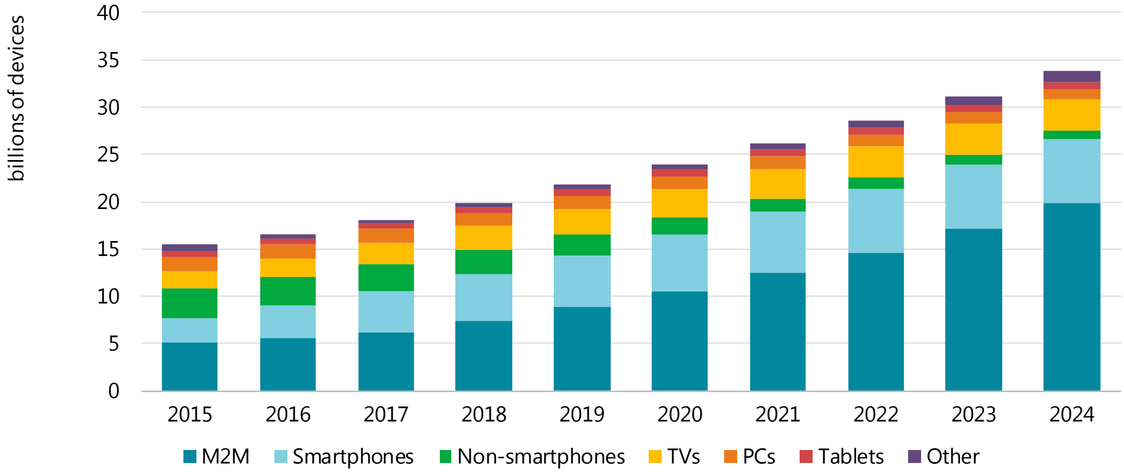
Understanding how these trends may affect global energy intensity is not straightforward. On one hand, the increase in demand for cooling and heating services may slow the global energy intensity improvement rate if it increases energy use without increasing GDP. On the other hand, increased comfort from mechanical space heating and cooling may lead to productivity gains. For example, in 2016 the average number of lost work days due to heat stress was 6.6 days in developing countries and 3.5 days for developed countries, suggesting that countries with more air conditioning are more productive (Yu et al., 2019). More research is needed to understand how cooling demand growth influences global energy intensity.

# Are our "digital lifestyles" more energy intensive?

In many parts of the world, digital technologies are pervasive in most aspects of life, from ordering a meal via a smart-phone app to streaming television series over the Internet. These services have been made possible by faster (and more mobile) connectivity and an ever-increasing number of digital devices.

Growth in digital activity is outpacing population and economic growth. Between 2015 and 2018, the number of digital devices globally increased from 15.5 billion to 20 billion (Figure 2.13). This growth, of around 8% per year was much higher than population growth (1.1%) or economic growth (3.5%).

**Figure 2.14 Global digital devices and connections, by type of device, 2015-24**






Note: M2M = machine-to-machine connections, which includes smart meters and devices used for video surveillance, healthcare monitoring, transportation, and package or asset tracking. TVs includes flat-panel TVs, set-top boxes, digital media adapters, Blu-ray disc players, and gaming consoles. Non-smartphones refers to phones that do not have "smart" capabilities. 2015 and 2016 are from Cisco (2016); 2017-22 are from Barnett, T. et al. (2019); 2023 and 2024 are extrapolated.

Sources: Based on Barnett et al.(2019), *Cisco Visual Networking Index: Forecast and Trends, 2017–2022* and Cisco (2016), *The Zettabyte Era: Trends and Analysis, July 2016*.

In 2017, each person in the world owned 2.4 digital devices on average, 9% more than in 2015. This is set to increase to 3.6 devices per person in 2022 (Barnett, 2019). Device ownership is spread unevenly geographically. Device ownership per person is 8 in North America and 5.4in Western Europe, but only 1.1 in the Middle East and Africa (Table 2.1).

**Table 2.1. Average per capita ownership of digital devices, by region (2017 and 2022)**

| | 2017 | 2022 |
|---|---|---|
| Asia Pacific | 2.1 | 3.1 |
| Central and Eastern Europe | 2.5 | 3.9 |
| Latin America | 2.1 | 2.9 |
| Middle East and Africa | 1.1 | 1.4 |
| North America | 8.0 | 13.4 |
| Western Europe | 5.4 | 9.4 |
| **Global** | **2.4** | **3.6** |

Source: Barnett et al. (2019), Cisco Visual Networking Index: Forecast and Trends, 2017–2022.

The growing number of devices and increasingly data-intensive activities (e.g. 4K and 8K video, virtual reality, and cloud-based artificial intelligence) are driving exponential growth in data traffic. Global internet traffic has tripled from 2015 to 2019, and is expected to further double between now and 2022 to 4.2 zettabytes per year (4.2 trillion gigabytes) (Sumits, 2015; Cisco, 2018; Barnett, 2019). Data centre workloads – a measure of service demand – have more than doubled since 2015.

## Strong efficiency gains have helped to keep energy use for digital services in check

Despite the strong growth in demand for digital services, major improvements in the efficiency of computing (Koomey et al 2011; Koomey & Naffziger, 2015; and Koomey & Naffziger, 2016) coupled with the short lifespans of devices and equipment, which hastens turnover, have improved the efficiency of the overall stock of devices, data centres and networks. Devices are becoming smaller and much more efficient, as evident, for example, in shifts from cathode ray tube (CRT) to liquid crystal display (LCD) television screens, and from personal computers to laptops, tablets and smartphones (Malmodin and Lundén, 2018; Stobb, et al., 2015; Urban et al., 2014).

Global energy use by devices, data centres and data transmission networks was roughly constant at around 800 terawatt hours (TWh) per year between 2010 and 2015 , with user devices responsible for around 340 TWh in 2015 (Malmodin and Lundén, 2018). The latest IEA analysis (using a different methodology and scope) estimates that data centres and data transmission networks together consumed around 460 TWh in 2018, or around 2% of global electricity demand (2019g).

### Box 2.1. Voluntary agreements delivering energy efficiency improvements in US broadband devices

In the United States, nearly all internet modems, routers and other equipment sold in 2018 for use by residential broadband subscribers met voluntary standards set in 2015 as part of a voluntary agreement signed by internet service providers covering more than 87 million homes (around 90% of the market).

The agreement, signed by internet services providers and product vendors, specifies that signatories target reductions in small network equipment energy use, with detailed explanations for how savings can be made in a range of devices.

To ensure the standards outlined in the voluntary agreement do not act as a "ceiling" on innovation, the agreement also outlines how service providers and vendors can add innovative new features for energy efficiency confidentially for a limited period of time, to avoid compromising their competitiveness.

The average idle mode energy usage of these products, relative to average broadband speed, has decreased by 66% since the agreement was ratified.

Source: Consumer Technology Association (2019), *Internet Service Providers and Device Manufacturers Exceed Energy Efficiency Commitments*, www.cta.tech/News/Press-Releases/2019/August/Internet-Service-Providers-and-Device-Manufacturer.aspx.

Strong growth in demand for data centre services has been offset by continued improvements in the efficiency of servers, storage devices, network switches and data centre infrastructure. The shift away from small, inefficient data centres to much larger cloud and hyperscale data centres is a major and growing source of energy efficiency gains (IEA, 2017).

Data transmission network technologies are also becoming more efficient, meaning more data can be sent using less energy. Fixed-line network energy intensity has halved every two years since 2000 in developed countries, while mobile access network energy efficiency has in recent years improved at annual rates of around of 10-20% (Aslan et al., 2017; Fehske et al., 2011; GSMA, 2012; Verizon, 2012). Mobile networks are shifting rapidly away from older networks towards more efficient 4G (and eventually 5G) technologies. By 2022, 4G and 5G are expected to carry a combined 83% of mobile traffic (Barnett, 2019).

## Impact of "digital lifestyles" on energy intensity remains uncertain

Assessing the net energy and environmental impacts of digital devices and services is complex (Horner, Shehabi and Azevedo, 2016). Some digital services may substitute for more energy-intensive activities (e.g. videoconferencing replacing a flight), while others may be more energy intensive than the non-digital devices and activities they displace. In addition, the landscape of digital devices and processes is constantly changing. For example, by 2018, Bitcoin mining – an activity that has only taken off in the last few years – had added an additional 50 TWh of electricity to the estimates quoted above (Kamiya, 2019).

Beyond the direct energy and environmental impacts for devices (production, use and disposal), shifts to digital activities could have direct and indirect rebound and structural effects. For example, the move from DVDs to streaming video could cut energy use from DVD production and transport, while increasing energy use by data centres and data transmission networks (Shehabi, Walker and Masanet, 2014). The convenience of such e-services could also result in rebound effects that encourage greater use of these services, resulting in higher energy use overall.

Whether and how increased use of energy for digital dvices has an impact on GDP is uncertain and warrants further study. A recent report estimates that between now and 2030, increasing the use of artificial intelligence could increase GDP by 3.1% to 4.4% while reducing energy sector carbon emissions by 2.2% (Microsoft and PwC, 2019). Further research is needed to better understand how the energy impacts of digital devices relate to their economic impacts, so that their role in helping or hindering global energy intensity improvements can be determined.

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# III. Technical efficiency progress in 2018

## Highlights

- The impact of technical efficiency improvements has been slowing down. The annual impact of technical efficiency improvements on demand has almost halved between 2015 and 2018, from 2.5% of final demand to 1.4% of final demand. Despite this, technical efficiency improvements in the years 2016-18 resulted in energy demand being 4% lower than it would have been without efficiency gains, a slight increase from the period 2013-15.

- Technical efficiency gains continue to deliver a range of benefits. Between 2015 and 2018, these gains avoided energy-related emissions of 3.5 billion tonnes of carbon dioxide, more than the energy-related emissions of Japan over the same period, helping to bring the world closer to an emissions trajectory consistent with achieving global climate change goals. Gains made during this period saved IEA member countries more than USD 100 billion (United States dollars) on energy expenditure in 2018.

- In 2018, mandatory policy coverage increased in line with recent trends but over 95% of the growth in coverage was due to existing policies. The strength of mandatory policies increased by over 0.4%. Although this increase was slightly higher than in the previous two years, it was still below the five-year historical average, indicating more can be done to ensure mandatory policies are effective. There was also little change in the coverage and strength of energy efficiency obligation programmes, the main market-based instrument tracked by the IEA.

- Levels of investment targeting efficiency have remained largely unchanged since 2014. At USD 240 billion, incremental efficiency investments across the buildings, transport and industry sectors were less than 1% higher in 2018 than 2017, still well below the levels required to harness the cost-effective opportunities available.

- In 2018, only electric vehicles (EVs), rail and lighting technologies were on track to reach the deployment levels envisioned in the IEA Sustainable Development Scenario (SDS). This indicates that potential efficiency gains in a range of other technologies remain largely untapped.

# Introduction

Opportunities exist in all sectors to move toward a more efficient world in 2040. Seizing these opportunities would:

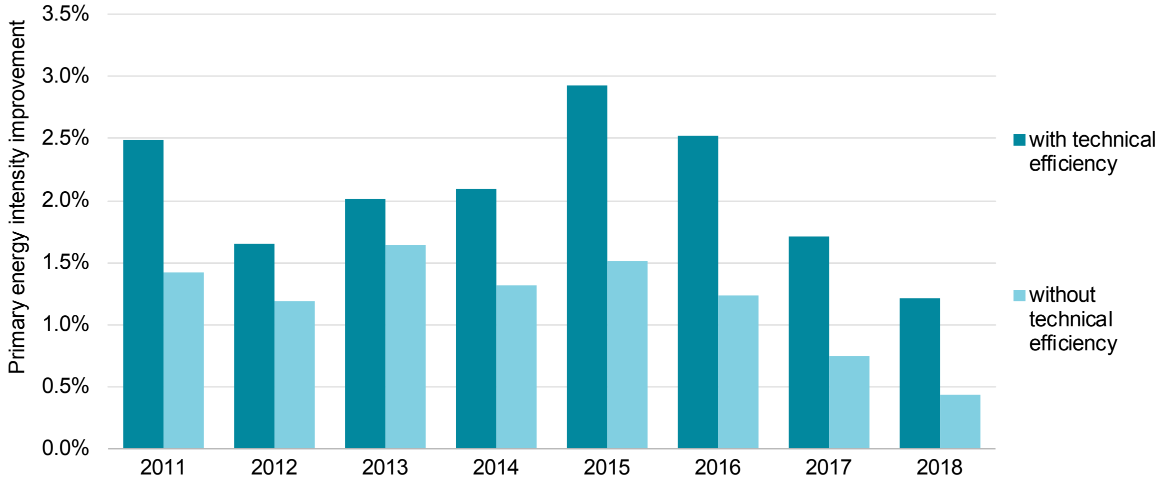
- flatten global energy demand for transport while doubling activity levels
- flatten energy demand for buildings while increasing total floor area by 60%
- enable industry to produce twice as much value from each unit of energy (IEA, 2018a).

As reported in the 2018 edition of this report, achieving these outcomes would also result in a 3% annual average improvement in primary energy intensity, a level consistent with meeting global goals such as those contained in the Paris Agreement on climate change and the SDGs (IEA, 2018a). That the primary energy intensity improvement rate remains so far below this suggests that significant potential remains untapped.

Chapter 2 showed that part of the reason for the slow-down in energy intensity improvements is that technical efficiency gains are being blunted by structural factors, which have added to energy demand in recent years. In this environment, future efforts to improve the net energy intensity of the economy may require careful consideration of how technical efficiency measures interact with activity and structural factors.

Nevertheless, technical efficiency continues to be the primary driver of energy intensity improvements. Global technical efficiency improvements made between 2015 and 2018 avoided around 4% more energy consumption in 2018, an amount nearly equivalent to the total primary energy demand of France and Italy combined. These technical efficiency gains more than doubled the global primary energy intensity improvement rate in 2018 (Figure 3.1).

**Figure 3.1 Impact of technical efficiency on primary energy intensity improvement (2011-18)**






This suggests that, irrespective of activity growth and structural trends, more ambitious efforts to strengthen technical efficiency would be a "no-regrets" strategy to raise the energy intensity improvement rate.

Chapter 3 investigates trends to help better understand how the drivers of technical efficiency improvements changed during 2018. In doing so, it aims to identify possible levers for ratcheting up technical efficiency. While policy is often crucial for providing incentives to switch to more efficient technologies and behaviours, other factors can affect energy efficiency progress, such as technological breakthroughs and fluctuations in the price of technologies and energy. Therefore, in addition to policy, this chapter examines recent changes in the landscape of energy technologies and tracks finance and investment for efficiency.

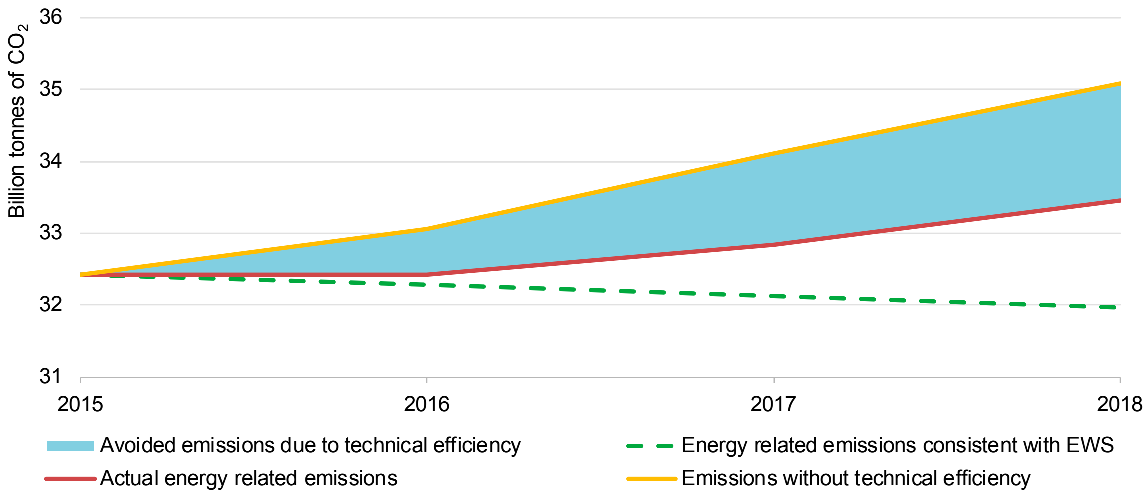
## Technical efficiency improvements continue to have multiple benefits

Global technical efficiency improvements delivered significant benefits for the climate, national budgets, and for energy consumers.

Technical efficiency gains from 2015 to 2018 avoided cumulative emissions of over 3.5 billion tonnes of additional $CO_2$ emissions, larger than the cumulative energy-related emissions of Japan over the same period. These efficiency gains made a considerable contribution to reducing the gap between actual global energy-related emissions and levels required to meet global emissions targets (Figure 3.2).

Due to the slowdown in intensity improvement, however, the energy sector fell short of the emissions trajectory consistent with the Efficient World Strategy (EWS). This shows that the world is continuing to miss out on the significant abatement opportunities available from energy efficiency, which could make a big contribution to global climate goals.

**Figure 3.2 Energy-related GHG emissions, actual, without technical efficiency improvements, and avoided from technical efficiency improvements, 2015-18**



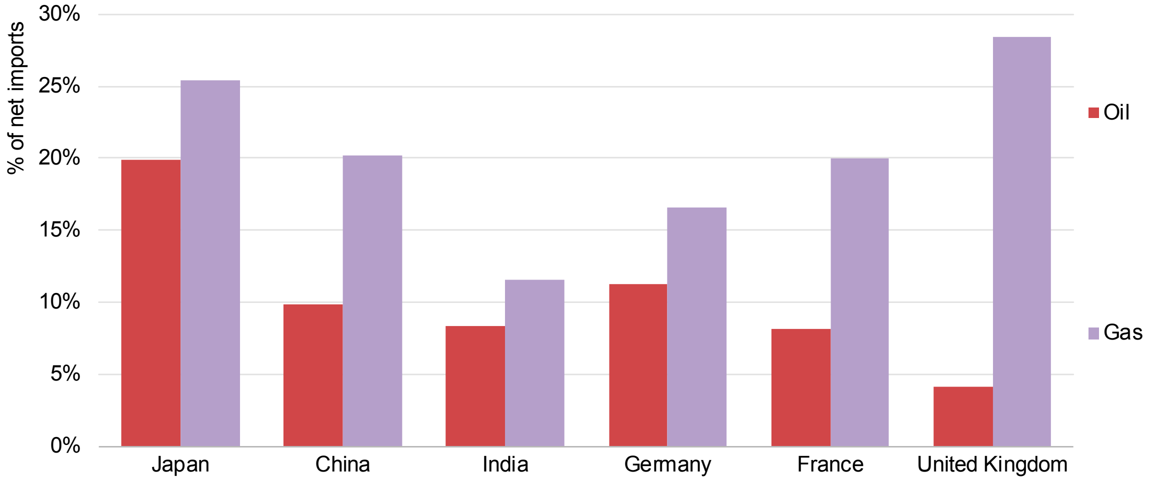



Notes: EWS = Efficient World Strategy. The EWS trajectory shown above includes only the impact of taking up all the cost-effective energy efficiency opportunities currently available. Energy-related emissions would have been even lower with a higher deployment of renewable energy and other abatement technologies.

Sources: Adapted from IEA (2019b) *Energy Efficiency Indicators 2019* (database); IEA (2019a) *World Energy Balances 2019* (database); IEA (2019c) *Energy Technology Perspectives* (buildings model); IEA (2019d), *Mobility Model* (database); Timmers et al. (2015), *World Input Output Database* (database); IBGE (2019), *Quarterly National Accounts* (database); ADB (2019a), *India: Input-Output Economic Indicators* (database); ADB (2019b), *People's Republic of China: Input-Output Economic Indicators* (database); ADB (2019c), *Indonesia: Input-Output Economic Indicators* (database); StatsSA (2019), *Gross Domestic Product (GDP), 4th Quarter 2018* (database); Quantec (2018), *Industry Service – RSA Standard Industry – Input Structure at basic prices* (database); INDEC, Republica Argentina (2019), *Macroeconomic aggregates (GDP)* (database); World KLEMS Data (2019), *Russia* (database); IEA (2019e), *$CO_2$ emissions from fuel combustion*; IEA (2019k), *Global Energy and $CO_2$ Status Report*.

At a global level, technical efficiency improvements since 2000 avoided around 13% more final energy use 2018, which translates to an estimated primary energy saving equivalent to the demand of India, Germany, Brazil and Canada combined. For countries reliant on imports to satisfy domestic demand, a major benefit of these efficiency gains is the avoidance of additional imports and associated expenditure, which improves both energy security and trade balances.

