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Perspectives for the Energy Transition

The Role of Energy Efficiency

INTERNATIONAL ENERGY AGENCY

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Foreword

Energy is an indispensable catalyst of economic activity and a source of comfort and well-being for all of us. Yet energy production and use is responsible for around two-thirds of global greenhouse gas emissions and is, therefore, central to achieving the goals of the Paris Agreement. The energy sector is also a key source of air pollution, the fourth-largest risk to human health globally. This is why energy is so important for the United Nations Sustainable Development Goals. These goals are a stark reminder that the foremost energy policy challenge for the coming decades is to simultaneously promote access to affordable and reliable energy for the billions of people currently deprived, while ensuring a transition towards cleaner and more sustainable use of energy. This transition will not be the same everywhere and will be shaped according to each country's circumstances. But, while indigenous endowments of fossil and renewable resources differ, there is one fuel to which all countries have access, a fuel that has everything needed for a sustainable and secure energy sector: energy efficiency.

The benefits of energy efficiency are numerous. Energy not consumed due to efficiency is carbon-free by default. And energy efficiency supports the clean energy transition more broadly across the energy system; for example, smart and efficient electricity use facilitates a faster decarbonisation of the power sector and supports the integration of renewable energies. A shift away from heavy industry towards less energy-intensive services can support overall system efficiency. Furthermore, energy efficiency not only reduces energy bills for consumers, but also the energy import bills of entire countries.

The International Energy Agency (IEA) has long recognised energy efficiency as the "first fuel" of the global energy system, supporting governments through analysis, sharing of policy best practices, and training activities. The coverage and stringency of energy efficiency policies have expanded in recent years, and the world's energy intensity has been steadily improving. Nonetheless, we cannot sit back: 68% of global final energy use is still not covered by energy efficiency codes or standards. And the most recent IEA data point to a slowing of global efforts on energy efficiency in 2017, while the need for an accelerated energy transition becomes ever more urgent. Further progress on efficiency is critical. Our analysis in this report demonstrates the compelling economic case for energy efficiency, and so it would seem paradoxical that so much efficiency potential remains untapped. But this highlights the crucial role that policy has to play in stimulating greater uptake of efficiency opportunities that are not pursued by the market alone.

The IEA family of countries now accounts for more than 70% of global energy consumption. We will work together with all our governments and beyond to make sure that best-practice energy efficiency policy is placed right where it belongs: at the top of the energy policy agenda.

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Acknowledgements

This publication was prepared by the International Energy Agency (IEA), with support and funding from the German Federal Ministry for Economic Affairs and Energy (BMWi).

The study benefited from the input of the following expert peer reviewers:

Kornelis Blok	Ecofys
Oreane Edelenbosch	PBL Netherlands Environmental Assessment Agency
Martha Ekkert	German Federal Ministry for Economic Affairs and Energy
Ellen Franconi	Rocky Mountain Institute
Dolf Gielen	International Renewable Energy Agency
Nicholas Howarth	King Abdullah Petroleum Studies and Research Center
Benoît Lebot	The International Partnership for Energy Efficiency Cooperation
David Lerch	German Federal Ministry for Economic Affairs and Energy
Yang Liu	National University of Singapore
Ajay Mathur	The Energy and Resources Institute
Steve Nadel	Alliance for an Energy Efficient Economy
Martin Schöpe	German Federal Ministry for Economic Affairs and Energy
Katia Simeonova	United Nations Framework Convention on Climate Change
Stefan Thomas	Wuppertal Institute
Yoshitake Yamaguchi	Toshiba

The individuals that contributed to this study are not responsible for any opinions or judgements contained in this study. All errors and omissions are solely the responsibility of the IEA.

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Executive summary

Energy efficiency is the cornerstone of any transition to a cleaner, more secure and more sustainable energy future. This report analyses two clean energy transition scenarios and shows that energy efficiency is just as important in a scenario combining climate change goals with other sustainable development objectives – such as achieving universal energy access and reducing air pollution – as it is in a scenario focusing only on the transition to a low-carbon energy system. In both scenarios, the pursuit of co-ordinated and ambitious energy efficiency policies can keep both global energy demand and energy-related carbon dioxide (CO_2) emissions in 2050 broadly at today's level, despite a near-tripling of the world economy and a global population that increases by nearly 2.3 billion. Although end-use energy efficiency alone is not sufficient to meet the temperature goals of the Paris Agreement, it can deliver 35% of the cumulative CO_2 savings required by 2050. While there are differences in the outlook for specific fuels between these scenarios, the widespread and comprehensive adoption of energy efficiency measures across all end-use sectors is a central pillar of both.