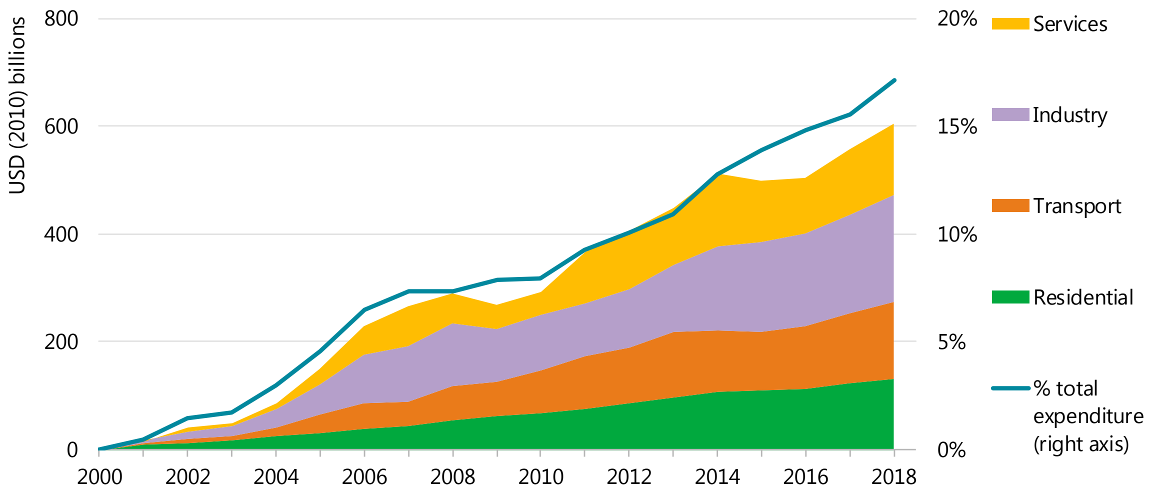
**Figure 3.3 Avoided oil and gas imports in 2018 due to technical efficiency gains since 2000**






Oil represents the largest proportion of import savings globally, with technical efficiency gains since 2000 saving of over 165 million tonnes of oil-equivalent in 2018, similar to the energy used in the transport sectors of Japan, Canada and Italy combined. Within IEA member countries alone, these savings translated to over USD 50 billion in avoided expenditure. The recent acceleration in gas market growth has seen energy efficiency's impact on gas imports grow faster than its impact on oil import savings. In 2018, technical efficiency gains since 2000 reduced gas imports by nearly 115 million tonnes of oil-equivalent, an amount greater than the gas demand of residential buildings in the European Union.

**Figure 3.4 Avoided expenditure on energy due to efficiency improvements since 2000, by sector**



At a country level, technical efficiency improvements in Japan since 2000 avoided 20% and 25% more oil and gas imports in 2018 respectively. These savings are linked to efficiency improvements for cars and trucks, as well as improvements in the efficiency of space heating and industrial processes. Gas savings have also be significant in Europe and the People's Republic of China ("China"), reflecting ongoing improvements in building performance and space heating efficiency (Figure 3.3).

Technical efficiency gains continue to create financial benefits for energy consumers across all sectors. In IEA member countries, technical efficiency gains since 2000 reduced expenditure on energy in 2018 by just over USD 600 billion, with the savings from gains since 2015 avoiding over USD 100 billion in 2018 (Figure 3.4). Economic benefits accrued in all sectors but have grown more recently in the transport sector, due to oil price rises.

# Policy drivers of efficiency

Government policies have a vital role to play in accelerating the development and adoption of energy-efficient appliances, equipment, buildings and vehicles in all end-use sectors. *Energy Efficiency 2019* tracks worldwide progress in implementing comprehensive policy packages and conducts in-depth analysis of three types of policy: mandatory policies, energy efficiency obligations and incentives.[1]

Governments are implementing a range of other important policies and programmes (including information provision, and training and capacity programmes), and industry is making voluntary commitments to improve efficiency.

## Policy highlights in 2018-19

Enabling policies are crucial to strengthening energy efficiency. A combination of regulations, market-based instruments, incentives, capacity building and information provision have a proven capacity to deliver large-scale energy efficiency improvements, especially if backed by comprehensive national strategies and targets. Between January 2018 and June 2019, several key policy changes took place.

### Air conditioning policy makes encouraging progress

Many of the policies adopted over the last year have targeted air conditioning, which is important given the projected increases in electricity demand for cooling (IEA, 2018b). Countries introducing minimum energy performance standards (MEPS) for air conditioning for the first time included Chile, Oman, Kenya, Morocco, Nigeria and Rwanda. Rwanda implemented a comprehensive National Cooling Plan, including air conditioning and refrigerators, which enters into force in 2021. Existing air conditioning MEPS were strengthened in Australia, China and Mexico, among others. Moldova introduced regulations in the sector, preparing the ground for the adoption of performance standards. In March 2019, India launched the Indian Cooling Action Plan, which aims to reduce cooling energy demand by 25 to 40% in the next 20 years. In June 2019, China released its Green and High-Efficiency Cooling Action Plan. Key components include

[1] For a description of policies included in these categories, refer to Annex B.

raising space cooling MEPS to the levels of standards in developed countries, or above; supporting the development of more efficient cooling technologies; and enhancing cooling-related energy saving retrofits (IGSD, 2019).

The Kigali Cooling Efficiency Program (K-CEP), a philanthropic collaborative, is working in tandem with the Kigali Amendment of the Montreal Protocol by supporing developing countries transition to energy-efficient, climate-friendly, and affordable cooling solutions (K-CEP, 2019).

## Transport fuel economy standards will improve in some markets

Several countries and regions are moving ahead with updated fuel economy standards, including the European Union and Japan, with proposed updates under consideration in China and Mexico (IEA and ICCT, 2019; Nikkei Asian Review, 2019). In the United States, strengthened standards for cars and light trucks came into force. As noted in the 2018 edition of this report, the government has proposed that Corporate Average Fuel Economy standards be frozen at their 2020 levels from 2021 to 2026 (NHTSA, 2018).

Truck standards are also expanding. In 2019, European heavy-duty fuel economy standards were adopted, providing a pathway to better fuel economy between now and 2030. In Japan, updated standards came into force and will be in place until 2025. A third phase of China's heavy-duty vehicle (HDV) standard also came into force in 2019 (IEA, 2019f; IEA, 2019g).

## A comprehensive European energy efficiency policy framework is set to take effect

The *Clean Energy for all Europeans* package is a set of eight legislative acts adopted by the European Union between May 2018 and May 2019, in order to implement the Energy Union Strategy and meet Europe's commitments under the Paris Agreement on climate change.

As reported in *Energy Efficiency 2018* (IEA, 2018a), a major part of the package was the *Energy Performance of Buildings Directive*, according to which all EU buildings must reach near zero energy performance levels by 2050. From 9 July 2018, countries have 20 months to respond to the directive, so major policy change is expected in the next six months leading up to the deadline.

In December 2018, another key component of the package was adopted. The Energy Efficiency Directive establishes a new binding target of 32.5 % energy efficiency improvement by 2030 relative to modelled projections made in 2007. A savings target of 1.5 % of annual energy sales to final customers has been retained until 2020 but EU countries will have to achieve additional annual energy savings of 0.8% of final energy consumption for the 2021-30 period (Directive (EU) 2018/2002).

## South Africa's carbon price enters into force

In May 2019 South Africa, the most energy-intensive economy in Africa, introduced a carbon tax. The policy makes South Africa one of only a few emerging economies with a legislated price on carbon. In the initial phase, up to December 2022, a tonne of carbon will cost roughly USD 8 (ZAR 120 [South African rand]), but will be lower for many industries, to provide them with a form of short-term transitional assistance. Nevertheless, a 2% annual increase in price is foreseen and industry assistance will be phased out after the pilot phase (Republic of South Africa, 2019).

## India launches a new residential building code

Following the update in 2018 of the Energy Conservation Building Code for commercial buildings, in December 2018 the Indian Ministry of Power launched *ECO Niwas Samhita*, an Energy Conservation Building Code for Residential buildings (ECBC-R). The government estimates this code has the potential to save 125 terawatt hours (TWh) of electricity per year by 2030, equal to half of India's current residential electricity demand (India Ministry of Power, 2018).

## A new phase of building energy rating begins in Australia

In April 2019, Australia launched a new phase of the National Australian Built Environment Rating System (NABERS). Following the success achieved over the past two decades – with USD 792 million in energy bills saved and 5.4 million tonnes of $CO_2$ (Mt $CO_2$) abated (NABERS, 2018) – this new phase will significantly expand the programme, aiming to reduce the environmental impact of all Australian commercial buildings to zero. In the coming five years this will enable new building types, such as schools, aged care, industrial warehouses and retail stores, to obtain an efficiency ratings (NABERS, 2019) In addition, a review of the mandatory disclosure programme for NABERS office energy ratings, the Commercial Building Disclosure Program, is examining the case for expanding the mandatory disclosure of ratings to new sectors.

## Financial Instruments for Brazil Energy Efficient Cities – FinBRAZEEC

FinBRAZEEC aims to unlock private financing for energy efficiency projects in urban areas of Brazil. In particular, it addresses efficient street lighting and industrial energy efficiency. The projects intend to reduce credit risk through loan syndication with commercial lenders and provide technical assistance through studies and capacity building. The programme was granted USD 200 million by the International Bank for Reconstruction and Development and is implemented by the Brazilian National Bank, Caixa Economica Federal (World Bank, 2018b). FinBRAZEEC joins several existing programmes that expanded their activity in 2018-2019, including the PROCEL Reluz Programme (street lighting), Brazil Mais Produtivo (industry), and the Strategic Alliance Programme for Energy Efficiency (industry).

## Azerbaijan's law on energy saving and energy efficiency

During 2018 the Ministry of Energy of the Republic of Azerbaijan developed the country's first comprehensive framework law for energy efficiency, with the support of the IEA EU4Energy programme. The law focuses on improving energy efficiency in buildings, as the current building stock results in large heating energy demands in winter. The adoption of this law is a crucial step for energy efficiency in Azerbaijan, which is now moving towards the next step: the development of its first National Energy Efficiency Action Plan (EU Neighbours, 2018).

# Mandatory policies

Mandatory policy coverage reached 35% in 2018.[2] Coverage growth was in line with average growth over the last decade, having increased by 1.4% year-on-year (Figure 3.5).

During the past five years, policy coverage growth was mainly driven by replacement of existing equipment stock with new stock subject to existing energy efficiency policies, and this trend continued in 2018. As in the previous two years, the contribution of new policies remains was

[2] For a definition of mandatory policies and the other policy types used referred to in this section, refer to Annex B

minor, at only 2% of the policy coverage growth. New policies include the implementation of HDV fuel economy standards in India, MEPS for air conditioning in Chile and other countries, and MEPS for motors in Singapore.

In China, the country with the largest share of energy use covered by mandatory policies, that share increases by 2 percentage points to 62% in 2018. Important increases were also registered in the European Union (3 percentage points), Canada (3 percentage points), Mexico (2 percentage points) Korea (1.5 percentage points), and South Africa (1 percentage point).

**Figure 3.5 Annual additions to the percentage of global energy use covered by mandatory energy efficiency policies and regulations, owing to new and existing policies**

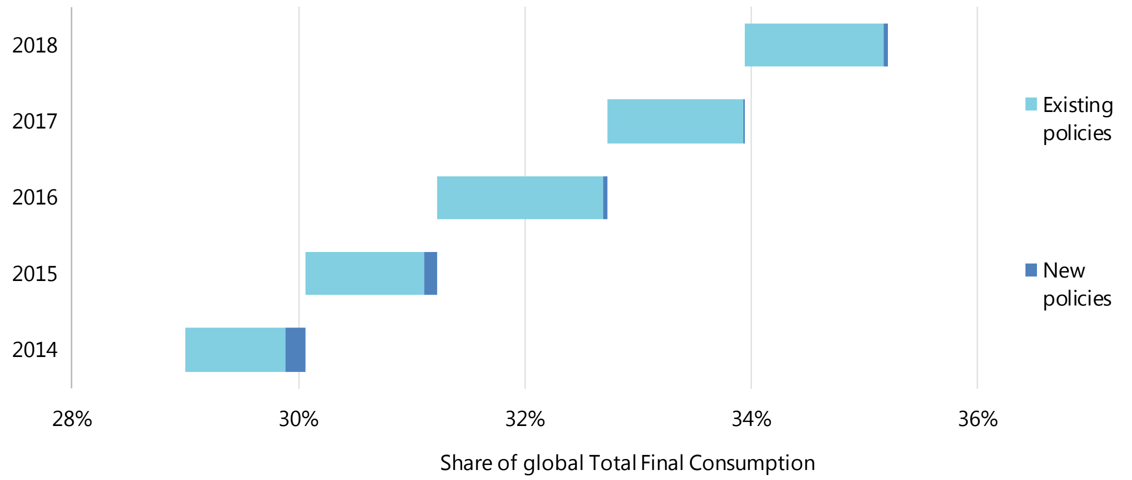
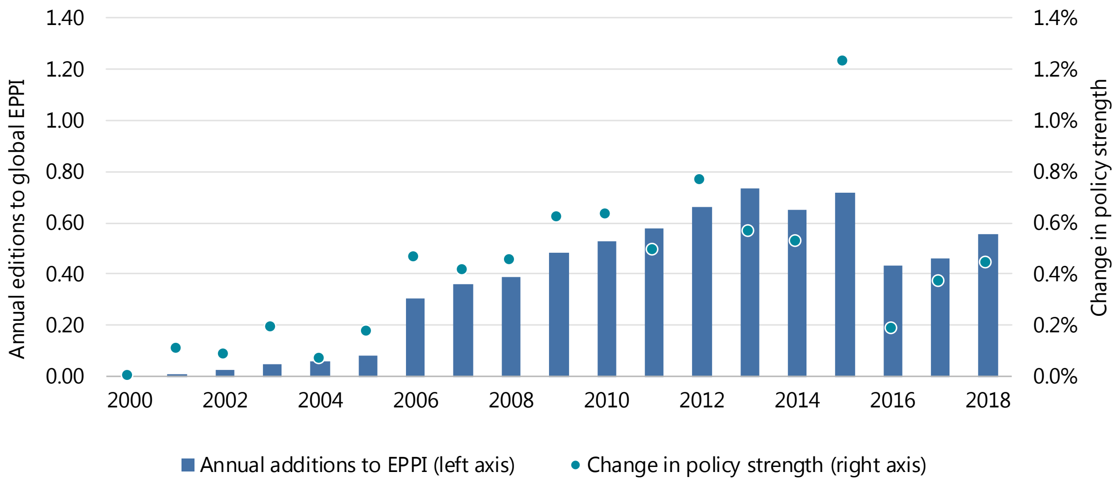





**Figure 3.6 Efficiency Policy Progress Index (EPPI) and annual changes in mandatory policy strength, 2000-17**






The strength of mandatory policies rose by over 0.4%, a slight increase compared with the previous two years, though still below increases observed during the five years prior, which averaged 0.72%. This indicates that while several new mandatory policies have recently been introduced more work will be needed to ensure these policies are effective. The 2018 strength improvement was driven by the upgrading of fuel-economy standards for both commercial and passenger light-duty vehicles (LDVs) in the United States and strengthened MEPS for central heating and cooling systems in Canada.

The combined changes in the coverage and strength of mandatory policies resulted in a nearly 0.6% increase in the Efficiency Policy Progress Index (EPPI) – the main IEA indicator of global progress on mandatory energy efficiency policy (Figure 3.6).[3] The EPPI increased the most in the non-residential sector, as a result of heating and cooling policies.

## New mandatory policies emerging in transport

In the last five years, various countries and subnational jurisdictions have started to implement policies that mandate specific shares of vehicle technologies – zero emission vehicle (ZEV) mandates – or that ban certain vehicle technologies. In most cases, these policies focus on new registrations, although certain policies also target the entire fleet. China, the only country with a national mandate, has concrete targets for 2020 (IEA, 2018c). In other countries ZEV mandates are being implemented at the subnational level. Ten US states have implemented them (IEA, 2019f) while in Canada, the provinces of Quebec and British Columbia have ZEV mandates in place. Several countries, such as the Netherlands, and many cities have also set targets to deploy electric buses during the next decade.

National and supra-national EV deployment targets have been complemented by several national governments pledging to end sales or registrations of new internal combustion engine (ICE) vehicles by a given year (IEA, 2018c). The number of countries that announced an ICE ban had grown to 15 by August 2019 (IEA, 2019f; SLoCAT, 2019). In addition, a number of local administrations have pledged to restrict ICE vehicles' access to certain areas, for example central business districts of cities.[4] The number of cities with a partial ICE car ban reached 19 in 2019, and while most are European, most continents are represented (IEA, 2018c). A growing number of cities have banned the use of ICE two-wheelers, spearheaded by China, which already has almost 300 million electric two-wheelers on the road (IEA, 2019f). European cities, such as Amsterdam, limit bans to two-stroke engines (Municipality of Amsterdam, n.d.).

# Energy efficiency obligations

The main market-based instruments tracked by the IEA are energy efficiency obligation programmes (Figure 3.7).[5] Obligation programmes, known as energy efficiency resource standards in the United States, require energy companies to achieve an energy efficiency target – typically, but not always, a set amount of energy savings. Policy progress is measured by monitoring changes in policy coverage (the share of total final energy demand covered by obligations) and policy strength (the share of total final energy demand required to be saved under the obligations in a given year). Obligations are not included in the EPPI.

[3] The EPPI combines the percentage of energy demand covered by mandatory policies and regulations with the increase in policy strength since 2000. For any given country or region, a 1-point increase in the EPPI means the global stock of energy-using vehicles, buildings and equipment is 1% more efficient than in 2000. An explanation of how the EPPI is calculated can be found at https://www.iea.org/efficiency2019.

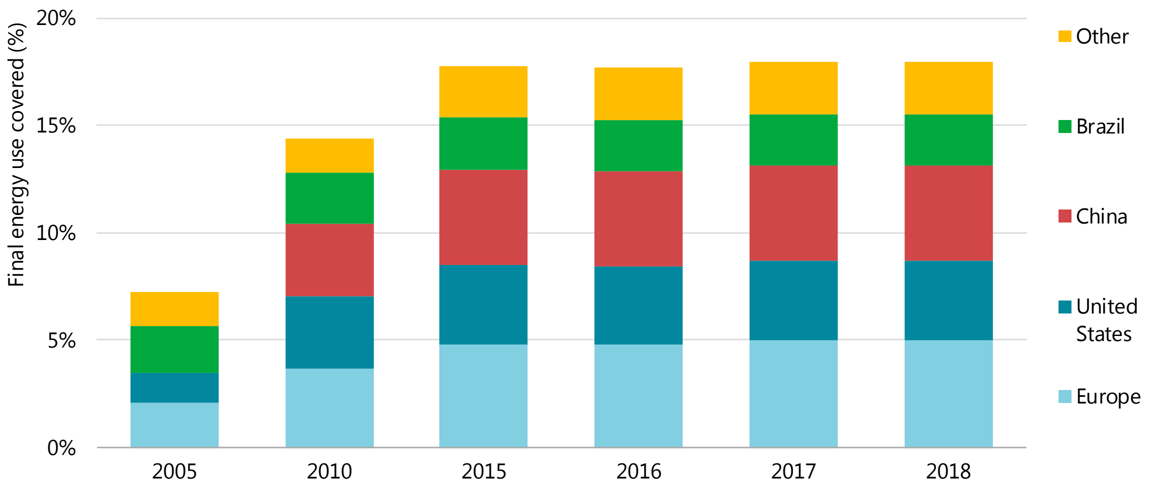
[4] Access restrictions are specific to the case and apply to different portions of an area under the jurisdiction of the local administration (e.g. city centres particular zones and/or entire metropolitan areas).

[5] For a definition of energy efficiency obligations and the other policy types referred to in this section, refer to Annex B.

In 2018, only minor changes were observed in obligation programmes. In the United States, new energy efficiency obligation programmes were implemented in New Hampshire and New Jersey. Overall, coverage remained flat at 18% in 2018.

In terms of the strength of obligation programmes, there was also little change. Targets were increased in the US states of Illinois and Vermont. On the contrary, in Ohio, House Bill 6 was signed into law in June 2019, significantly reducing the energy efficiency obligation to a level already reached in the market, reducing its effectiveness. In Europe, a strengthening of the target in France, led to an increase in certificate prices for both standard and fuel poverty white certificates. Greece and Slovenia also strengthened programme targets, while the other countries' targets remained unchanged. Global cumulative savings[6] since 2005 varied substantially among countries, with the highest in France (78%), Italy (6%) and Denmark (5%). The average among countries with obligations was around 2.5%.

**Figure 3.7 Final energy use coverage of energy efficiency obligations, by country/region**



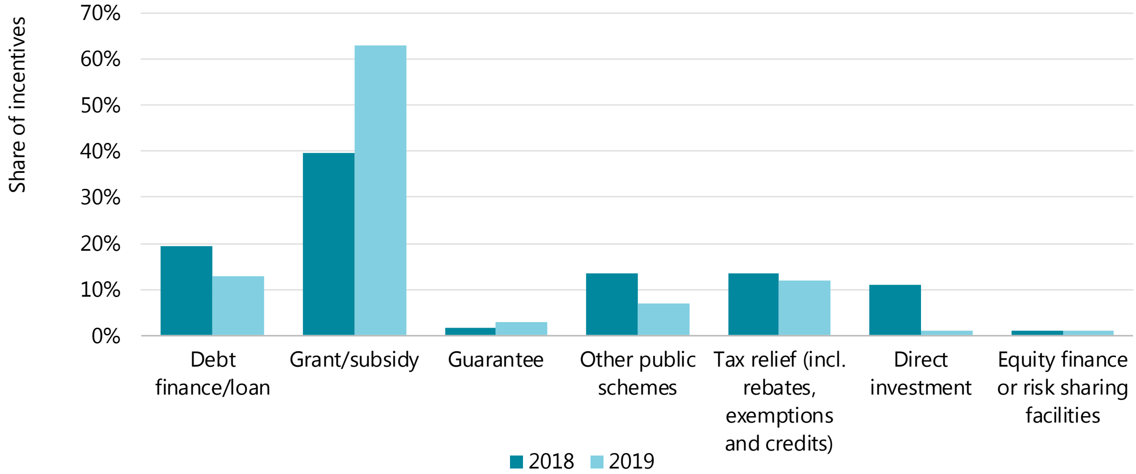

IEA (2019). All rights reserved.

## Financial incentives

In 2018, expenditure on national financial incentives[7] for energy efficiency by the 17 countries that provided data[8] equated to around USD 12 billion. This figure is not directly comparable with data collected in 2017 as the countries that provided data in each year were different. However, the breakdown of the *types* of incentives is comparable and shows that in 2018, grants and subsidies continued to be the policy tool of choice (Figure 3.8).

[6] The impact of over a decade of energy efficiency obligations has increased year-on-year, not just because of increases in coverage and strength, but also because of the long-lived nature of many energy efficiency measures. For example, a more efficient refrigerator bought in 2005 as a result of an incentive delivered through an obligation programme will deliver savings for its whole lifetime.
[7] For a definition of financial incentives and the other policy types referred to in this section, refer to Annex B.
[8] Countries included in this analysis are Australia, Austria, Canada, Czech Republic, Greece, Ireland, Italy, Japan, New Zealand, Norway, Portugal, Slovak Republic, Spain, Switzerland, Turkey, United Kingdom, and United States.

**Figure 3.8 Government incentives for energy efficiency by type of incentive**






Notes: Countries included in this analysis for 2019 are Australia, Austria, Canada, Czech Republic, Greece, Ireland, Italy, Japan, New Zealand, Norway, Portugal, Slovak Republic, Spain, Switzerland, Turkey, United Kingdom and United States.

**Box 3.1. In Europe, efficiency incentives deliver results**

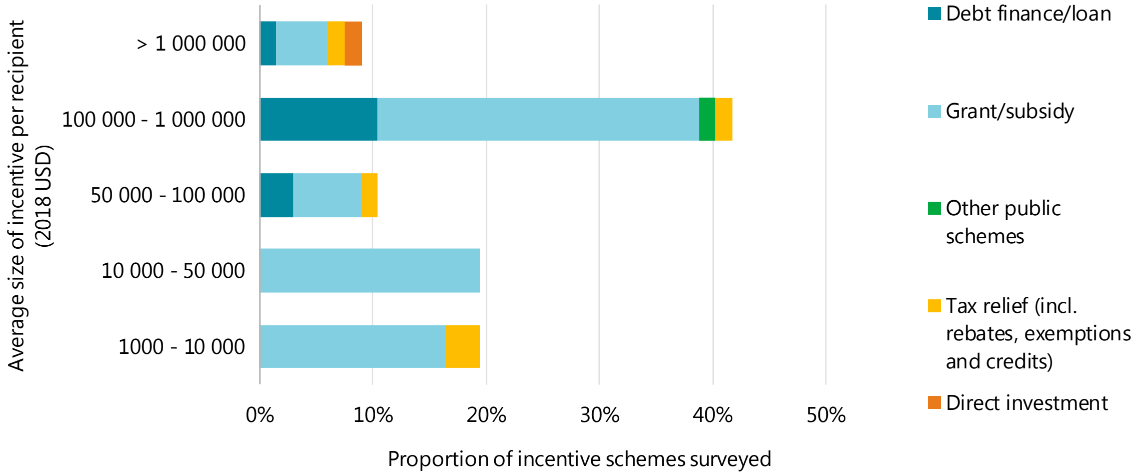
The Norwegian Energy Efficiency Scheme, administered by ENOVA and financed by the Norway Climate and Energy Fund, provides subsidies in five end-use sectors. Thanks to investments made in 2018, 1 560 gigawatt hours (GWh) of energy savings were achieved, corresponding to the annual consumption of 97 500 households in Norway (Norwegian Ministry of Petroleum and Energy, 2019). The majority of the savings (45%) were made in the transport sector, in part due to generous incentives for zero emissions vehicles.

In Portugal, a series of incentives were introduced as part of the National Energy Efficiency Action Plan, aiming at improving efficiency across sectors. In particular, the Call 20 FEE programme provided direct subsidies for energy efficiency measures in both residential and service buildings. Thanks to this programme, which began in 2016, improvements have been made in 695 households and 58 service buildings, achieving energy savings of 303 tonnes of oil equivalent (toe) per year.

In Italy, the Ecobonus programme helped almost 2 million households improve their energy efficiency, through tax credits equivalent to 50% to 75% of the measures' costs. Over the last year, 2.4 million m² of floors and roofs, 2.1 million m² of walls and 0.25 million m² of windows and shutters underwent retrofitting, and 65 000 condensing boilers, 21 000 heat pumps and 5 000 biomass boilers were installed. Overall, the programme achieved cumulative energy savings of 4.55 million tonnes of oil equivalent (Mtoe) between 2014 and 2018.

The average size of incentives received per recipient varied in 2018, with 42% of incentives providing assistance in the range of USD 100 000 to 1 million (Figure 3.9). Incentives in this size were mainly received for projects in industry, commercial buildings, apartment blocks and public transport, suggesting governments may be targeting incentives at large-scale, high-impact improvements or alternatively, that these recipients are easier to reach. Despite the size of the incentives being awarded, grants were still favoured as the primary policy tool, although this segment also received the largest share of debt finance. At the other end of the scale, 19% of incentive programmes provided an average of USD 1 000-10 000 per recipient, which were almost all received by the residential sector.

**Figure 3.9 Average size of incentive received by individual recipients by type of incentive programme (weighted by incentive type)**






Note: Countries included in this analysis include Australia, Czech Republic, Greece, Italy, Ireland, Norway, Portugal, Slovak Republic, Spain, Switzerland and United States.

## Electric vehicle incentives scale up

Government incentives for electric passenger vehicles expanded by 72% to USD 15 billion[9] in 2018 (Paoli and Bennett, 2019). This expenditure growth was a similar level to the 68% growth in EV sales, though monetary support per EV sold increased due to the launch of the Tesla Model 3 in North America and stronger preferences for high-end EVs in China. This growth trend is expected to slow down in 2019, as governments in key markets, such as the United States and China, have begun to adjust EV incentives to reduce budgetry impacts and steer the market toward specific vehicle types (IEA, 2019f).

Incentives for electric two- and three-wheelers are also scaling up. For example, India introduced a new phase of its Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME II) incentive programme, which includes support for commercial electric three-wheelers as part of its four-year budget of USD 1.42 billion.

# Finance and investment

The IEA's Efficient World Strategy suggests that to unlock the full potential of efficiency, global investments would need to double by 2025, and double again between 2025 and 2040 (IEA,

[9] This figure is in addition to the USD 12 billion quoted on page 42, and was compiled using a different methodology.

2018a). Despite progress in some areas, in 2018 investments in efficiency fell short of the levels envisaged by the strategy.

Energy efficiency financing trends can be examined by taking stock of how much was invested in efficiency in 2018 – and how policies and standards enabled these investments – in four key areas:

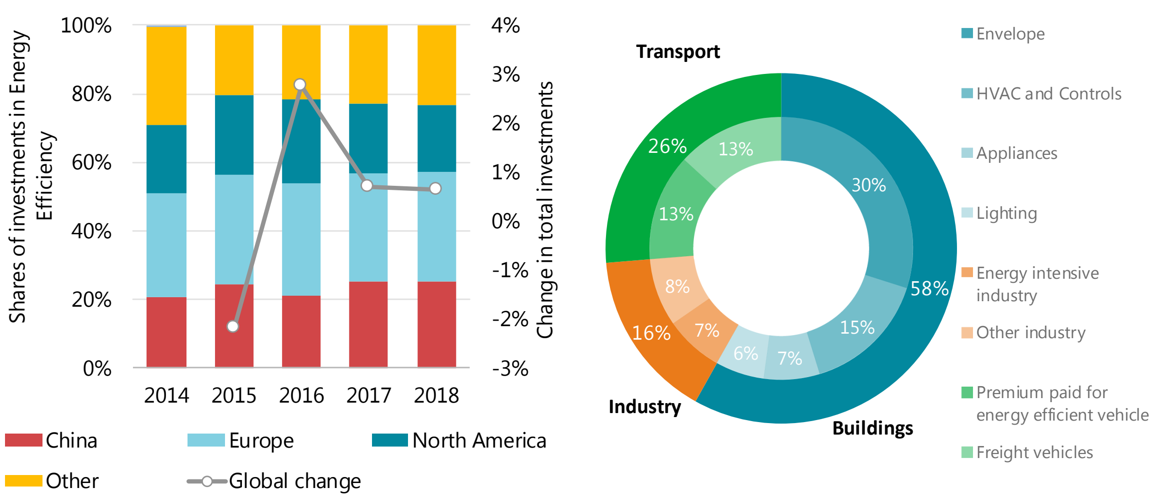
- incremental spending on more efficient technologies
- project investments by energy service companies (ESCOs)
- green mortgages, green bonds and property based repayment schemes
- climate mitigation investments by international financial institutions (IFIs).

The role of policy and standards to enable efficiency investments is also discussed.

## Incremental investments

2018 presents a mixed picture when it comes to incremental spending by companies, governments, and individuals on technologies that are more efficient than available alternatives. An example of an incremental investment is purchasing a highly efficient washing machine rather than a less efficient model.[10] At USD 240 billion (IEA, 2019i), incremental efficiency investments across the buildings, transport and industry sectors were less than 1% higher in 2018 than the USD 236 billion invested in 2017 (IEA, 2018a). This increase is significantly less than would have been needed for the world to take up the cost-effective energy efficiency opportunities currently available (IEA, 2018a).

**Figure 3.10 Energy efficiency investment by region, 2014-18 (left) and by sector in 2018 (right)**






[10] Defining and measuring investment in energy efficiency is far less straightforward than for investment in energy supply. The IEA defines an energy efficiency investment as the incremental spending to acquire equipment that consumes less energy than would otherwise have been used to provide the service, such as lighting, heating or mobility, had the consumer not bought a more efficient option (i.e. the baseline). The additional cost of a more efficient alternative can represent only a small share of total spending on a particular energy-related good or service. Furthermore, investment and spending is carried out by many millions of households and firms, often without external financing. As much as possible, a bottom-up analysis using sales and investment data on sales of efficient goods is used.

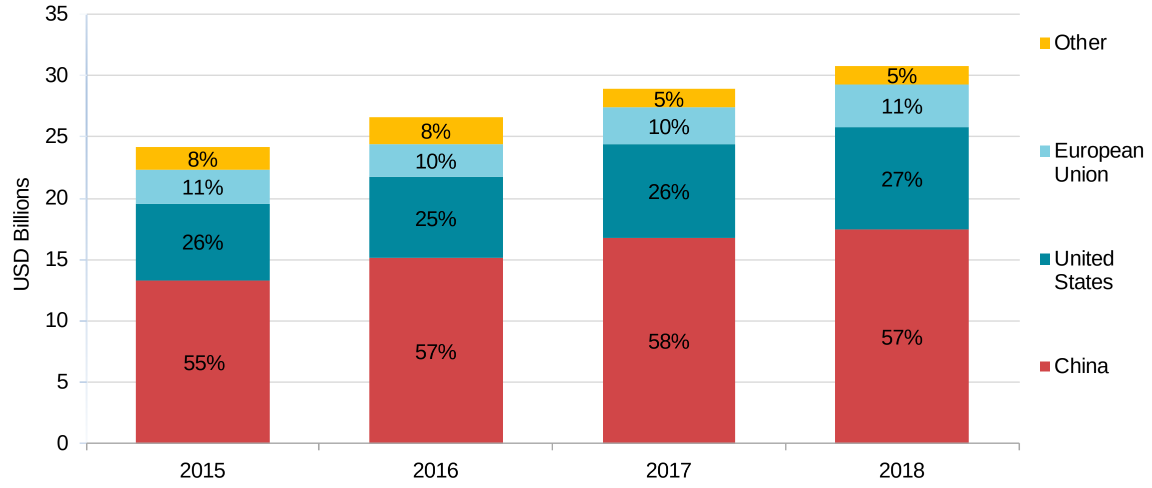
Within this global picture, trends vary from sector to sector and between advanced and emerging economies (Figure 3.10). Investments in the buildings sector, for example, declined by 2% in 2018. However, at USD 139 billion, buildings still attracted the highest share of global investments in efficiency.

Industrial energy efficiency investments increased in China by 12% and in India by 5%, but have continued to decline in the United States since 2015. Transport efficiency investments increased only slightly in 2018, and mainly in freight, while sales of less efficient light-duty trucks increased (IEA, 2019i).

## Energy service companies

ESCOs are key enablers of investments in energy efficiency, because they deliver efficiency projects based on long-term contracts tied to energy performance. ESCOs may finance initial project costs directly or with the involvement of a third party, while the customer is not required to make upfront capital expenditure. This contracting structure is critical to the success of ESCO financing. since upfront costs for efficiency upgrades often present a barrier to investment, and long-term contracts allow ESCOs to deliver more comprehensive energy efficiency improvements.

**Figure 3.11 Global ESCO market growth 2015-18**






Note: Results are based on a series of surveys and interviews conducted in 2018 with ESCO associations, international organisations and experts, as well as on desktop research. Growth figures for 2018 were estimated for the US based on data limitations.

The IEA tracks key trends and developments in the global ESCO market, which grew to USD 30.9 billion in 2018, from USD 28.6 billion in 2017 (Figure 3.11). China continues to dominate the global ESCO market (Box 2).

Policy makers seeking to increase investments in efficiency through ESCOs can draw on lessons from both emerging and developed economies. ESCO associations, for example, have been established in several countries. They are vital sources of information for policy makers and help to raise awareness among financial institutions. They connect ESCO representatives with customers and/or public officials, and support the development of important tools, for example standardised contracts or protocols for measuring and verifying efficiency savings. Governments have also promoted ESCO markets by inviting ESCOs to bid for performance contracts to retrofit public buildings, for example. Additional measures that have been effectively deployed in several countries include ESCO project databases and other information tools, and capacity building such as training for public officials tasked with developing complex calls for ESCO project tenders.

**Box 3.2. China: The story of an evolving ESCO market**

In 2018, revenue from Chinese ESCOs totalled CNY 117 billion (Chinese Yuan renminbi, USD 16.4 billion), up 3% from 2017. Compared with 2011-2015, when the average annual growth rate was over 25%, the market is expanding at a significantly slower pace, reflecting changes to the policy landscape and market dynamics.

Initially, government subsidies rewarded ESCOs for the energy savings they achieved, in order to spur the market. Since 2015, central government agencies have phased out five subsidies and financial incentive programmes, with the goal of directing the ESCO industry from a policy-driven to a market-driven environment (Ministry of Finance, China, 2015).

The withdrawal of national government subsidies does not appear to have halted the ESCO market growth trend, probably because the Chinese ESCO market is mature and provincial and municipal governments have continued some tax rebates and financial incentives. In some regions, however, companies that were overly reliant on favourable national policies are gradually exiting the market (EMCA, 2019).

Another dynamic demonstrating the maturity of the Chinese ESCO market is the diversification of business models and actors in the market. In the early stages of China's ESCO market, the only contractual models used were energy performance certificates under the shared savings model. By 2018, shared savings contracts had declined to 48% of market share, with other contract models, including guaranteed savings, outsourced energy services and financial leasing, taking up more than half (EMCA, 2019).

Over time, more diverse actors have joined the ESCO market, which had been dominated by "traditional" ESCOs focused on equipment replacement. More companies are gradually entering that have expertise in other sectors, including technology (hardware) providers, software developers and building service management companies. This shift reflects technology trends, as emerging digital technologies allow for additional energy saving opportunities and other value-add services to be captured. It also signals a potential shift in the demands of ESCO clients, which may be moving beyond a singular focus on energy savings.

## Green mortgages and green bonds

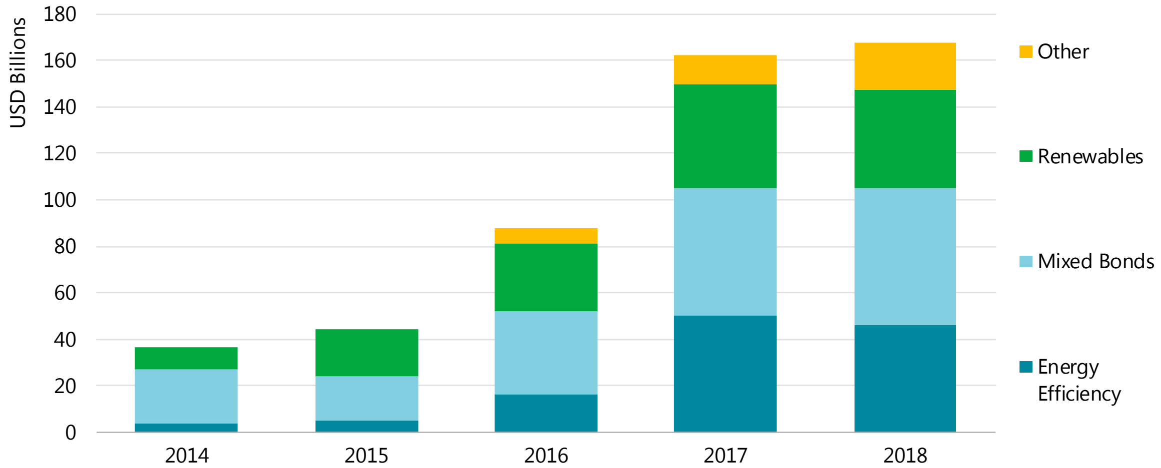
Mortgage-based loans for energy efficiency improvements in residential buildings, also known as green mortgages, have been a key driver for the development of green bonds, a type of asset-backed security traded on financial markets. Green bonds differ from conventional bonds because they contain a component devoted to sustainability (water or forestry, for example) or clean energy. A significant portion of green bonds are securitised green mortgages, although efficiency is also a component of green bonds linked to rooftop solar projects or grid improvements that enable demand response, for example. By connecting investors to projects that deliver efficiency gains, green bonds bring investment into energy efficiency from global financial markets.

Between 2014 and 2017, green bond issuance soared, driven to a large extent by the US lender Fannie Mae's Green Rewards programme, which provides preferential financing and audit support to enable efficiency investments in buildings, particularly residential properties. (IEA, 2019i). Year-on-year issuance in 2018 declined by 8% to just over USD 45 billion, but issuance was still significantly higher than the USD 3.8 billion in 2014, suggesting that green bonds with an efficiency component have gained some footing in financial markets (CBI, 2019) (Figure 3.12).

Outside of the United States, green mortgages and bonds are less developed, but governments and industry stakeholders are making efforts to stimulate market development. The EU-funded Energy Efficiency Mortgages Action Plan ( EeMAP), for example, has continued to expand since its launch in 2017, with a long list of commercial lenders and companies endorsing the creation of a standardised framework and data protocols that enable green mortgage development(EeMAP, 2019). In addition, the United Kingdom has unveiled a GBP 5 million (British pounds) fund (USD 6.1 million) to help commercial lenders develop green mortgages, part of the government's green finance strategy (HM Government, 2019).

Beyond government-led initiatives, private lenders are also looking to "green" their mortgage portfolio. The Netherlands-based bank ING, for example, has announced its intention to bring its EUR 600 billion lending portfolio (USD 655 billion) into line with the Paris Agreement goals. As mortgages account for nearly 50% of the bank's lending, green mortgages are central to its greening initiative. ING has also emphasised the need for accurate data on building energy performance as well as a supportive policy environment (Schoonhoven, 2019).

**Figure 3.12 Global green bond growth 2014-18**






Note: Energy efficiency green bonds as indicated in the chart refer primarily to real estate-based green bonds, meaning securitised green mortgages. The renewables green bonds do not include all green bonds for renewables issued over this time, only those with an efficiency component. Mixed bonds contain grid or infrastructure investments with an efficiency component, but do not include mixed bonds without a efficiency component.

Source: CBI (2019), *Climate Bonds Initiative*, www.climatebonds.net/.

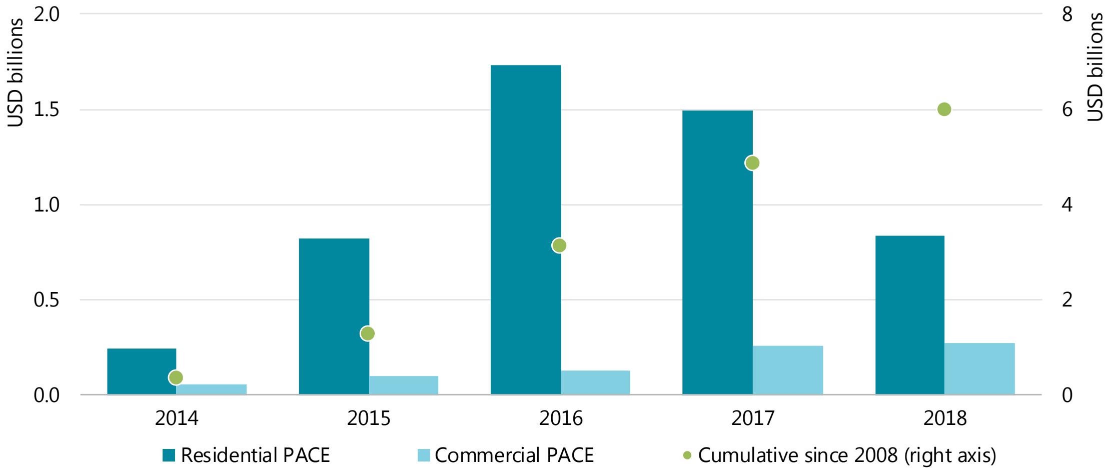
The global market for green bonds has also grown strongly since the first green bond was issued just over a decade ago. By November 2018, cumulative bond issuance had exceeded USD 500 billion. Although this growth is encouraging, it is important to put it in perspective. In 2018, the global bond market was worth roughly USD 100 trillion (BIS, 2019). Green bonds represent only 0.5% of the total, and green bonds for energy efficiency accounted for a mere 0.05% of global debt security issuance in 2018.