Energy efficiency has vast potential that remains untapped

Global energy efficiency improvements slowed dramatically in 2017, one of the key reasons for an annual increase in global energy-related CO_2 emissions – the first increase after three years without emissions growth. Global energy intensity improved by only 1.7% in 2017, much lower than the annual average of 2.3% over the last three years, and well below the 3% annual average required through 2050 to reach the goals of the clean energy transition scenarios. This shows that while important policy progress has been made on energy efficiency, current efforts are insufficient and the full potential of energy efficiency is being missed. Mandatory efficiency standards, for example, currently cover less than a third of global energy consumption and in recent years the growth of coverage of such standards has slowed. The importance and benefits of energy efficiency have been well documented and proven across all key economic sectors, both in developed and in emerging economies. Governments are increasingly aware that energy efficiency measures can deliver multiple benefits to the economy, including cost savings, cleaner air, energy security, productivity and trade balance improvements, and facilitating the integration of renewable electricity generation.

Strengthening efficiency is not only fundamental to meeting climate change goals, but also to strengthen energy security, improve access to energy and reduce local air pollution. In the 66% 2°C Scenario – a rapid low-carbon transition scenario that is the main focus of this report – efficiency measures would be the key to reducing energy demand in end-use sectors. They would support an overall reduction of oil by 67 million barrels per day (mb/d); of gas by 3 000 billion cubic metres (bcm); and of coal by 3 600 million tonnes of coal equivalent (Mtce) by 2050, relative to the New Policies Scenario (which reflects existing and announced polices and measures). Efficiency improvements in the buildings sector would contribute to a significant reduction in natural gas demand, falling nearly 740 bcm (or 67%) below the level of the New Policies Scenario by 2050. Boosting efficiency and electrification would be central for transport to save nearly 50 mb/d of global oil demand in 2050. The share of electricity in the end-use sectors would expand from around 20% today to 35% in 2050 in the 66% 2 °C Scenario, much higher than the 25% projected in the New Policies Scenario. Overall electricity demand growth would nonetheless be at the same level as in the New Policies Scenario, contained by energy efficiency. In a scenario incorporating other development objectives (the Sustainable Development Scenario), energy efficiency is also important for achieving universal access to clean cooking facilities, as more efficient stoves contribute to a shift away from the use of solid biomass in traditional stoves. This would sharply reduce household air pollution, currently responsible for around 2.8 million premature deaths each year.

Realising these potential efficiency gains would require a substantial shift in the balance of energy sector investment from the supply-side to the demand-side. In a recent joint study by the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), IEA analysis showed that the 66% 2 °C Scenario would require a fundamental reorientation of energy supply investment and a rapid increase in low-carbon demand-side investment. Average annual demand-side investment needs would amount to USD 1.7 trillion through 2050, the majority of which for energy efficiency and the electrification of transport. Conversely, total supply-side investment would remain fairly stable in the 66% 2 °C Scenario as efficiency gains achieved by demand-side investment would reduce the need for energy supply. There is a major shift, however, from fossil fuel investment to renewables and other low-carbon technologies (nuclear and carbon capture, utilisation and storage [CCUS]). The levels of demand-side investment required in the 66% 2 °C Scenario may appear daunting. Fuel cost savings over the lifetime of most technologies are larger than the investment required, however, indicating an important economic benefit arising from energy efficiency in clean energy transitions.

The economic case of energy efficiency is compelling in all end-use sectors

In buildings, the additional energy efficiency efforts in the 66% 2 °C Scenario would be sufficient to almost completely offset the increases in the demand for energy services out to 2050. Energy savings in 2050 in the 66% 2 °C Scenario, relative to the New Policies Scenario, would total around 950 million tonnes of oil equivalent (Mtoe), equivalent to one-third of today's energy consumption in buildings. The bulk of savings would come from increasing energy efficiency in space heating (more than one-third of energy savings) and cooling (almost one-quarter). The increased use of electric heat pumps to provide space and water heating and electricity for cooking would increase the share of electricity in building energy demand to 50% in 2050 in the 66% 2 °C Scenario (from around 30% today), resulting in a decline of other energy sources. Despite this, electricity demand would be contained by energy efficiency measures, with demand in the 66% 2 °C Scenario in 2050 some 16% below the level in the New Policies Scenario. Energy efficiency investment in the buildings sector would amount to almost USD 550 billion per year in the 66% 2 °C Scenario, but investments would generally pay back within the lifetime of the respective technologies: from less than one year (such as for lighting) to 14 years depending on the specific end-use. Universal adoption of mandatory and stringent energy-related building codes for new residential and services sector buildings, and the extension of codes to existing buildings, would be important measures to improve building envelope performance. Minimum energy performance standards (MEPS) would be critical to incentivise accelerated adoption of the best available end-use technologies.