## Property-based repayment schemes

Property-based repayment schemes facilitate the repayment of loans for energy efficiency improvements through property taxes. Like green mortgages, they can be securitised and traded on financial markets. To date, the most successful example of this kind of financing is property-assessed clean energy (PACE). PACE has emerged as an important investment vehicle for energy efficiency, particularly in the United States. Since 2014, over USD 6.6 billion has been invested through PACE securitisation in the United States, with the majority, USD 5.6 billion, going into residential (R-PACE) projects, while USD 1 billion has been invested in commercial (C-PACE) projects (PACENation, 2019).

However, lending declined by nearly 45% from 2017 to 2018, particularly for R-PACE projects (Figure 3.13. Among other factors, strengthened consumer protection requirements introduced by California lawmakers, including income-based underwriting, have reduced the number of eligible homeowners and increased the reluctance of project developers to offer PACE financing to their customers (DeVries, 2018).

**Figure 3.13 PACE lending in the United States, 2014-2018, annual and cumulative**






Source: PACENation (2019).

EU policy makers and energy efficiency finance stakeholders are also exploring the development of a PACE-like financing model in Europe. In contrast with the United States, however, a European version of PACE is unlikely to be linked to property taxes, but rather secured by a lien (claim) on the property and collected regularly with the support of the public authority that initiated the programme. The legal basis for the mechanism will be subject to local laws and will differ from country to country. The financing itself will require evaluating both the property's characteristics and the creditworthiness of the homeowner making the loan request (EuroPACE, 2019).

## Policy support and market guidance for energy efficiency investments and projects

Policy makers and efficiency industry stakeholders are exploring ways to support the growth of green bonds and other sustainable investment vehicles in financial markets, and to develop energy efficiency service markets and projects (Box 3.3).

The European Commission, for example, released an action plan in 2018 on financing sustainable growth, which features a "green" taxonomy to provide clarity and consistency for markets on what constitutes an energy efficiency or other sustainable investment (EC, 2018). The European Commission is also in the process of developing an EU taxonomy for sustainable activities (EU TEG, 2019a)[11] and a Green Bond Standard through its Technical Expert Group on Sustainable Finance (EU TEG, 2019b).

**Box 3.3. Cooling as a Service (CaaS) – innovation in efficiency financing**

The high upfront cost of installing state-of-the-art energy efficient technology is one of the most frequently cited and most persistent barriers to improving energy efficiency in public and private organisations. Even when organisations technically possess the means to procure efficient equipment, annual budget restrictions, accounting rules and other factors may limit the amount of capital expenditure a government entity or company is able to dedicate to it.

Paying for efficiency as a service – as an *operational* rather than as a capital expenditure – is one means to overcome upfront cost barriers. As is already done with printers, software or vehicles, organisations can benefit from efficient technologies by entering into a service agreement rather than being required to purchase these technologies.

The CaaS initiative, led by the Basel Agency of Sustainable Energy (BASE) on behalf of K-CEP, is working to scale up the global market for space cooling as a service (BASE, 2019). Launched in March 2019, the model works on the premise that organisations pay for tonnes of refrigeration, or units of cooled air, whereby technology providers install and maintain the equipment. BASE is currently working to create a toolkit of standardised CaaS mechanisms while raising awareness among technology providers, financial institutions and policy makers.

In China, seven government agencies[12] recently launched a Green Industry Guidance Catalogue, creating a green taxonomy for six broad categories of goods and services (NDRC, 2019). The consistent definitions in these taxonomies are meant to provide a complementary foundation to regulatory guidelines for green bonds and create opportunities to scale up and innovate in green finance (Th Paulson Institute, 2019).

The green taxonomy is the latest addition to China's comprehensive policy framework for green finance, which already includes Green Credit Guidelines, Energy Efficiency Credit Guidelines and Guidelines for Establishing the Green Financial System. Further, a guideline is being developed to encourage more lending from commercial banks for energy efficiency projects in the buildings sector (Ge et al., 2017).

Energy efficiency features clearly and strongly throughout the eligibility criteria in the taxonomies being developed both in China and the European Union, in particular in manufacturing, the energy sector and municipal services (such as water supply and waste management) (NDRC, 2019; EU TEG, 2019a).

[11] Input to the EU Taxonomy on energy efficiency was provided by a working group of the Energy Efficiency Financial Institutions Group, convened by the European Commission and the UNEP Finance Initiative.
[12] Including the National Development and Reform Commission, the People's Bank of China, and the Ministry of Ecology and Environment.

The Investor Confidence Project (ICP), which brings together investors from Europe and North America, provides standardised protocols, training and certification designed to de-risk and scale up investments in energy efficiency projects (ICP, 2019). A similar effort, Asset Class Energy Efficiency (ACE), aims to provide structure and tools for efficiency investments in Germany, based on the methodology developed by the ICP(Schinck et al., 2018). The International Organization for Standardization (ISO) also introduced in 2018 a voluntary standard for Sustainable Finance (ISO, 2018). The Basel Agency of Sustainable Energy (BASE) is working on behalf of the Kigali Cooling Efficiency Program (K-CEP) to scale up the global market for space cooling as a service (Box 3.3).

In Latin America, the Inter-American Development Bank (IADB), together with the Danish Energy Agency, is supporting the development of an insurance product for efficiency projects undertaken by small and medium-sized enterprises (SMEs). Technology solutions providers will be able to purchase the insurance to back their contractual guarantees to their SME clients on the performance of their energy efficiency products (GFL, 2019). The programme also includes measures such as standardised contracts to reduce transaction costs; third-party verification to ensure the quality of energy service providers and their projects; credit lines from development banks; and grant support to sustain market demand (GFL, 2019).

## The role of international financial institutions

Energy efficiency is an important climate mitigation mechanism for IFIs. Currently, IFIs mainly support the deployment of efficiency measures in buildings, industry and other sectors through project finance, for example with loans or lines of credit. Such financing may be accompanied by advisory and/or capacity building services. IFIs are also exploring ways to increase investment in energy efficiency by de-risking efficiency investments and leveraging greater private sector financing. They may provide loan guarantees, for example, notably in emerging economies, where policy and investment frameworks may create barriers to private financing for clean energy and energy efficiency projects (EEFTG, 2017). This is one of the topics being explored by the Efficient World Financing Forum, established in October 2018 (Box 3.4).

IFI financing for energy efficiency – primarily via loans – is increasing. In 2018, 18% of global mitigation financing, or over USD 5.5 billion, was invested in efficiency measures, notably in Eastern Europe and Central Asia (EBRD, 2018). Only renewable energy projects received significantly more IFI funds than efficiency measures in 2018. The proportion of IFI financing going to efficiency projects was 4% higher in 2018 than the annual average between 2012 and 2014(Boyd, 2017).

IFI funding for efficiency looks set to grow in the coming years. The World Bank Group, for example, announced in late 2018 that it would double its investments in this area to USD 200 billion between 2021 and 2025, with the funds supporting efficiency measures expected to enable 1.5 million GWh in energy savings (WBG, 2018). In 2015, as part of its Green Economy Transition, the European Bank for Reconstruction and Development (EBRD) significantly increased its focus on efficiency spending, alongside other climate and resource efficiency investments. In 2017, it invested EUR 1.2 billion (EBRD, 2019). The European Investment Bank (EIB) launched a consultation in early 2019 to determine future levels of funding for efficiency (EIB, 2019). Other regional IFIs are expanding their energy efficiency lending activities, including through dedicated credit lines, technical assistance and dedicated mechanisms such as energy saving insurance.

# Efficient technologies

The energy sector is in a critical transition phase, in which the rollout of technologies to rapidly increase efficiency and reduce energy demand must be quickened to align with the IEA Sustainable Development Scenario. This section summarises trends in the deployment of efficient technologies, building on work undertaken for *Tracking Clean Energy Progress* (IEA, 2019g). It focuses on recent technological developments, excluding those related to digitalisation, which are discussed in Chapter 4, *Emerging Trends: Digitalisation*.

**Box 3.4. The Efficient World Financing Forum**

The Efficient World Financing Forum (EWFF) was established in late 2018 through collaboration among IFIs to scale up energy efficiency and small-scale clean energy finance. The IEA Efficient World Strategy will help guide the work of the forum.

The current members of the EWFF are: Asian Development Bank (ADB), African Development Bank (AfDB), Development Bank of Latin America (CAF), EBRD, EIB, Green Climate Fund (GCF), IADB, Islamic Development Bank (IsDB), KfW Development Bank (KfW) and World Bank.

An action plan has been developed, which comprises four areas of collaboration:

- strategic prioritisation of efficiency through institutional decision-making and asset allocation processes
- enabling policy conditions and their interaction with finance, to identify priority areas for future policy support
- sector-specific processes and tools, including in the buildings and transport sectors
- facilitating capacity building.

Through each of these work streams, EWFF participants will share best practices in bridging financing gaps in specific sectors; leveraging their diverse experiences in implementation, delivery models and financing mechanisms for energy efficiency; and blending analysis, policy advice and public finance. The work aims to build upon the efforts of other international initiatives and create new insights that help to advance country-level and institutional goals in energy efficiency and small-scale clean energy finance.

## Buildings sector technologies

### Recent developments

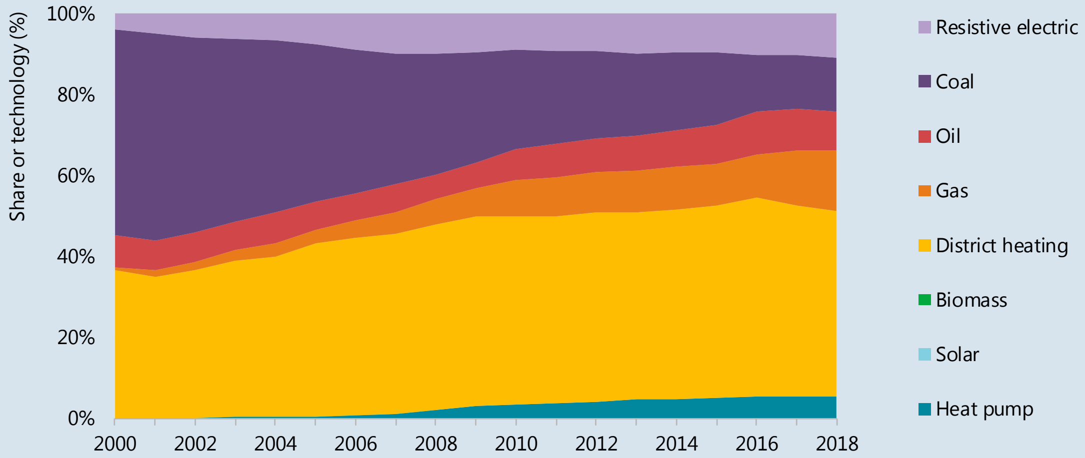
Of the core end-uses in the buildings sector, only lighting is on track with the IEA's Sustainable Development Scenario (Table 3.1). Cooling and appliances are both showing improvement, but building envelopes and heating are well off track. Sales of heat pumps and renewable heating equipment such as solar hot water systems have continued to increase by around 5% per year since 2010, and represented 10% of heating equipment sales in 2018 (IEA, 2019g). Cooling is the fastest-growing energy end use in buildings, with most people purchasing new air conditioners that are only one-third to one-half as efficient as the best available (IEA, 2018b).

Although cooling is not on track, technological improvements for reducing cooling energy use in buildings are emerging. For example, the India-based Global Cooling Prize received 445 submissions for affordable and greater-than-5-times more efficient window air conditioner designs, indicating that the technical options for highly efficient cooling equipment may becoming more widely available (RMI, 2019).

### Box 3.5. Chinese homes switch to more efficient heating

Householders in China have historically relied on coal to heat their homes. Since 2000, heating systems in Chinese homes have moved dramatically away from coal (Figure 3.12). This transition is driven partly by migration from rural areas to cities where there are more likely to be district heating systems. However, since December 2017, and as part of the overall pollution control budget, subsidies have been introduced for cities to replace coal heating systems with natural gas or electric heating systems. CNY 25 billion (USD 3.76 billion[13]) has been provided in 35 cities (IEA, 2019j). Furthermore, district heating systems that were predominantly coal-based boilers and co-generation are moving towards cleaner fuels. For example, urban areas in Beijing are now entirely fuelled by four large gas co-generation plants (Tsinghua University and IEA, 2017).

**Technology fuel mix for heating in China, 2000-18**






Source: IEA (2019) *Energy Technology Perspectives* (buildings model).

In 2018, according to the Ministry of Ecology and Environment, 4.8 million households changed from coal to cleaner energy sources like gas and electricity, 20% more than in 2017. This trend is expected to continue in the near future: the *Natural gas heating development targets for 2017–2021* (NDRC, 2017) includes a target of converting 12 million households from coal-fired to gas-fired boilers, representing an incremental increase in gas demand of 9 billion cubic metres (bcm) by 2021.

[13] Using the average 2018 rate of USD 1 = CNY 6.64.

**Table 3.1. Status of key buildings sector end uses**

| Technology | Status in relation to the Sustainable Development Scenario (SDS) |
|---|---|
| Lighting | Green |
| Cooling | Yellow |
| Appliances and equipment | Yellow |
| Heating | Red |
| Heat pumps | Red |
| Building envelopes | Red |

Notes: Green = On track to reach the levels envisioned in the SDS; yellow = More efforts are needed to reach the levels envisioned in the SDS; red = Not on track with the levels envisioned in the SDS.

Source: IEA (2019g), *Tracking Clean Energy Progress*, www.iea.org/tcep.

## Medium-term technological change

Several key, proven technologies are growing strongly and are expected to achieve greater penetration in the medium term. For example, as LED costs continue to fall, sales of LEDs are on track, although continued robust growth is needed to make up over 90% of sales by 2030 (IEA, 2019g). Heat pump technology is set to take on a larger share of space conditioning and water heating technologies. Clean cooking technology (such as induction cooking and insulated cookware) will also continue to grow, driven by increased wealth and access to clean energy.

As the global climate warms and extreme weather events become more frequent, more comfortable, energy-efficient buildings need to be constructed. This is a major challenge requiring technological change. Key technologies include shading devices, improved insulation, low-emissivity windows, draught-proofing and, in extreme climates, energy recovery ventilation systems. For example, India is developing locally manufactured, external movable shading systems to reduce solar heat gain and the need for mechanical air conditioning (BEEP, 2019).

In the medium term, the buildings sector could also support building resilience, while reducing both embodied energy and operational energy, by using more industrialised and automated construction techniques, such as prefabrication and 3D printing (see Chapter4).

# Industry sector technologies

## Recent developments

More efforts are needed across all sub-sectors to put industry on track with the IEA's Sustainable Development Scenario (Table 3.2). Scrap metal collection and sorting avenues could be improved in the iron, steel and aluminium sectors so that the rate of metals recycling can increase, reducing energy and emissions intensity. Increased recycling rates for plastics, paper and cardboard, allowing for less energy-intensive production routes, are also vital to get the chemicals and pulp and paper sectors on track. Reducing average clinker-to-cement ratios is crucial to reduce energy intensity and process emissions in cement manufacturing. To achieve such a reduction, more blended cements need to be adopted that use binding materials other than clinker, the production of which is the most energy-intensive component of cement manufacturing.

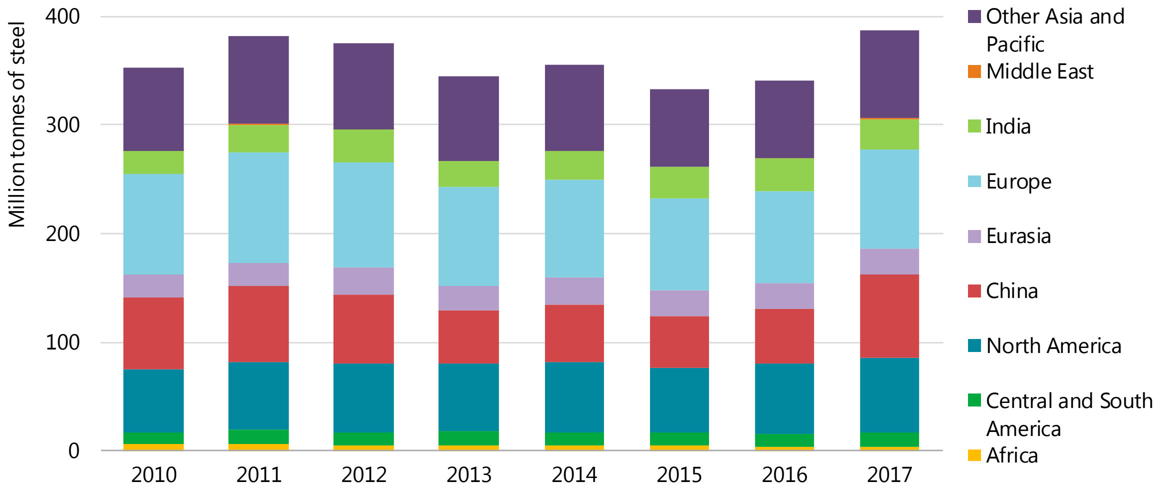
**Table 3.2. Progress of energy-intensive industry sub-sectors against the IEA Sustainable Development Scenario**

| Technology | Status in relation to the Sustainable Development Scenario |
|---|---|
| Chemicals | ● |
| Iron and steel | ● |
| Cement | ● |
| Pulp and paper | ● |
| Aluminium | ● |

Source: IEA (2019g), *Tracking Clean Energy Progress*, www.iea.org/tcep.
Notes: Green = On track; Yellow = More efforts needed; Red = Not on track.

Improvements in energy efficiency in the iron and steel sector, in which activity jumped in 2017 and 2018, depend on increasing the amount of steel produced from recycled scrap through electric arc furnaces, in addition to adoption of best available technologies. Crude steel production in an electric arc furnace using scrap is 60% to 70% less energy-intensive than primary production (IEA, 2018a), meaning that the amount of metal recycling is reflected in the energy intensity of the total iron and steel sector. The ability to scale up metals recycling depends on the availability of cost-effective scrap metal, which, globally, continues to be exceeded by demand for crude steel.

**Figure 3.14 Estimated steel production from scrap in electric arc furnaces, by region, 2010-17**






Note: Steel recycling reflects production from electric furnaces minus the production of direct reduced iron as a percentage of total crude steel production.
Source: World Steel (2018), Steel Statistical Yearbook 2018.

Production of steel from recycled scrap in an electric arc furnace is estimated to have jumped by around 15% in 2017 as a result of a 52% increase in Chinese production, which returned to levels not seen for several years (Figure 3.13). Europe remains the largest producer of steel from recycled scrap, with 25% of the global total in 2017. North America, China and the group of other Asia and Pacific countries each produced around 20% of global total. Greater production capacity in Europe reflects its more favourable availability of scrap metal, resulting from longer-lived infrastructure. Electric arc production capacity in China is growing but its share of total steel production has been constrained by the availability of cost-effective scrap metal.

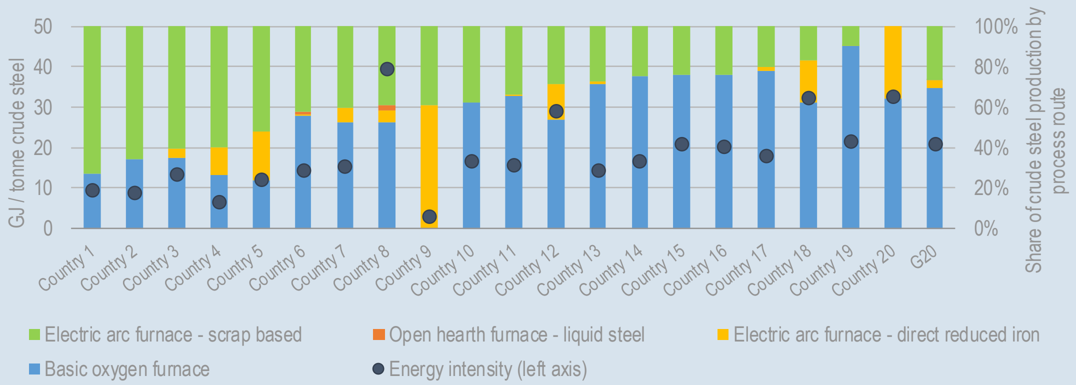
### Box 3.6. Benchmarking industrial energy intensity in G20 countries

Benchmarking can be a powerful tool for understanding energy performance and opportunities for improvement at a process, company, sector or country level. It is a component of several industrial energy efficiency policy mechanisms, including Japan's industry benchmarking policy and India's Perform, Achieve, Trade (PAT) programme. To expand the use of benchmarking, appropriate indicators need to be selected with which to compare performance and data needs to be made available at the appropriate level of detail.

Benchmarking the energy intensity of crude steel production is an example of how simple indicators, such as energy use per tonne of crude steel, can be combined with the shares of production from various process routes to reveal drivers of energy efficiency. The energy intensity of steel production varies across all G20 countries, influenced heavily by shares of different steel production routes. Specifically, greater levels of metals recycling and electric arc furnace production drive down energy intensity.

As part of its 2019 G20 Presidency, Japan sought to highlight the benefits of benchmarking to drive improvements in energy efficiency. The IEA provided support to illustrate how benchmarks could be developed for energy-intensive industries, as well as within the transport and building end-use sectors. This work was highlighted in the G20 Karuizawa Innovation Action Plan. The IEA is continuing to support Japan in promoting the value of benchmarking activities and analyses, as well as facilitating data collection to improve industrial energy efficiency policy making.

**Final energy use per tonne of crude steel and share of steel production by process route in G20 countries in 2016**






Notes: Country names have been removed as agreement has not yet been reached to undertake cross-country comparisons.

## Transport sector technologies

### Recent developments

Of the key end uses in transport, only electric vehicles and rail are currently in line with projections under the Sustainable Development Scenario, whereas the overall fuel economy of cars and vans is not on track (Table 3.3).

**Table 3.3. Status of key transport sector end uses with impacts for global energy efficiency**

| Technology | Status in relation to the Sustainable Development Scenario |
|---|---|
| Electric vehicles | 🟢 |
| Rail | 🟢 |
| Aviation | 🟡 |
| Trucks and buses | 🟡 |
| International shipping | 🟡 |
| Fuel economy | 🔴 |

Notes: Green = on track; yellow = more efforts needed; red = not on track.
Source: IEA (2019g), *Tracking Clean Energy Progress*, www.iea.org/tcep.

The electrification of transport continues to be a major technological shift but is yet to have a significant impact on total electricity demand. In 2018, electricity demand in transport (including rail) grew by 70% but still represented less than 3% of total electricity demand growth (IEA, 2019g).

Electric car sales set another record in 2018, with sales of nearly 2 million EVs (IEA, 2019f). EVs' share of new vehicles sales reached almost 50% in Norway and double digits in California and Iceland. As the market for new cars shrinks in many countries, such growth increases the technical efficiency of the overall passenger transport fleet. The growth in electric road vehicles, while still small, is on track. It includes cars, urban buses and two-wheelers, with the latter led by Chinese efforts. There were already more than 400 000 electric buses on the road in 2018 and nearly 300 million electric two-wheelers (IEA, 2019f). Overall, the entire stock of electric road vehicles displaced 0.43 million barrels of oil per day in 2018, one-third of overall oil demand growth (IEA, 2019f). Overall improvements in vehicle weight, and lower aerodynamic and rolling resistance, could help speed up electrification (IEA, 2019g).

Medium-term technological change

Electrification will continue to be an important medium-term energy efficiency technology trend in transport. Electrification is rapidly advancing in two-wheelers, buses and cars, but remains a challenge in heavy-duty vehicles and long-distance transport (IEA, 2019f).

Car manufacturers have set a wide range of targets to supply the vehicle market with EVs (IEA, 2019g). The number of EV models is expanding rapidly: car makers have announced dozens of models in various size segments, most of them coming online between 2020 and 2025. The number of available electric car models in 2018 was unevenly distributed among different size segments and countries. Announced models would cover a much wider spectrum, improving technology availability for a larger share of the population (IEA, 2019f). Nearly all major manufacturers have announced electrification strategies, with deployment ranging between 44 and 95 million electric cars by 2025. This range is largely in line with current government targets. Next to vehicle deployment, charging infrastructure is crucial to support EVs; progress is also being made on this front (IEA, 2019f).

Making electric vehicles more affordable depends on rapidly reducing the cost of automotive batteries, a key component. In 2018, the average lithium battery price fell 18% from 2017, to USD 176 per kWh (Baker, 2019). With battery production expected to grow nearly thirty-fold by 2030, significant battery cost reductions can be expected through the combination of battery pack size increases, battery chemistry changes and economies of scale thanks to increasing manufac turing plant size. The growing size of the Chinese automotive battery market and, more broadly, the global market, is instrumental to reap the benefits of economies of scale, as it prompts expansion of battery manufacturing capacity.

The growth of a new major industrial sector inevitably has consequences for material and supply chains (IEA, 2019f). It is important that governments and the auto manufacturing industry develop the capacity to anticipate the associated risks and design strategies to manage material supply risks. Extraction of lithium and cobalt is particularly concentrated geographically, whereas the further processing of lithium, copper, cobalt and nickel is mostly concentrated in China. The OECD has developed a Due Diligence Guidance for Responsible Mineral supply chains to help address these material supply risks (OECD, 2011).

Electric mobility, and in many cases shared micro-mobility (e.g. electric foot scooters), is transforming transportation in some cities, though the medium to long-term efficiency effects remain uncertain (IEA, 2019f).

For aviation and shipping, several dynamic years are expected as key policy measures come into force, requiring technology changes that in most cases include energy efficiency. The 2020 International Maritime Organisation sulphur cap mandates shippers to use less-polluting fuel, which generally costs more than bunker fuel (IEA, 2019h). Energy efficiency measures could alleviate some of these cost escalations (Halff et al., 2019).

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# IV. Emerging trends: Digitalisation

## Highlights

- Digitalisation is reshaping the entire energy system. This transformation is being driven by advances in three fields: volumes of data are increasing thanks to the declining costs of sensors and data storage, rapid progress is being made in advanced analytics and computing capabilities, and connectivity is being boosted by faster and cheaper data transmission.

- At a time of deep change in the energy system, with growing shares of intermittent generation from renewable energy sources, digitalisation is making demand-side energy efficiency a more valuable resource. As well as improving end-use efficiency, many digital technologies provide other services, such as flexible load, that increase the efficiency of the entire system. While end-use efficiency has always had system benefits, digitalisation allows for these benefits to be measured and valued faster and more accurately.

- Digital technologies could benefit all sectors and end-uses. Digitalisation could reduce global buildings sector demand by up to 10% by 2040. Digitalisation could also increase demand response capacity more than ten-fold, from 40 GW today to 450 GW in 2040. However, the exact scale of these impacts is uncertain, and depends on policy responses, which also need to consider the risk of increased energy demand from the growth of digital devices. More evidence is needed on how digital technologies could combine to deliver system-wide improvements, and how rebound effects might curtail their benefits if the spread of digital devices increases energy use.

- Policies explicitly focused on digital technologies for efficiency are rare but starting to emerge. Technology deployment can be accelerated by policies that recognise the energy system benefits of digital technologies and help overcome barriers to implementation.

- The IEA has created the Readiness for Digital Energy Efficiency policy framework, a set of critical policy considerations for harnessing digital technologies for energy efficiency. The framework is designed to ensure that the benefits of digital energy efficiency are realised through policies that address a range of issues: from balancing data accessibility with data privacy, to helping remove regulatory barriers to innovation.

# Introduction

Digitalisation is the growing application of information and communications technology (ICT) across the economy, including energy systems. The process of digitalisation involves increasing interaction and convergence between the digital and physical worlds. Three elements are fundamental to the process of digitalisation:

- **Data**: digital information.
- **Analytics**: computing vast amounts of data to produce actionable insights.
- **Connectivity**: exchange of data between machines or humans and machines, through digital communications networks.

People have been using digital technologies for decades. What is new today is the scale and pace of digitalisation, and its increasing focus on connectivity. The trend toward greater digitalisation is enabled by advances in all three of these areas: volumes of data are increasing thanks to the declining costs of sensors and data storage, advanced analytics and computing capabilities are making rapid progress, and connectivity is increasing as transmission becomes faster and cheaper.

Digitalisation's impact on energy demand is multi-faceted. Digital devices offer large improvements in energy efficiency for the transport, buildings and industry sectors. If not managed carefully, however, they could contribute to increases in energy use, as devices become more prevalent (including Internet-connected devices that consume energy constantly to remain connected) and more transmission networks and data centres are required to transmit, house and process the data they produce.

One risk of increased digitalisation is that by offering a better quality of service, digital technologies may result in a rebound effect, whereby energy users consume more energy services than they would have without digital technologies. Estimates of the potential for rebound effects stemming from digital technologies vary between sectors, ranging from less than 10% to nearly 30% more energy consumed for some technologies and end uses (Global e-Sustainability Initiative and Accenture, 2015).

This rest of this chapter is structured as follows:

First, information is presented on how digital technologies can combine to improve energy efficiency. Technological change has been rapid since the IEA published *Digitalisation and Energy* (IEA, 2017) so this section provides examples of recent applications of digital technologies on the demand side.

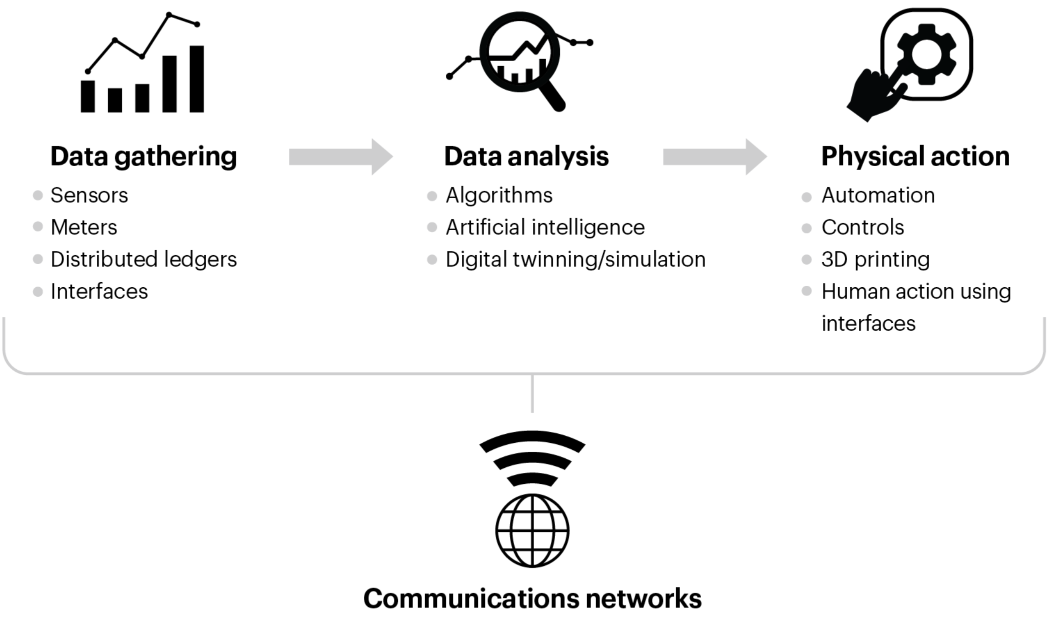
Second, some recent estimates of digitalisation's impacts at a global level are provided for buildings, industry and transport, from the IEA and other sources. Estimated impacts of digitalisation on individual energy-using components in each sector are also presented. This section explains how digitalisation is modernising energy efficiency, extending its benefits from individual end-uses to the energy system as a whole and allowing these benefits to be measured and valued faster and more accurately.

Third, the chapter investigates policy settings necessary to harness digital technologies for energy efficiency, and overcome barriers that exist in all sectors. It then outlines the IEA Readiness for Digital Energy Efficiency policy framework, a set of policy principles for harnessing digital technologies for energy efficiency.

# How can digital technologies combine to improve energy efficiency?

Digitalisation offers the potential to increase energy efficiency through technologies that gather and analyse data, then use it to make changes to the physical environment (either automatically, or through human intervention). All of these processes are underpinned by digital communications networks, both wired and wireless, which allow people and machines to send and receive data and analysis to one another in larger volumes and faster than ever (Figure 4.1).

**Figure 4.1. How digital technologies, when combined, could boost energy efficiency**





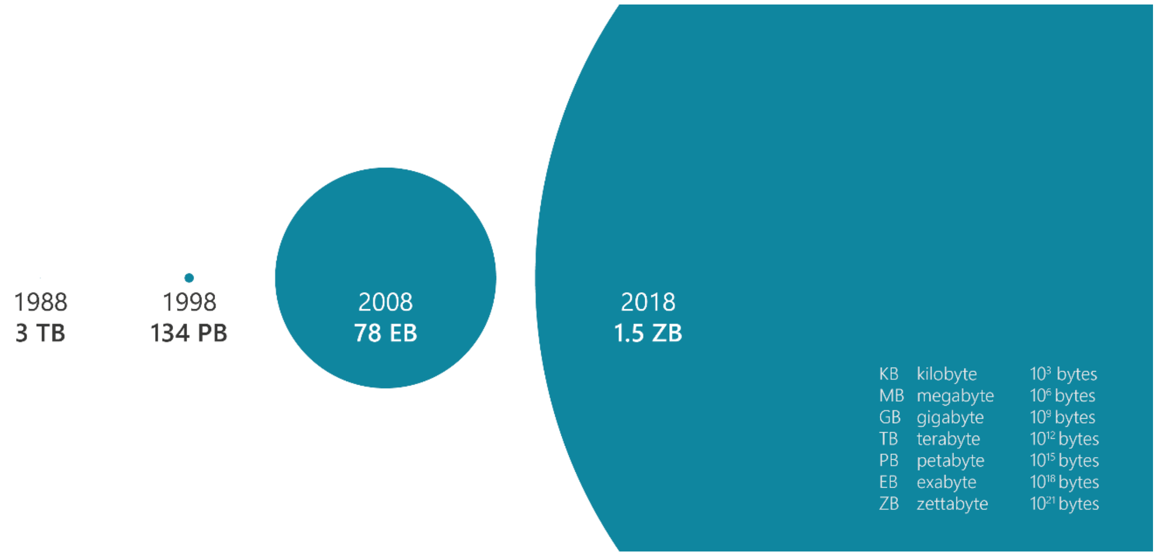

## Data gathering

One of the biggest changes brought about by the digital era is the proliferation of data. For example, global Internet traffic generated 1.5 zettabytes of data in 2018, 19 times more than a decade ago (Figure 4.2).

A wide range of data are created every second, that are directly relevant to energy efficiency. These include not only data on energy consumption but also data *related* to energy consumption, such as weather conditions, consumer purchasing decisions and behaviour. Examples of such data include smart meter data; data on commuter movements; data gathered from mobile telephone networks; and data on changing consumer preferences, gathered through online shopping sites and social media channels.

High-level technology types that can generate and collect data relevant to energy efficiency include sensors, meters, distributed ledgers, interfaces and many more.

**Figure 4.2. Global annual Internet traffic**






Sources: Based on Barnett et al.(2019), *Cisco Visual Networking Index: Forecast and Trends, 2017–2022*; Cisco (2016), *The Zettabyte Era: Trends and Analysis, July 2016*; and Sumits, A. (2015), *The History and Future of Internet Traffic*.

## Sensors

Sensors detect or measure input from the physical environment, such as daylight, temperature, motion or pressure. While sensors are not new, they have proliferated thanks to reductions in cost, improvements in performance, and size reductions. Policy has also boosted sensor deployment in the buildings sector, particularly in the EU and US markets, where building codes have helped drive change over the last 15 years (Walker, 2013).

**Box 4.1. Sensors, connectivity, and automation for energy-efficient freight transport**

One application of sensors, in combination with other technologies, that promises possible future gains in transport energy efficiency is "platooning". Platooning refers to operating two or more vehicles at high speeds with a small enough gap between them to reduce drag losses. In road freight, trucks that are equipped with state-of-the-art driving support systems can form a "platoon", guided by smart vehicle communication and automation technologies. Pilots suggest platooning of freight trucks could improve highway fuel economy by up to 10-25% (Wadud, MacKenzie and Leiby, 2016).

As well as the sensors found on most modern vehicles, additional types of sensors are crucial for platooning. Radar-based collision mitigation systems precisely detect the distance from one truck to another as well as other objects and obstacles on the road. These sensors can track everything around the vehicle simultaneously, 50 times per second (Peloton, 2018). GPS sensors are also used to track the location of individual vehicles within the platoon. They also provide information about the platoon's location relative to hazards or obstacles that might slow the journey or increase fuel consumption, such as traffic congestion.

Source: Wadud et al. (2016), *Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles*; Peloton (2018), *Platooning combines advanced technologies to improve safety and fuel efficiency*, https://peloton-tech.com/how-it-works/.

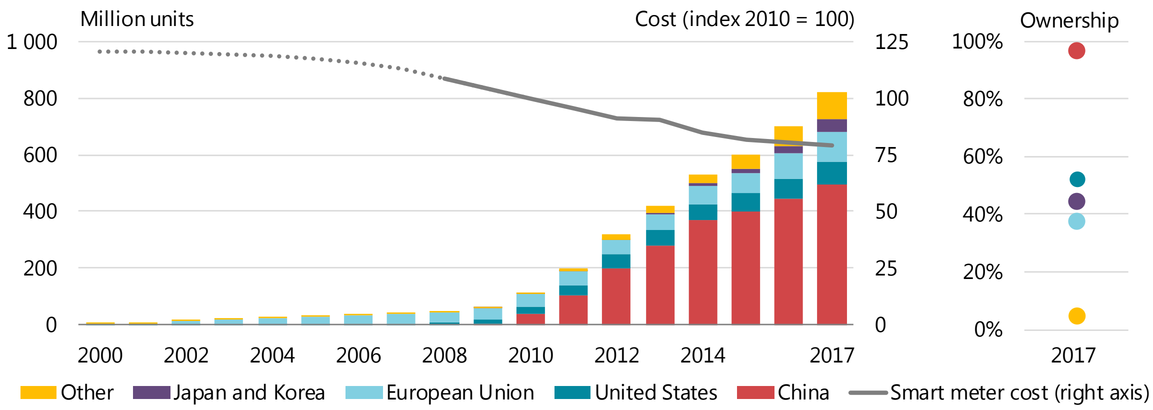
Another recent development is that sensors increasingly accompany people via their smart phones, generating whole new datasets on people's movement and behaviour that was formerly only available through time- and resource-intensive surveys. A typical smart phone contains at least 10 different sensors, measuring properties such as location and movement, orientation and light conditions.

## Meters

Meters that capture and send information on energy consumption to utilities or grid operators automatically have been in place for several decades. However, smart meters – which can capture high resolution information on real-time energy use, faults, reverse flow and other factors – are now becoming ubiquitous, allowing for detailed analyses of energy demand efficiency opportunities. Smart meters also facilitate two-way communication between the home or business meter and an energy retailer or distribution network operator.

Smart meters have spread rapidly since the beginning of the decade, principally in the People's Republic of China ("China"), where 500 million smart meters had been deployed by 2017, equipping the vast majority of Chinese households (Figure 4.3). In other parts of the world, penetration is much lower, although cost decreases and government support programmes are likely to increase deployment levels. While many governments have been focusing on replacing existing metering infrastructure with utility quality smart meters, adapters to allow existing "dumb meters" to communicate real-time data to the cloud are now emerging.

**Figure 4.3. Smart meter deployment, cost and penetration, 2000-17**






Source: IEA (2019), *Perspectives for the Clean Energy Transition: The Critical Role of Buildings*.

## Distributed ledgers

Distributed ledgers are secure, digital records of data. Strictly speaking, digital ledgers a way of storing data securely, rather than a technology for collecting data. However, because of their security features, distributed ledgers can support the data collection process by providing transparency and helping data providers and consumers to have confidence that the data they provide or use is reliable and has not been tampered with.

The best-known distributed ledger technology (DLT) is blockchain. Energy sector applications are emerging quickly, focusing mainly on increasing flexibility, supporting more decentralised energy generation or improving the efficiency of the system overall (Andoni, et al., 2019). Less attention has been given specifically to energy efficiency but ideas are starting to emerge.

Blockchain could reduce transaction costs and encourage more efficient energy consumption where energy efficiency contracts are involved or energy savings need to be validated (Box 4.2).

### Box 4.2. Could blockchain support greater end-use efficiency?

Proposals and pilots for using blockchain to improve energy efficiency have recently begun to appear.

In the **buildings sector**, blockchain could simplify the process of establishing energy performance contracts involving multiple parties (customers, ESCOs, utilities, financial institutions) and reduce administrative costs. As a secure ledger of transactions, blockchain could also support the creation of digital building energy performance certificates, increasing building owners' confidence that their building energy performance rating matches the physical properties of the building. It could also greatly improve the traceability and transparency of white certificate and other tradeable certificate programmes.

Blockchain could also be used to monitor and regulate the energy use of individual smart appliances autonomously by assigning them energy consumption "budgets" using cryptocurrencies, an idea recently patented by Walmart (US Patent & Trademark Office, 2018). Devices that hit their budget target could trade more energy from other devices automatically, inside or outside the local network.

In **transport**, DLTs including blockchain could support the delivery of emerging mobility services in cities, including Mobility as a Service (MaaS), by allowing users to enter into direct relationships with each other with a high degree of trust without having to go through a central authority (ITF, 2018). In freight transport, blockchain could help better match freight capacity with demand, ensuring vehicle loads are maximised. Also, storing customs information in a digital ledger could reduce paperwork associated with border crossings, as well as time spent in transit and the associated risks of spoilage (of temperature-controlled goods, for example).

In **industry**, blockchain could be used to record data on inputs (including energy inputs) at every step along a supply chain. This would allow energy managers, or environmental impact assessors, to identify ways to minimise wastage and maximise efficiency.

Blockchain may also have implications for energy efficiency policy. Case studies from Italy and the United Kingdom show that blockchain could improve white certificate schemes by increasing transparency and speed, while reducing transaction costs (Khatoon, Verma, Southernwood, Massey, & Corcoran, 2019).