In industry, a wide range of low-carbon technologies and processes would need to be adopted at a faster pace and larger scale than before if the sector is to meet the ambition of the 66% 2 °C Scenario. CO_2 emissions from fuel combustion in industry would be reduced by two-thirds in 2050 compared with the New Policies Scenario, and by more than half compared with today's levels. Key energy-intensive subsectors driving down energy demand would be iron and steel (almost one-quarter of the total savings by 2050) and chemicals (one-fifth). While the share of heat from electricity would more than triple by 2050 from today's level, further deployment of efficient electric motor systems would counteract the increase, contributing 2 700 terawatt-hours (TWh) of electricity savings in 2050. Energy efficiency investment of about USD 130 billion per year through 2050 would be needed across industry in the 66% 2 °C Scenario. Light industry sectors would make an important contribution to energy savings, and the majority of those energy efficiency investments would pay back within three years, while energy-intensive sectors require slightly longer average payback periods. Across industry, an important policy challenge is to trigger investment in efficiency options with short payback periods by overcoming non-economic barriers to their deployment. Even more stringent mandatory MEPS than those in the New Policies Scenario, as well as supporting measures for systematic implementation of energy management systems, would be important for the large-scale and rapid deployment of efficient technologies and processes.

Energy efficiency improvements in conventional engines are a key driver of energy demand savings in transport, although the economic case diminishes over time, particularly for cars, as the incremental costs of further efficiency improvements rise and render electric cars more competitive. In the 66% 2 °C Scenario, transport energy demand would peak by the mid-2020s and decline at 0.8% per year thereafter to 2050. Road transport would account for 70% of transport energy efficiency savings, 60% of which would come from light-duty vehicles that would see their average specific on-road consumption in 2050 reduced by a factor of more than three, compared with today. There is great potential for more efficient trucks to contribute to energy savings as only five countries have adopted fuel-economy standards for heavy-duty vehicles today. Together with improved logistics, truck efficiency would contribute almost 30% of energy savings from road transport. Transport electricity demand would increase by more than 8 000 TWh in the 66% 2 °C Scenario in 2050, relative to today, four-times the level in the New Policies Scenario and compensating declines in other sectors. The required energy efficiency investment in transport, at USD 375 billion per year through 2050, would pay back over the lifetime of all vehicles. For passenger cars in particular, however, the economic case for conventional engine vehicles would fade in the 66% 2 °C Scenario as the high levels of efficiency required would mean that investment in electric cars pays back more quickly as battery costs decline. Strengthened fuel-economy and emissions standards would be central to achieving the goals of the 66% 2 °C Scenario, but would need to be complemented by measures to support the roll-out of electric recharging infrastructure and policies to support smarter more intelligent transport systems.

It will take strong and determined policies to unleash the economic potential of energy efficiency

The combination of economic and non-economic barriers to efficiency means that delivering the energy efficiency gains in the 66% 2 °C scenario would be an enormous policy challenge. Although energy efficiency investments would pay back over the lifetime of technologies in the 66% 2 °C Scenario, the time required is often well beyond what consumers or industries would typically accept. Payback periods vary across sectors, and there are many low-hanging fruits in the short-term. But payback periods generally become longer over time as the efficiency of technologies increases and additional efficiency gains become more costly, despite technology learning effects. Such economic barriers for efficiency are frequently compounded by non-economic barriers, such as lack of awareness or information, and split incentives whereby those who pay for the additional energy efficiency do not reap the benefits. In many countries, fossil fuel consumption subsidies discourage investment in energy efficiency and low-carbon technologies, so phasing out subsidies that promote wasteful consumption of fossil fuels is an important consideration for policy makers.

Ramping up energy efficiency will require a strategic approach to efficiency policy: a clear long-term government commitment, combined with well-designed packages of efficiency policies reinforced by adequate capacity for implementation and sufficient enforcement. Delivering the highest possible contribution of energy efficiency to clean energy transitions, in the sectors where it can have the most benefit, requires decisive, consistent and effective policies, underscored by political will and good governance. Good policy making can affect the amount of investment needed, who pays for it and when, and ultimately the amount of energy efficiency delivered. Long-term commitments are critical in that they provide clarity and predictability for energy efficiency markets, notably for investors and companies who need to consider multi-year plans involving significant capital expenditure or borrowing. Long-term efficiency commitments can also be linked explicitly to climate change, air pollution and broader societal goals, as well as to help ensure optimal integration with other energy policy goals, such as increasing the use of clean energy sources.