Sources: Rogers (2018), *How can blockchain save energy? Here are three possible ways*, https://aceee.org/blog/2018/10/how-can-blockchain-save-energy-here; US Patent & Trademark Office (2018), *Blockchain-based Identity Authentication Method, Device, Node and System*, http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=12&f=G&l=50&co1=AND&d=PG01&s1=blockchain&OS=blockchain&RS=blockchain; Khatoon et al. (2019), *Blockchain in Energy Efficiency: Potential Applications and Benefits*; ITF (2018), *Blockchain and Beyond: Encoding 21st Century Transport*.

DLTs such as blockchain are still at the early stages of deployment in the energy sector. Current platforms are not able to support the speed, volume of transactions, or end-to-end integration at the scale that energy sector applications require and regulations do not yet support commercial operations running on the blockchain. In most suggested DLT applications, alternative technologies – digital or otherwise – may prove to be less costly or easier to implement, or deliver higher value.

## Interfaces

Interfaces connect a person to a machine, system or device, and allow people to create machine-readable data and instructions, for example, via a keyboard, touchscreen, voice recorder or other input device. Examples of interfaces used to capture energy-related data include websites, smartphone apps (Box 4.3) and the dashboard in a building or industrial facility energy management system.

**Box 4.3. Interfaces can streamline data collection to meet efficiency regulations**

Digital technologies are increasingly assisting companies and individuals to submit data to comply with policy requirements, such as mandatory reporting. This brings significant benefits for all parties, reducing reporting burdens for regulated parties while increasing the speed of collecting information and the quality of that information.

In Australia, a smartphone app called Wattly is being used to help create white certificates accepted by energy efficiency obligation schemes in the states of New South Wales and Victoria. The app allows users to collect data verifying energy efficiency upgrades, through a user-friendly interface that guides the citizen installer though all the requirements. Photos taken though the app are geotagged and the app can also collect signatures, barcodes and quantities. Moreover, thanks to the real-time collaboration feature, office-based experts can check the data collected, instantly notifying the user when issues arise (Wattly, 2019).

Unlike automatic data collection devices, interfaces involve human interaction, so their effectiveness as a data collection device is often dependent on how well their design accounts for human behaviour.

# Data analysis

Data analysis technologies combine large volumes of data gathered from sensors, meters and interfaces with other data (from databases or online) and analyse them to produce instructions or advice for energy efficiency improvements.

Data analysis technologies are crucial for energy efficiency actions because they give meaning to data. For example, data from a motion sensor showing that an office is unoccupied only play a role in improving building energy efficiency once paired with a set of instructions telling the building's lighting and heating systems to switch off in response.

## Algorithms and artificial intelligence

An algorithm is a simple or complex set of programmed instructions used to solve problems. In the context of energy management, algorithms analyse data gathered from various sources (including sensors, meters or the Internet), and produce useful recommendations for optimising energy use.

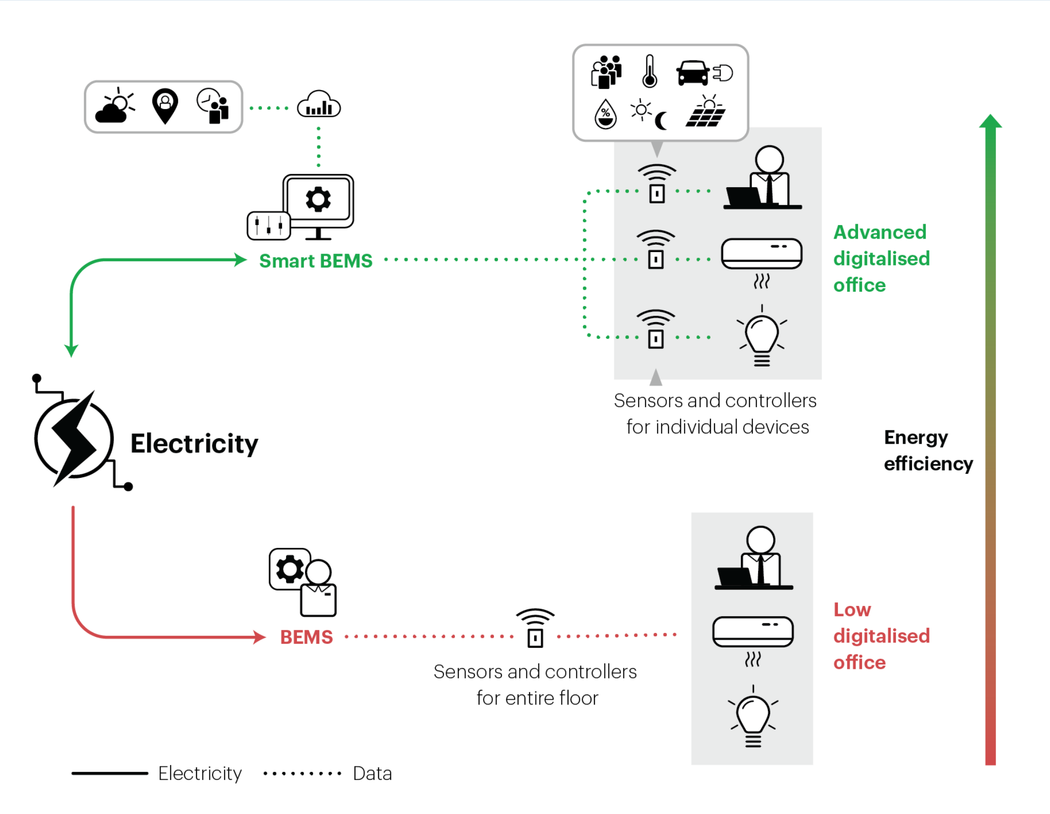
Algorithms are "artificially intelligent" when they include the ability to "learn" – adjusting and optimising their programming depending on data received over time, or self-correcting when their analysis seems infeasible. Artificial intelligence (AI) can draw meaningful insights from huge amounts of data, much faster than humanly possible, opening up new possibilities for identifying energy efficiency opportunities.

### Box 4.4. From traditional to intelligent building energy management

In a traditional building energy management system (BEMS), networked sensors and controls collect data from heating, ventilation and air-conditioning (HVAC), from thermostats, networked lighting systems, room occupancy sensors, and/or other building technologies. These data are then displayed on a standard dashboard for a building energy manager or facility manager, for example, who is able to make decisions that improve the energy or operational efficiency of the facility.

A smart BEMS combines data from a traditional BEMS with other data sources (for example weather conditions, planned staffing levels or traffic patterns affecting staff arrival times, patient operation scheduling, lecture hall times, etc.) These data are then analysed using advanced software, incorporating AI algorithms.

**The role of a smart BEMS in an efficient, highly-digitalised office building**






The AI in these systems generates much larger quantities and ranges of real-time, actionable insights than traditional BEMS can. For example, a smart BEMS can provide intelligence on when a building should operate certain systems to maximise the consumption of renewable energy, while also balancing building occupants' comfort requirements.

An AI-enabled smart BEMS can also forecast how a facility is likely to "behave", based on patterns identified in historical data such as weather, occupancy rates and energy prices. These predictive capabilities open up the possibility of buildings providing their flexible load to the grid, a process the software can also manage automatically. This results in not only more efficient buildings, but also a more efficient grid, as flexible load resources can reduce curtailment of renewable energy sources and shave peaks in demand.

AI can be used at all scales: in an individual piece of equipment, a building (Box 4.4) or the entire energy system. At a micro scale, smart thermostats include AI algorithms that optimise air conditioner energy use while maximising comfort, taking account into factors such as building occupancy and the weather at a particular time of year.

AI can also optimise the efficiency of networks of buildings or devices. Google recently applied its own artificial intelligence algorithm, known as DeepMind, to identify energy savings opportunities in its network of data centres. The algorithm was able to reduce cooling demand by 40%, a large increase in efficiency (DeepMind, 2016).

In cooler climates, district heating systems are now starting to benefit from AI, which is being used to optimise their energy use and increase their flexibility, making them better adapted to renewable energy sources. By combining and analysing data from indoor sensors, weather and district heat, AI can reduce peak power demand by up to 20% (Leanheat, 2019). Moreover, AI-enabled heating systems are able to become more efficient over time by learning and adapting to data shared between buildings and exchanged with production and distribution networks (European Commission, 2019a).

At an energy system scale, AI could improve responsiveness to price signals, better forecast the short- and long-term energy needs of the energy grid, and better co-ordinate decentralised minigrids to reduce losses, among other benefits. One study on the impacts of AI for the environment has estimated that changes in the energy sector such as these could collectively reduce global $CO_2$ emissions by up to 1.3 $GtCO_2$ annually in 2030 (Microsoft and PwC, 2019).

## Simulation software and digital twins

Simulation software models how changes to an object or system would affect energy use. In the buildings sector, building information modelling (BIM) software can estimate the impacts on energy demand of changes to a building's fabric, systems or occupancy. Advancements in BIM software have increased the reliability of computer-aided thermal analysis, reducing the performance gaps between expected and real energy performance in buildings. BIM has also underpinned more efficient building techniques, such as 3D-printed construction (Box 4.6).

Similarly, in industrial facilities and buildings a "digital twin" – an exact digital replica of a physical asset within the production process – can be used to simulate and optimise how changes to its design affect its energy use (Box 4.5).

Simulation software can also be used to make predictions about efficiency interventions at the system level, such as a transport system or even a city. Often, this involves analysing seemingly unrelated datasets to draw useful insights. For example, companies such as Teralytics are using data collected by the telecoms industry with the intention of helping governments solve mobility issues such as adapting public transport to users' needs, planning infrastructure development based on mobility patterns and optimising shared mobility services. Such data could also be used to monitor air quality without the need to deploy sensors across cities (Teralytics, 2019).

# Physical action

For digital technologies to improve energy efficiency, they need to trigger changes in the physical environment that reduce energy consumed. This requires a connection between the digital and physical worlds.

Digital data and analysis can be converted into a physical energy-efficient action automatically, through machine-to-machine communications, or manually, via human actions in response to data and analysis.

## Actuators

Actuators are devices that convert data into real-world energy efficiency actions. For example, a smart lamp contains a sensor that detects changes in lighting conditions. When the light levels reach a certain point, an actuator inside the lamp increases or decreases the flow of electricity to ensure that the lamp provides light at an optimal level for the conditions.

In industrial facilities, actuators are used in a wide array of applications, from opening valves in pipes to control the flow of gases and liquids, to moving heavy objects along a production line. "Smart actuators" are generally powered by electricity (as opposed to hydraulics or other power sources) and can communicate data captured through on-board electronics. As a result, smart actuators are extremely accurate and can communicate problems with their own operation as well as the operation of other components in a system. With fewer moving parts, they require much less maintenance than mechanical actuators.

## 3D printers

3D printing, or additive manufacturing, is a computer-controlled technology that processes digital instructions to build objects by depositing consecutive layers of material. 3D printers are a good example of a technology that bridges the gap between data-driven analysis and the physical world to achieve real gains in energy efficiency. Every 3D-printed object begins as a software-generated digital model. The 3D printer itself (a group of mechanical actuators) use these models as instructions for "printing" an object in 3D.

**Box 4.5. 3D printing in the construction sector – from virtual to real energy efficiency**

Building construction is one area where 3D printers are beginning to show great promise for efficiency gains. Construction waste and the quantity of raw material required for construction can be reduced by up to 30% through the use of 3D printing (Perkins and Skitmore, 2015). Reducing construction waste could improve the energy and carbon footprint of the construction industry, as building materials such as bricks and cement are energy and carbon-intensive; the cement industry is the second-largest industrial sector emitter of $CO_2$, producing 7% of total energy-related $CO_2$ emissions (IEA, 2018a).

3D-printed buildings may also save energy during a building's use. Accurately reproducing digital models as printed buildings – relying less and less on human intervention – reduces building defects such as cracks, leaks and other common problems in the integrity and envelope of buildings, which compromise air-tightness and energy performance.

3D printing also opens up the possibility of improving efficiency through design, producing highly efficient building geometries that are often avoided using traditional construction methods due to their complexity and cost. For example, designs that avoid unnecessary joins are more air-tight, improving energy efficiency by reducing heat losses while others take advantage of natural resources to enable passive heating, cooling, lighting and natural ventilation.

**3D-printed Chicon House by ICON, in the United States**

Notes: Courtesy of ICON. Photography by @CaseyDunn and @ICON3DTech
Source: ICON Build website, www.iconbuild.com

3D printers have several advantages over conventional manufacturing, including reductions in lead time, reduction of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space and the ability to deliver manufactured pieces with complex shapes and geometries that can optimise material efficiency and weight (Huang, 2016) (Box 4.6).

One of the key advantages of 3D printers from an energy efficiency perspective is that they can receive instructions remotely, allowing industrial process engineers and building construction managers to change printers' actions and outputs without having to spend time, energy and resources travelling to industrial plants or building sites to retool production lines.

## Interfaces

In addition to their function as data gathering technologies, interfaces are a key technology for converting data-driven analysis into real-world energy efficiency improvements. Unlike technologies operating via machine-to-machine communications, however, interfaces carry out physical changes in conjunction with human action. Examples of interfaces for converting data into real-world efficiency improvements include smartphone apps providing tailored advice on the most efficient route for a commuter; in-home displays connected to smart meters, and virtual assistants providing tailored information on energy-saving actions (Box 4.6). In each case, to realise the energy efficiency improvement, the user needs to act on the advice provided.

### Box 4.6. Virtual assistants and smart speakers – an interface for more efficient household energy use

Virtual assistants, including Amazon's Alexa, Google Assistant and Apple's Siri, are now present in many homes, owing to their integration into smartphones and other smart devices such as smart speakers. Smart speakers – voice-controlled speakers with integrated virtual assistants are growing rapidly in popularity: expected sales of around 94 million in 2019 are forecast to increase the installed base to more than 200 million in 2019, growing to 500 million in 2023 (Canalys, 2019).

Increasingly, virtual assistants are being recognised for their potential to boost household energy management. Several utilities in the United States, Canada and the United Kingdom are now delivering information to customers on their energy use, account balances, electricity outages, as well as allowing customers to make payments via virtual assistants.

Virtual assistants could also be an effective interface for increasing energy efficiency, and some utilities are now using them to provide consumers with energy efficiency tips. However, much of the advice provided to consumers tends to be generic, and the more sophisticated uses of virtual assistants to improve energy efficiency are still largely untapped (Snell, 2018).

For example, virtual assistants could provide consumers with tailored information about available energy efficiency rebates; help them to take advantage of time-of-use tariffs; permit utilities access to a households' smart devices as part of a demand-response programme; or even walk them through a virtual energy audit (Snell, 2018).

In 2019, Octopus Energy in the UK began offering time-of-use tariffs linked to Amazon's Alexa virtual assistant. Customers can ask their virtual assistant questions such as, "When will electricity be cheapest today?" and plan their energy use accordingly, leading to gains in energy system efficiency (Octopus Energy, 2019).

Sources: Canalys (2019), *Global smart speaker installed base to top 200 million by end of 2019*, www.canalys.com/newsroom/canalys-global-smart-speaker-installed-base-to-top-200-million-by-end-of-2019 (press release); Snell (2018), *Voice Control Changes Everything: Why Utilities Should Care About Virtual Assistants*, www.esource.com/10059-001/3/voice-control-changes-everything-why-utilities-should-care-about-virtual-assistants; Octopus Energy (2019), *Octopus Energy and Amazon Alexa*, http://www.octopusreferral.link/octopus-energy-amazon-alexa/.

# Impacts of digitalisation

While digitalisation offers various ways to improve energy efficiency, the net impacts of digitalisation on energy demand and efficiency are still uncertain. The growing prevalence of digital devices is pushing up energy demand, but the most energy-hungry digital devices are largely unrelated with energy management, such as streaming video or cryptocurrency mining. Meanwhile, the technical energy efficiency of digital devices, data networks and servers has been improving (Chapter 2), suggesting that some of the more pessimistic predictions of digital device energy use may not be realised.

Some studies suggest the benefits of digitalisation for energy demand and emissions could be nearly 10 times greater than any negative impacts (Global e-Sustainability Initiative and Accenture, 2015) but more evidence is needed on how digital technologies could combine to deliver system-wide improvements, and how rebound effects might curtail their benefits if the spread of digital devices increases energy use.

The following section collates recent estimates of the benefits digitalisation could have for energy demand and energy-related emissions.

# Estimated global impacts

In buildings, digitalisation could cut total energy use between now and 2040 by as much as 10%, assuming limited rebound effects in consumer energy demand. Cumulative energy savings over the period to 2040 would amount to 234 EJ – equivalent to over half the amount of final demand consumed by the world in a year (IEA, 2017a).

In transport, estimates of digitalisation's impacts vary significantly, depending on the mode of transport. For instance, over the long term, under a best-case scenario of improved efficiency through automation and ride-sharing, energy use could halve compared with current levels. Conversely, if efficiency improvements do not materialise and rebound effects from automation result in substantially more travel, energy use could more than double (IEA, 2017a).

More recent modelling of innovative technologies in urban transport – including many enabled by digitalisation, such as teleworking, massive shared mobility, and autonomous vehicles – suggests that with appropriate policies in place, transport $CO_2$ emissions could be reduced by over 50% in 2050, compared with business as usual (ITF, 2019). The application of artificial intelligence alone could reduce transport-related GHG emissions by around 1 Gt $CO_2$ in 2030 (Microsoft and PwC, 2019).

In industry, estimates of impacts on energy demand depend heavily on the industry in question. One study estimates that smart manufacturing could deliver 15 EJ in energy savings between 2014 and 2030, more than the total primary energy demand of Germany, as well as reducing water consumption by 81 billion litres (Global e-Sustainability Initiative and Accenture, 2015).

Impacts will vary from region to region, depending on market readiness. In the European Union, a recent study suggests that in 2050, digitalisation could unlock an extra 1-2 EJ of energy savings, reducing European final energy demand by an extra 5% on top of the gains achievable by pursuing a strong strategy of "energy efficiency first", and removing market barriers to all available technical energy efficiency improvements. However, the modelling showed significant variation between scenarios. In a worst case scenario, digitalisation, in combination with other societal trends, could result in large increases in European final demand, compared with the baseline scenario (Fraunhofer, 2019).

# Unlocking flexible demand

By 2040, under existing and planned policies, global demand response capacity is expected to increase to around 200 GW GW from 40 GW today. Unlike today, where the majority of demand response resources are in industry, by 2040 85% of capacity could exist in buildings and transport, with the majority linked to flexible cooling demand (IEA, 2018b).

Digitalisation promises to further increase the size of available demand response capacity. With digital strategies and smart infrastructure, demand response capacity could increase to 450 GW globally, more than 10 times the resource available today (IEA, 2018b). Under some scenarios, 1 billion smart households and 11 billion smart appliances could be deployed by 2050, meaning residential buildings could make up a much larger share of global demand response capacity than today and help to shift demand from peaks to off-peak periods (IEA, 2019).

Tables 4.1-4.4 present selected estimates of the benefits of digital technologies globally and at the sectoral level.

**Table 4.1. Possible global benefits of digital technology**

| Sector | Description | Possible benefits |
|---|---|---|
| **Buildings** | Between 2017 and 2040, increased digitalisation of both commercial and residential buildings, including 1 billion connected buildings and 11 billion connected devices. | Up to 10% less energy used. Cumulative energy savings of 234 EJ. |
| **Transport** | In urban transport, between 2015 and 2050 digitally enabled innovative technologies, including teleworking, massive shared mobility and autonomous vehicles, significantly reduce passenger kilometres travelled. | More than 50% lower $CO_2$ emissions in 2050. |
| **Industry** | Estimated cumulative impact from combining a range of digital technologies and advanced software applications. | Up to 30% energy savings. |
| **Flexible demand capacity** | With increased policy action prioritising digital strategies and smart infrastructure, flexible demand capacity increases from 40 GW to 450 GW. | Ten times more flexible demand capacity by 2040. |

Sources: IEA (2019), *Perspectives for the Clean Energy Transition: The Critical Role of Buildings*, www.iea.org/publications/reports/PerspectivesfortheCleanEnergyTransition; IEA (2018b), *World Energy Outlook 2018;* IEA (2017b), *Digitalisation and Energy*; Schneider Electric (personal communication); ITF (2019), *ITF Transport Outlook 2019*.

# Sectoral benefits

In residential buildings, digitalisation could save energy across a range of end-uses. While savings are achievable in each end-use, by combining a range of connected devices through a home energy management system optimised for efficiency and with automation, savings could be as high as 30% (Table 4.2).

**Table 4.2. Residential buildings: Possible benefits of digital technology**

| Technology | Description | Possible benefits |
|---|---|---|
| **Smart thermostat** | Heating and cooling controlled remotely (or automatically) and temperature adjusted according to preferences or sensor inputs. | 5-20% less energy use for heating or cooling. |
| **Smart zoning** | Individual rooms or zones heated or cooled to specific temperatures at specific times. | 10% less energy use for heating or cooling. |
| **Smart window control** | Controls amount of light let through and can block heat or cold. | 10-20% less energy use for heating or cooling. |
| **Smart lighting (including occupancy control)** | Remote control of lighting, automation, adjustment to occupancy. | 1-10% less home energy use; 30-40% less lighting energy use. |
| **Smart plugs** | Turns unconnected products into connected devices. | 1-5% less home energy use. |
| **Home energy management system** | Enhances control and automation of energy-using appliances and equipment. | 8-20% less home energy use. |

| Technology | Description | Possible benefits |
|---|---|---|
| **Extensive system of management and automation optimised for energy efficiency** | Combination of technologies providing measurement, monitoring, dynamic benchmarking, information displays, management, control, automation, zoning, occupancy systems, maintenance management, etc. | 30% less home energy use. |
| **Smart district heating** | Artificial intelligence combined with sensors to optimise district heating use in apartment blocks. | ~10% less apartment block energy use.<br>~20% more apartment block peak energy savings |

Sources: Adapted from 4E TCP EDNA (2018), Intelligent Efficiency: A Case Study of Barriers and Solutions; Leanheat (2019), More Efficient Energy Systems with Artificial Intelligence Controlled Buildings.

Note: Since multiple technologies can address the same energy end-use, the achievable combined savings potential is less than the sum of the potential of different technologies, however additional savings and benefits can be achieved by intelligently co-ordinating technologies.

Digital technologies could also help deliver energy savings across a range of commercial building end-uses. In heating and cooling, these include improvements to chiller plants, cooling towers and boiler plants. In lighting, they include automatically controlled shading, daylighting and occupancy-based control (Institute for Buidling Efficiency, 2014). While savings for each of these end-uses individually are often less than 10%, many of them have short pay-back periods (less than 3 years) and the net gains may be larger when considered as a package, a feature of smart building energy management systems.

In industry, while the magnitude of benefits will vary considerably between industrial processes, digitalisation could offer energy savings of up to 30%. Other benefits of digitalisation include resource efficiency gains, increased health and safety, and reduced operating costs (Global e-Sustainability Initiative and Accenture, 2015).

**Table 4.3. Industry: Possible benefits of digital technology**

| Technology | Description | Possible benefits |
|---|---|---|
| **Artificial intelligence algorithms** | AI to predict the future performance of industrial equipment and alert plant operators to potential faults before they disrupt production. | Energy savings of up to 10% in energy-intensive industrial applications. |
| **Advanced/intelligent energy management** | A combination of concepts from traditional industrial energy management systems (e.g. ISO 50001) with digital technologies and advanced software applications. | Possible energy savings of over 10-30% depending on industrial process and technology. |

Source: Schneider Electric (personal communication); General Electric (personal communication); IBM (2019), *Cognitive Manufacturing: An Overview of Four Applications that are Transforming Manufacturing Today*; IEA (2018) *Energy Efficiency 2017*.

Digital technologies could improve the efficiency of both passenger and freight transport, offering significant energy savings of around 20-25%. In both passenger and freight transport, some of the larger gains could be obtained via increased automation.

**Table 4.4. Transport: Possible benefits of digital technology**

| Technology | Description | Possible benefits |
|---|---|---|
| **Road: connected and automated vehicles** | Connected and automated vehicles (CAV) could reduce energy intensity of road transport at the vehicle, fleet, and urban systems levels. However, CAVs may result in rebound effects as a result of lower travel costs and new users. | Vehicle-level energy savings include platooning (up to 25%), eco-driving (up to 20%), and vehicle right-sizing (20-45%). |
| **Road: shared mobility services** | Shared vehicles (e.g. bicycles, scooters, cars) and shared mobility services (e.g. ride-sourcing) could help reduce energy use by shifting mobility from private cars to less energy-intensive modes. | Carsharing could reduce individual transport energy use by half.<br><br>Distances driven, energy use and $CO_2$ emissions in 2050 are around one-third lower if vehicles are shared, electric and automated. |
| **Road freight** | Digital solutions for road freight include: GPS coupled with real-time traffic information for route optimisation; on-board monitoring and feedback for eco-driving; CAV platooning for fuel-efficient driving; and data sharing between companies across the supply chain to ship more goods with fewer trips. | Applying digital solutions to truck operations and logistics could reduce road freight energy use by 20-25%. |
| **Rail** | Automated train operations (ATO), communications-based train controls, real-time driver advisory services (DAS) and energy-efficient timetabling can reduce energy consumption by optimising driving patterns, increasing utilisation and promoting energy-efficient driving. | ATO can cut energy consumption by up to 20%, while potential energy savings from DAS range from 5% to 20%. Energy-efficient train timetabling can unlock energy savings of up to 35%. |

Source: Taiebat et al. (2018), A review on energy, environmental, and sustainability implications of connected and automated vehicles; Wadud et al. (2016), Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles; Chen & Kockelman (2016), *Carsharing's life-cycle impacts on energy use and greenhouse gas emissions*; Fulton, Mason, & Meroux (2017), *Three revolutions in urban transportation: How to achieve the full potential of vehicle electrification, automation, and shared mobility in urban transportation systems around the world by 2050*; IEA (2017b) *The Future of Trucks;* Scheepmaker, Goverde, & Kroon (2017) *Review of energy-efficient train control and timetabling;* Douglas et al. (2015), *An assessment of available measures to reduce traction energy use in railway networks*; González-Gil et al. (2014), *A systems approach to reduce urban rail energy consumption*; Trentesaux et al. (2018), *The Autonomous Train*; Dunbar et al. (2017), *A tool for the rapid selection of a railway signalling strategy to implement train control optimisation for energy saving*; Urien (2013), *Energy Optimization for Public Transportation Applications*.

# How digitalisation is changing energy efficiency

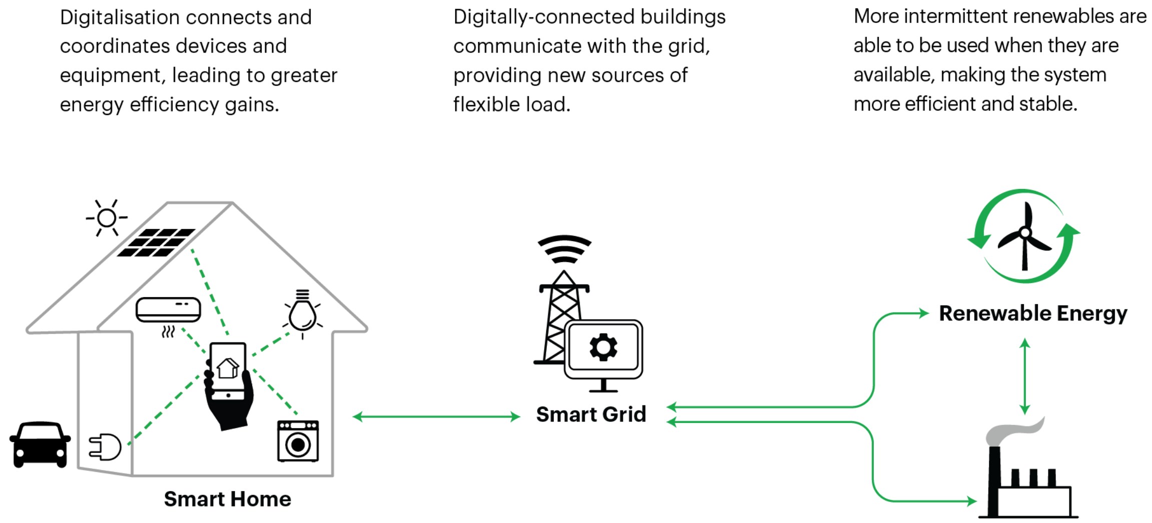
Digital technologies can increase energy efficiency as traditionally defined, by reducing energy used per unit of activity, known as end-use efficiency. They can also improve the energy efficiency of the entire energy system. In both cases, efficiency improvements are delivered by increasing connectivity.

Connectivity is vital for two reasons. First, it helps connect individual components that could achieve more end-use efficiency together than on their own. Digital technologies that connect components to form a network (such as a network within a building) may help to identify new ways that components can work together to increase end-use efficiency by operating differently and overcome technical efficiency ceilings that components could soon reach (Alliance to Save Energy, 2016).

Second, connectivity also underpins new sources of demand response, which are increasingly valuable. The value of demand response is growing because the world's energy systems are undergoing an immense transformation. Variable renewables continue to be added to the grid, the electrification of energy consumption is increasing, while "prosumers" (energy users that both consume and produce energy) are emerging. In this context, demand-side flexibility is increasingly important to ensure the energy system runs as efficiently as possible, with energy supplied when it is needed, and consumed when it is available.

A large number of connected energy-using devices, vehicles, buildings, and industrial facilities can provide significant and valuable demand response resources to the energy market. Demand response can provide two broad categories of value to the power system: energy value, derived from time-of-use arbitrage in energy markets, and capacity value, derived from avoided capacity investments.

**Figure 4.4. Example of how digitalisation leads to a more efficient energy system**






With increased variability and decentralisation, further sources of value are being identified. For example, by resolving short-term imbalances in supply and demand, demand response can provide so-called flexibility value. Additionally, demand response can offer network value, which is increasingly used at both transmission and distribution levels to avoid the costs of network reinforcement or expansion. In the future, digitalisation could enable a host of additional services, allowing the participation of demand response in distribution ancillary services.

The demand response resources that digital technologies make available, alongside improvements in end-use efficiency, can increase the efficiency of the entire energy system by reducing losses associated with producing and distributing energy, avoiding curtailment of renewables, and avoiding investments in energy infrastructure (Figure 4.4).

By offering both end-use and system efficiency benefits, digitalisation is also reshaping views of energy efficiency and demand response: It is no longer possible to view the two processes as being separate, or in conflict. By joining up end-use energy efficiency with distributed flexible load, generation and storage, digitalisation is helping to redefine the term "energy efficiency" to encompass both end-use and system efficiency.

## Digitalisation helps to value energy efficiency more accurately and faster than ever

End-use efficiency has always had benefits for the energy system. However, these benefits have not always been recognised, or not recognised in a timely way that would allow decision makers to consider the impacts of efficiency when planning generation and network infrastructure investments.

Part of the problem has been measurement: It was often hard to predict or measure exactly what impact an intervention to increase end-use efficiency would have on the system until too late, after planning decisions on new capacity and infrastructure had already been made. This meant that system operators often misjudged the impacts of energy efficiency, risking overestimating or underestimating how much grid infrastructure was required to service demand.

In addition, although efficient homes and commercial buildings could provide a permanent reduction in demand, they were unable to offer demand response services because most equipment and devices were unable to communicate. Therefore, system operators mainly sought demand response from large industrial facilities, which agreed to provide such services via contracts, signed well in advance of any events requiring demand response.

More recently, as decarbonisation has become a priority for electricity system planners, valuing energy efficiency improvements at times of the day when the electricity mix is more carbon intensive has become a necessity, to try and better align people's energy use with the availability of low-carbon electricty.

Digitalisation addresses these issues, offering a much more predictable and measurable type of energy efficiency that is easier for system operators to reward. Today's digitally connected energy efficient buildings, vehicles and equipment allow system operators to accurately predict and measure how an efficiency improvement can both lower demand and shift peaks in demand. Equipped with software tools to quantify and predict the impacts of energy efficient technologies and behaviours, and "pay for performance" schemes to provide transparent measurements, system operators are able to more accurately value energy efficiency that helps decarbonise the grid (Golden et al., 2019).

This information can then be used to reward energy users for the benefits their actions have for the energy system—such as consuming energy during times when renewables are plentiful—in addition to the benefits they obtain themselves from increased energy efficiency. The whole process takes place over a much shorter timeframe (in the case of demand response, almost instantaneously) and results in much more accurate forecasts of future demand, allowing system operators to build only the infrastructure that is needed, and avoid overspending.

## Digitalisation is all but inevitable and can be leveraged for greater energy efficiency

The process of digitalisation will continue as there are multiple reasons for homes and businesses to adopt digital technologies.

Surveys of businesses consistently reveal that commercial opportunities flowing from more efficient production processes are a key driver for digitalising their operations (Geissbauer et al., 2016). While digitalisation may improve energy efficiency, unless energy is a high-cost input to production, in most cases businesses are more likely to invest in digital technologies for many other reasons. Aside from energy efficiency, increased digitalisation tends to improve productivity, safety, and maintenance, among other benefits, all of which can help reduce the cost of producing a product or service.

Household sector smart home device owners list convenience as a key driver for having purchased such devices, with only 6% of respondents in one survey listing energy savings or efficiency as a motivator for purchases (PwC, 2017). Interestingly, in the same survey 86% of respondents yet to purchase smart home devices listed energy efficiency or energy bill savings as a motivator, suggesting that consumers might aspire to use digital technologies for more efficient energy use, even if they fail to do so in practice.

However, the increased uptake of digital technnelogies in all markets seems all but inevitable, regardless of the motivations for adopting them. For the energy efficiency community, the opportunity to tap into these networks of smart devices to create a more efficient energy system is now waiting to be taken, but policy will be crucial.

## How policy can harness digital technologies for energy efficiency

Efficiency policies have been helping to drive digital technology uptake in recent years, although not always by design. For example, despite not directly promoting sensors for smart buildings, the 2003 European directive on the energy performance in buildings[1] helped spur the uptake of these sensors in the region. Similarly, the requirement for the states of the United States to adopt the 2010 version of ASHRAE 90.1 boosted lighting control adoption in North America (Walker, 2013). In industry, policies incentivising businesses to become ISO 50 001 compliant have helped to increase the use of digital technologies for energy management.

Policies explicitly targeting an increase in digital technologies for efficiency, such as Europe's new Energy Performance of Buildings Directive (EPBD), are just starting to emerge. Annex I of the EPDB establishes a smart readiness indicator, which aims at assessing the capabilities of a building to adapt its operations to the needs of both the occupant and the grid in order to improve energy efficiency through the deployment of smart technologies.

[1] Directive 2002/91/EC

## Addressing barriers will be crucial

While digital technologies offer benefits for both end-use and system efficiency, there are barriers in all sectors to their deployment and different markets are at different stages of readiness to adopt them.

In industry, despite strong commercial incentives to deploy digital technologies, barriers to faster uptake exist. For example, business customers for Internet of Things (IoT) solutions continue to report the existence of barriers to adoption of IoT/analytics solutions, including security concerns, the poor integration of IT and operational technologies, and a lack of clarity about the possible returns on investment (Bain & Company, 2018).

Surveys of business intentions to invest in commercial building energy efficiency reveal similar concerns, with cybersecurity topping the list of issues businesses perceive will have the biggest impact on the implementation of smart buildings over the next five years (Johnson Controls, 2018).

In the household sector, barriers to digital technology uptake also include privacy concerns, although studies suggest that in certain markets, energy users appear willing to trade privacy for financial reward, in the form of lower energy bills (Kowalski, 2016 in Kowalski & Matusiak, 2018). Still, others barriers persist to a greater uptake of home energy management systems, including ease of use, and a mismatch between users' expectations of financial savings from such systems and actual savings possible (Kowalski & Matusiak, 2019).

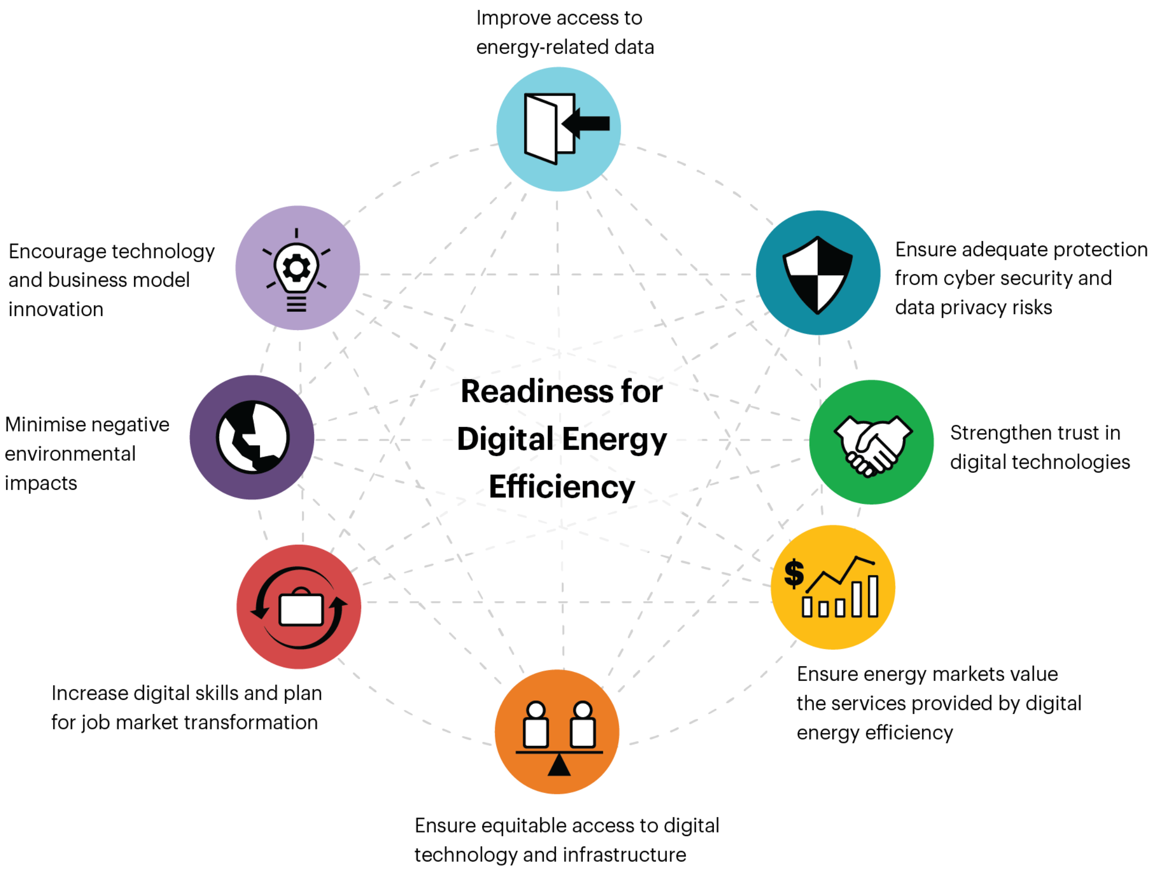
In transport, the challenges are different. Private enterprise has been strongly involved in pushing so-called "smart mobility" solutions into cities, often on the grounds of efficiency improvements. However, the technology sector ultimately has an incentive to maximise the sale of its products, so there are significant risks in it leading a full-scale change transport and infrastructure planning. These include induced demand resulting in a net increase in transport activity, issues with allocating public space and taxes to support private profit (e.g. for charging infrastructure and vehicle storage), data asymmetries, and equity issues (Docherty, Marsden, & Anable, 2018).

## A proposed framework of policy principles

Governments have a vital role to play in ensuring that digitalisation improves efficiency without causing environmental, social or economic harm.

Drawing on previous work examining digital transformation policy, such as the OECD's *Going Digital Integrated Policy Framework* (OECD, 2019a), the IEA has identified a set of policy issues that governments need to consider when they are seeking to increase the use of digital technologies for energy efficiency. Together these principles form the Readiness for Digital Energy Efficiency (RDEE) framework (Figure 4.5).

**Figure 4.5. Policy principles comprising the Readiness for Digital Energy Efficiency framework**






The IEA developed the RDEE framework by identifying barriers faced by all related parties, including consumers, product manufacturers, service providers and utilities. As the digital transformation of the energy sector continues to evolve, so will the RDEE framework, with input from the energy efficiency and digitalisation policy communities.

## Improve access to energy-related data

The effective use of digital technologies to improve energy efficiency requires timely and standardised access to data. This includes data related to energy consumption directly, such as high-resolution electricity demand data, and indirectly, such as data on climate, appliance and equipment sales, or demographics.

Making data accessible to both energy users and third parties is essential to develop and deploy energy efficiency technologies and services. In the light of data privacy concerns from consumers and others, however, policy makers need to pay considerable attention to data ownership, privacy and protection.

Governments also have a role to play in opening up large-scale sources of energy data that can be used in innovative ways – ways that were often unforeseen when the data were collected. For instance, Mexico has made available the aggregated results of its household survey, linked with the already existing Base of Energy Efficiency Indicators (BIEE) database. This publicly available database provides insights on appliance energy use throughout the country (BIEE, 2019).

Governments can also provide access to other data sources, including administrative data such as census, tax or population data. When used in conjunction with energy data, these sources are crucial for understanding energy efficiency (IEA, 2014).

## Ensure that data and cybersecurity protection is robust

One of the biggest barriers to the adoption of digital technologies – by individuals, companies and governments – is concern about data privacy, ownership and cybersecurity.

Ownership, sharing and use of consumers' data have become of increasing concern (IEA, 2017a). For example, while 43% of U.S. broadband households plan to buy smart home devices before the end of 2019, 35% of consumers were apprehensive about data privacy and security (Parks Associates, 2019). Fears that personal information could be accessed and misused, for instance for analytical service and marketing purposes, have made consumers suspicious of government smart-meter rollouts (Collison, 2017).

In the public and private sector, cybersecurity breaches are a major concern, as they can compromise the continuity of operations and/or result in the theft of proprietary information. Governments have been aware for some time of the need to support the development of secure platforms for managing and sharing data. Recent security breaches to critical infrastructure networks, however, have prompted governments to step up action to improve their cybersecurity capabilities. In North America and Europe, as well as in China and India, governments have put in place legal frameworks for cybersecurity. Similarly, ASEAN leaders have established an initiative to foster regional cybersecurity co-operation and capacity building (ASEAN, 2016).

## Strengthen energy users' trust in digital technologies

The quality of users' experience digital energy efficiency technologies can determine whether or not such technologies are adopted. These experiences range from becoming aware of a technology and its expected benefits, to developing trust and confidence in digital technology's long-term performance and reliability.

A user's experience of digital technologies can be affected by:

- complexity of installation and use
- performance and reliability, as well as product obsolescence in a rapidly changing market
- vendor "lock-in", when the use of proprietary software and hardware forces consumers to remain with one technology provider.

Unlocking the system efficiency gains offered by increased automation and AI requires earning a high level of trust from energy users that granting machines access to appliances and equipment in residential and commercial buildings will not have adverse impacts (Box 4.7).

Government policy may help to foster users' trust. OECD countries recently agreed to a set of principles for AI, which include that AI systems should include appropriate safeguards to ensure a fair and just society and to maximise transparency so that users can understand and challenge AI-based outcomes (OECD, 2019b). G20 countries recently adopted a similar set of "human-centred" AI principles (Ministry of Foreign Affairs of Japan, 2019).

**Box 4.7. The "social licence" to leverage automation**

The ability to automate access to distributed energy resources (DER) – such as flexible load, storage and small-scale generation in residential and commercial buildings – is one of the key benefits of digital technologies, which could have widespread benefits for the energy system.

Some energy users, however, could perceive it as intrusive and risky to grant energy utilities control of digitally connected appliances and equipment, so a high level of trust is required. The term social licence is used to describe a situation where individuals or communities affected by a project accept and even support it, which grid operators are likely to require in order to automate access to DER.

The IEA User-Centred Energy Systems Technology Collaboration Programme (Users TCP) has established a project to examine what is needed for residential energy consumers to grant a social license to automate the use of DER. National experts will collaborate to analyse emerging research in social sciences, technology and policy and identify key social, organisational, economic and regulatory ingredients for creating a user-centric approach to automating DER.*

* For more information, please contact tony.fullelove@monash.edu.

## Ensure that energy markets value the services provided by digital energy efficiency

Many connected, energy-using devices, vehicles, buildings and industrial facilities can provide significant and valuable sources of demand response to the energy market. However, tapping into these sources requires structures and rules that recognise the value these services bring to the broader energy market, including by:

- establishing dynamic pricing schemes that enable demand response resources – both implicit and explicit –by accommodating different consumer preferences and exploiting the full spectrum of system benefits from demand-side flexibility;
- going beyond recognising the value of flexible load resources in emergency situations and further opening capacity, wholesale energy and distribution network service markets to flexible resources, in order to improve system security;
- creating avenues for energy service companies or aggregators to "pool" demand response resources, particularly within the residential sector, so that they can be provided to the broader energy market; ensuring that energy market rules do not pose a barrier to entry by smaller bids of flexible load can assist here.

One good example of an energy market providing clear signals to encourage flexible load is in Singapore. Under the Energy Market Authority's demand response programme, consumers who voluntarily reduce their electricity demand are rewarded with a share in the system-wide benefits, via cash payments equivalent to one-third of the wholesale value of the reduced load (EMA, 2016).

## Give all parts of society access to digital efficient technologies and infrastructure

As digitalisation becomes central to many aspects of society and daily life, a lack of access to ICT could worsen existing social inequalities. The "digital divide" is the gap that exists between individuals, households, businesses and geographic areas at different socio-economic levels with regard to both the access and use of ICT (OECD, 2001).

For example, low-income households are likely to derive the greatest marginal benefits from access to smart devices such as building sensors and smart meters but may be more discouraged by the upfront costs, in contrast to higher-income households.

Benefiting from the energy efficiency improvements delivered by digital technologies may also require access to infrastructure, such as broadband Internet or smart meters. Where access to this infrastructure is poor, the digital divide may be larger.

Some people may also find using digital technologies daunting, especially if they have spent much of their lives without using them. Unless they receive tailored information and training, these people may continue to prefer minimising their use of digital technologies, including those that would increase energy efficiency.

The Living Smart Home programme in West Essex, in the United Kingdom, helps elderly and disabled people to "road test" smart home technologies in a safe environment. The programme has set up homes equipped with smart appliances where people can spend time and improve their digital literacy. They receive assistance with devices such as remote-controlled appliances, smart meters and thermostats. The programme received a grant of GBP 400 000 (British pounds - about USD 490 000 [United States dollars]) from the Digital Inclusion Innovation Fund (Digital Boomers, 2019).

## Ensure the workforce is ready to use digital technologies

The digital transformation will have both benefits and disadvantages for the existing workforce, requiring policy responses in industry, education, training and re-skilling. Governments need to foster a range of skills in the workforce, to ensure workers are equipped to succeed in the digital workplace (OECD, 2019).

For energy efficiency policy makers, it will be critical to monitor the existing energy efficiency job market to identify skills shortages that may affect the rollout of digital energy efficiency technologies. Moreover, technical skills *within* policy making bodies will need to increase, as the adoption of digital tools at all points of the policy cycle will become increasingly common with the digital transformation of government.

Aside from specific segments in the residential sector, installation and use of digital energy efficiency technologies can often be managed by users themselves, supported through existing computer and electronics retailers. For more complicated residential installations, however, and in the commercial and industrial sectors, a workforce equipped with the specialised expertise to design and install technologies will be required.

Policy makers can assist to develop and/or help the private sector develop education and training courses as well as certification programmes. For example, a particularly useful tool is provided through the online-platform hosted by the US Department of Energy, which lists all the training programmes available relating to clean energy, including everything from training for energy management professionals to training for building retrofit planning and certification (EERE, 2019).

## Minimise negative environmental impacts

A key concern about digitalisation is its net environmental impact, particularly in relation to energy use. Energy management devices are a small segment of digital technologies so their net impact on energy demand is likely to be minor, especially in comparison with the environmental benefits they may be capable of delivering (Microsoft and PwC, 2019).

Like all digital technologies, however, those involved in energy management require resources for production and contain embodied energy, so minimising their environmental impact should still be a policy priority, especially considering the rapid pace of change and stock turnover for many digital technologies.

Digital devices often contain a range of metals and rare minerals, which are resource-intensive to extract and are becoming increasingly scarce. In addition, battery-powered devices rely on elements such as lithium and cadmium, which are often mined in conflict-ridden areas and are politically sensitive due to their toxicity.

In addition to the devices themselves, consumer behaviour also affects the environmental impact of digital devices and it is important not to assume that technological solutions are a "silver bullet", especially given possible rebound effects (discussed above).

Smart meters are one example. Their long-term impacts on energy-using behaviour are uncertain, with evidence so far pointing in both directions. A survey in the United Kingdom suggests that people who have had their smart meter for longer engage in more energy-saving activities, (Smart Energy GB and Populus, 2018). In Denmark, however, the evidence is mixed. There, energy consumption changes post-renovation reportedly ranged from a 39% decrease to an 18% increase (Gurzu, 2017).

## Give technology providers and businesses incentives to innovate

In many countries, the market for digital energy efficiency technologies is not yet mature and there remains potential for continuous innovation in technology and business models to reap the benefits of digital-enabled energy efficiency.

While the uptake of connected devices has increased rapidly, many products are yet to reach the so-called "early majority" stage.[2] In these markets, technology innovators can perceive risks, stemming from uncertainty about overall demand (or the viability and profitability of new products or business models) and/or concern about barriers to entry, from incumbents or existing regulations.

To reduce uncertainty about demand or viability, governments seeking to scale up digital energy efficiency may need to consider whether the right skills are being fostered for developing new technologies and services and whether the market encourages innovation by providing support for researchers and entrepreneurs to take risks.

Removing barriers to entry requires considering existing market structures and existing regulations. For example, as all digital technologies involve communications protocols to send

[2] This term comes from Roger's Technology Adoption Curve, a typology of the different stages technology adoption. The five stages of adoption, in order from the early to the late stage, are: Innovators, Early Adopters, Early Majority, Late Majority and Laggards.

and receive data, a common market barrier involves market incumbents adopting their own proprietary communication protocols, which can result in the segmentation of the market dominated by a few large players.

This can create obstacles for new smaller market players as protocol owners can charge licence fees if companies wish to connect their devices to existing systems. This imposes costs to market entry, both in terms of licensing fees and drafting legally binding confidentiality agreements.

Existing regulations can also pose a barrier to innovation. For example, energy market rules that do not value demand response, particularly from smaller players, may prevent new business models from emerging that could capitalise of these aspects of digital energy-efficient technologies. For this reason, governments (for example, in Malaysia, Singapore and several European countries) have recently begun using regulatory sandboxes in the energy sector. A regulatory sandbox provides an environment where businesses can test innovative products, services and market arrangements, with the support of regulators. In the sandbox, there may be relief from regulatory requirements that would otherwise prevent the pilot taking place.

OVO Energy in the United Kingdom is an example of a business testing an innovative digital energy efficiency product in a regulatory sandbox. Using the United Kingdom's regulatory sandbox, the company trialled an innovative tariff structure partnered with smart electric water heaters in the residential sector, to reduce bills while enabling grid balancing capabilities (Ofgem, 2018).

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# Annexes

## Annex A: Definition of factors included in decomposition analysis

Decomposition analysis provides a greater understanding of the impact of various factors on energy use. Analysis involves the decomposition of energy demand into three distinct factors:

- Activity – the change in the level of action that creates demand for energy.
- Structure – the mix of activities within an economy or sector.
- Technical efficiency – the amount of energy used per unit of activity. The term "technical efficiency effect" is used in this report to avoid confusion with the term "energy intensity".

The decomposition analysis presented in *Energy Efficiency 2019* covers 75% of global energy use and includes all IEA member countries plus Argentina, Brazil, the People's Republic of China, India, Indonesia, Mexico, the Russian Federation and South Africa. "Energy use" excludes non-energy use (i.e. feedstocks) and energy supply.

**Table A.1 Sectors and indicators included in the IEA decomposition analysis**

| Sector | Service/sub-sector | Activity | Structure | Technical efficiency effect |
|---|---|---|---|---|
| Residential and non-residential buildings | Space heating | Population (and climate) | Floor area per population | Space heating energy* per floor area |
| | Water heating | Population (and climate) | Occupied dwellings per population | Water heating energy per occupied dwellings |
| | Cooking | Population | Occupied dwellings per population | Cooking energy per occupied dwellings |
| | Space cooling | Population (and climate) | Floor area per population | Space cooling energy* per floor area |
| | Lighting | Population | Floor area per population | Lighting energy per floor area |
| Residential buildings | Cooking | Population | Occupied dwellings per population | Cooking energy per occupied dwellings |
| | Appliances | Population | Appliance stock per population | Appliances energy per appliance stock |
| Passenger transport | Car; bus; rail; shipping; aviation | Passenger kilometre | Share of passenger kilometres by mode, share of LDPV passenger kilometres in light trucks and persons per vehicle | Energy per vehicle kilometre |
| Freight transport | Truck; rail; domestic shipping; aviation | Tonne kilometre | Share of tonne kilometres by mode, share of road freight tonne kilometres by vehicle type | Energy per tonne kilometre |

| Sector | Service/sub-sector | Activity | Structure | Technical efficiency effect |
|---|---|---|---|---|
| Industry | Food, beverage and tobacco; paper, pulp and printing; chemicals and chemical products; non-metallic minerals; primary metals; metal products and equipment; motor vehicles and transport equipment; and other manufacturing | Value-added | Share of value-added | Energy per value-added |
| Services | Service | Value-added | Share of value-added | Energy per value-added |
| Other industries** | Agriculture and fishing; construction | Value-added | Share of value-added | Energy per value-added |

* Adjusted for climate variation using heating and cooling degree-days.

** Because they are energy producing sectors and outside the scope of this analysis, the following sectors are not included: mining and quarrying; fuel processing; and electricity; gas and water supply. "Other industries" are analysed only to a very limited extent.

# Annex B: Efficiency policy types monitored by the IEA

**Mandatory policies** and regulations with minimum energy efficiency performance requirements. These include mandatory minimum energy performance standards (MEPS) for appliances and equipment, mandatory building codes, fuel economy standards and targets for industry. For these policies, progress is measured using the Efficiency Policy Progress Index (EPPI). The EPPI measures the percentage of energy use covered by mandatory polices, combined with the increase in policy strength since 2000. Although most energy efficiency obligation programmes have mandatory targets, these policies are not included under this definition as they are analysed separately.

**Energy efficiency obligation programmes.** Also known as energy efficiency resource standards in the United States, obligation programmes require energy companies to achieve an energy efficiency target – typically a set amount of energy savings. Policy progress is measured by monitoring changes in policy coverage (the share of total final energy consumption supplied by obligated parties); and policy strength (the share of total final energy consumption required to be saved under the obligations in a given year). Obligations are not included in the EPPI.

**Financial incentives**. These include policies put in place to encourage the take-up of energy-efficient technologies and behaviour through financial or fiscal rewards, including grants and subsidies, tax relief, equity finance, loans and debt finance, guarantees, on-bill finance and other incentives.

# Glossary

## List of acronyms, abbreviations and units of measure

### Acronyms and abbreviations

| | |
|---|---|
| 4E TCP EDNA | Energy Efficient End-use Equipment Technology Collaboration Programme Electronic Devices and Networks |
| 4G | fourth generation of broadband cellular network technology |
| 4K | digital video resolution of approximately 4000 pixels |
| 5G | fifth generation of broadband cellular network technology |
| 8K | digital video resolution of approximately 8000 pixels |
| AC | Air Conditioning |
| ACE | Asset Class Energy Efficiency |
| ADB | Asian Development Bank |
| AfDB | African Development Bank |
| AI | Artificial intelligence |
| ASEAN | Association of Southeat Asian Nations |
| ATO | automated train operations |
| BASE | Basel Agency of Sustainable Energy |
| BEA | United States Bureau of Economic Analysis |
| BEMS | building energy management system |
| BIEE | Base of Energy Efficiency Indicators |
| BIM | building information modelling |
| BIS | Bank for International Settlements |
| C-PACE | commercial property assessed clean energy |
| CaaS | Cooling as a Service |
| CAF | Development Bank of Latin America |
| CBI | Climate Bonds Initiative |
| CEC | China Electricity Council |
| CRT | cathod ray tube |
| DER | distributed energy resources |
| DLT | distributed ledger technology |
| EBRD | European Bank for Reconstruction and Development |
| EC | European Commission |
| ECBC-R | Energy Conservation Building Code for Residential buildings |
| EDNA | Electronic Devices & Networks Annex |
| EEFTG | G20 Energy Efficiency Finance Task Group |
| EeMAP | Energy Efficiency Mortgages Action Plan |
| EERE | Office of Energy Efficiency & Renewable Energy |
| EIA | United States Energy Information Administration |
| EIB | European Investment Bank |
| EMA | Energy Market Authority |
| EMCA | ESCO Committee of China Energy Conservation Association |
| ENTSO-E | European Network of Transmission System Operators |
| EPBD | Energy Performance of Buildings Directive |
| EPPI | Efficiency Policy Progress Index |
| ESCO | energy service company |
| EU | European Union |
| EU TEG | European Union Technical Expert Group |
| EV | electric vehicle |
| EWFF | Efficient World Financing Forum |
| EWS | Efficient World Strategy |
| FAME II | Faster Adoption and Manufacturing of Hybrid and Electric Vehicles |
| FinBRAZEEC | Financial Instruments for Brazil Energy Efficient Cities |
| GCF | Green Climate Fund |
| GDP | gross domestic product |
| GFL | Green Finance for Latin America and the Caribbean |
| GPS | Global Positioning System |
| HDV | heavy duty vehicle |
| HVAC | heating, ventilation and air-conditioning |
| IADB | Inter-American Development Bank |
| ICAP | Indian Cooling Action Plan |
| ICCT | International Council on Clean Transportation |
| ICE | internal combustion engine |
| ICP | Investor Confidence Project |
| ICT | information and communications technology |

| | |
|---|---|
| IFIs | international financial institutions |
| IGSD | Institute for Governance and Sustainable Development |
| INDEC | Insitituto Nacional De Estadistica y Censos, Republica Argentina [National Statistics and Censuses Institute] |
| IsDB | Islamic Development Bank |
| ISO | International Organization for Standardization |
| ITF | International Transport Forum |
| K-CEP | Kigali Cooling Efficiency Program |
| KfW | KfW Development Bank |
| LCD | liquid crystal display |
| LDV | light duty vehicle |
| MaaS | mobility as a service |
| MEPS | minimum energy performance standard |
| METI | Ministry of Economy Trade and Industry |
| NABERS | National Australian Built Environment Rating System |
| NDRC | National Development and Reform Commission |
| NHTSA | National Highway Traffic Safety Association |
| NOAA | National Oceanic and Atmospheric Administration |
| OECD | Organisation for Economic Cooperation and Development |
| OICA | Organisation Internationale des Constructeurs d'Automobiles [International Organization of Automobile Manufacturers] |
| PACE | property assessed clean energy |
| PAT | Perform, Achieve, Trade |
| PPA | Power Purchase Agreement |
| RDEE | Readiness for Digital Energy Efficiency |
| R-PACE | residential property assessed clean energy |
| SMEs | small and medium sized enterprises |
| SUV | sport-utility vehicles |
| TFC | total final consumption |
| TPES | total primary energy supply |
| US DoE | United States Department of Energy |
| Users TCP | User-Centred Energy Systems Technology Collaboration Programme |
| WLTP | worldwide light-duty test procedure |
| ZEV | zero emission vehicle |

## Units of measure

| | |
|---|---|
| bcm | billion cubic metres |
| C | Celsius |
| CNY | Chinese Yuan |
| EJ | exajoule |
| kWh | kilowatt hour |
| $GtCO_2$ | gigatonne of carbon dioxide |
| $GtCO_2$-eq | gigatonne of carbon dioxide equivalent |
| GVA | gross value added |
| GW | gigawatt |
| GWh | gigawatt hour |
| Mtoe | million tonnes of oil equivalent |
| PJ | petajoule |
| pkm | passenger kilometre |
| TWh | terrawatt hour |
| USD | United States Dollars |
| ZAR | South African Rand |

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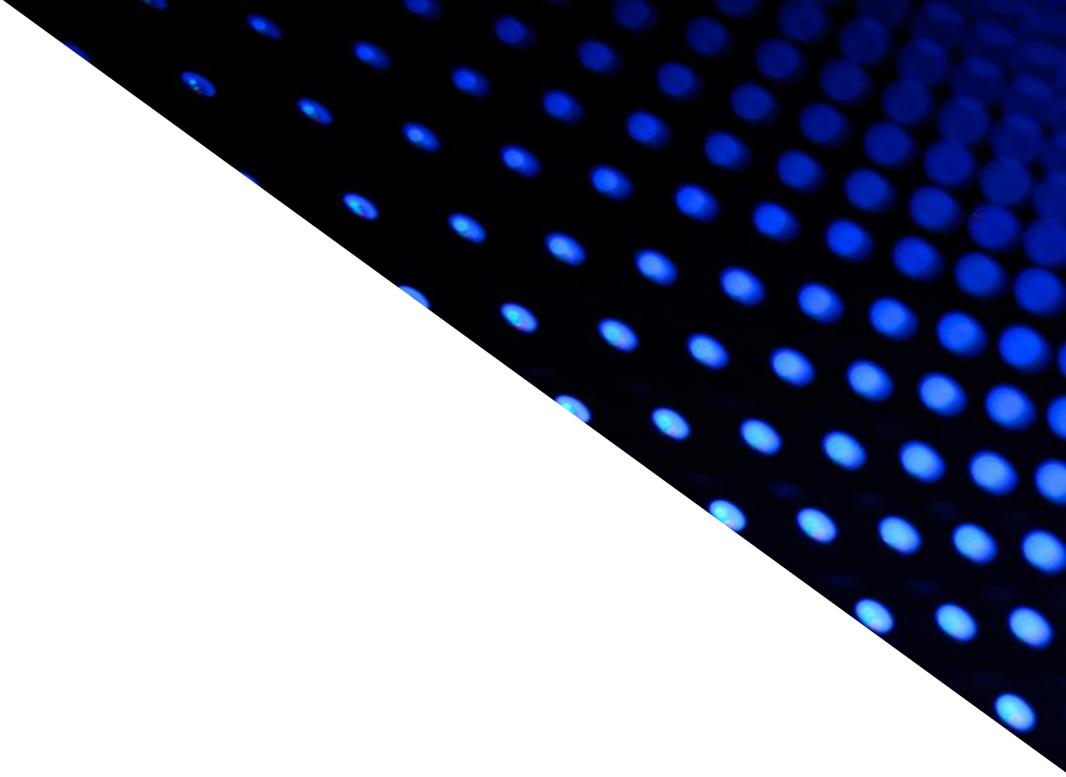

**Energy Efficiency 2019**

Since 2015, improvements in global energy intensity have been weakening each year. Energy Efficiency 2019 examines the reasons for this slowdown, which has major implications for consumers, businesses, governments and the environment. The rate at which energy-using technologies are becoming more efficient is slackening, and at the same time societal changes are adding to energy demand faster than technological change can keep up. On top of this, progress on policy and investment remains flat.

In addition to tracking trends in energy efficiency policy, investment, and technology, this year's report highlights how the digitalisation of our homes, businesses and transport systems provides immense opportunities to improve energy efficiency in systems and end uses. However, policy makers must engage with a range of challenging issues if the world is to harness digitalisation for greater energy efficiency. The IEA explores these with its new Readiness for Digital Energy Efficiency policy framework, presented in this report for the first time.

Energy Efficiency 2019 is the authoritative tracker of global energy efficiency trends, providing policy makers and others in the energy sector with crucial insights into the status of global energy efficiency.