The policy solutions for energy efficiency are well known, including regulations and standards, market-based incentives and innovative financing models. Regulatory approaches are crucial in many sectors. Standards and codes should increase in strength incrementally over time, with coverage expanding to other sectors and economies. Other strategic supporting policies will also be required. These include information and incentive-based policies, such as labelling and fiscal measures, which help to develop the market for efficiency products and prepare the ground for tighter regulations in future. Market-based instruments, such as tradable white certificates, can usefully complement to regulatory measures. For projects with longer payback periods or lack of financing opportunities, business and financing models such as energy performance contracting can be effective. Policy makers can play a crucial role in promoting these kinds of business models through standardisation, ensuring access to high quality information, awareness raising and training programmes.

Policy success in energy efficiency relies on strong institutional capacity and good governance. Implementation and enforcement capacity needs to be enhanced in many countries to enable rapid deployment of effective efficiency measures. This means not only increasing governments' capacity to implement policies, but also to operate them effectively as part of ongoing programmes. Effective evaluation, monitoring, verification and enforcement are critical for ensuring policy measures deliver, especially with regard to long-term efficiency targets. This requires detailed energy use data, in order to better understand how and why energy is being used. Sharing best practices and co-ordinating actions among economies will enable policy makers to realise decisive and effective measures.

Energy efficiency is the first fuel and can make the energy transition affordable, faster and more beneficial across all sectors of our economies. Any energy transition strategy must be led by energy efficiency, and the IEA is ready to continue to support governments in reaping the multiple benefits of energy efficiency through detailed analysis, sharing of policy best-practices and training activities. The IEA family of countries now covers more than 70% of global energy consumption, and we will continue to work together to ensure that best-practice energy efficiency policy is being adopted.

Introduction

The global energy sector is undergoing a rapidly accelerating transition. Investment patterns are changing, prompted by a multitude of drivers, including technological change, evolving consumer preferences and policy measures. Policies affecting the energy sector are motivated by a range of objectives. Tackling climate change is a critical consideration among those objectives, but governments continually are faced with other priorities such as ensuring affordable energy supply, improving energy security, delivering universal energy access and reducing air pollution. Technological change, both in energy supply and end-use technologies, is partly driven by this complex policy landscape. Evolving consumer preferences – such as for larger cars or warmer homes – further complicate the picture.

The energy sector – production, transformation and use of energy – is central to the climate change challenge. The sector accounts for around two-thirds of global greenhouse gas (GHG) emissions and about 90% of carbon dioxide (CO_2) emissions, the most prevalent GHG. Therefore the energy sector features prominently in countries' Nationally Determined Contributions (NDC) to the Paris Agreement on climate change, the 2015 landmark international accord that entered into force in November 2016. Even so, countries' NDCs are collectively not commensurate with the ambition of the agreement as a whole, as together they would suggest a long-term global temperature rise of at least 2.7 °C (degree Celsius). This clearly is not in line with the Paris Agreement's ambitious global objective of "holding the increase in the global average temperature to well below 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C."

The Paris Agreement also recognises that tackling climate change must be done in the context of sustainable development and efforts to eradicate poverty. The 17 Sustainable Development Goals (SDGs) of the United Nations, also agreed internationally in 2015, set broad and ambitious targets for making progress on sustainable development by 2030. Energy is central for achievement of many of the SDGs. Three goals in particular are closely related to energy, including affordable and clean energy for all (SDG 7), urgent action on climate change (SDG 13) as well as efforts to reduce air pollution which are included under the goals for health (SDG 3).

Understanding where governments can do more to stimulate the necessary investment and to drive more rapid transformation of the energy sector therefore is important, both for climate change and broader sustainable development objectives. In that context, the German government, in support of its 2017 presidency of the G20,[1] requested the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) to shed further light on how an energy transition to address climate change might look. The resulting publication, *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System* (IEA/IRENA, 2017), focused on the scale and scope of investments that would be necessary across the energy sector including power generation, transport, buildings and industry to achieve deep decarbonisation. In the report,

[1] The G20 is an informal group of the world's largest economies, comprising 19 countries and the European Union.

the IEA highlighted that while energy sector investment would need to increase substantially from today's levels, if the world is to meet climate objectives, the incremental increase is modest relative to the substantial investments anyway required in energy systems.

In parallel, the German government also requested the Organisation for Economic Co-operation and Development (OECD) to investigate the broader economy-wide investments needed for the transition to a low-carbon economy. The resulting study, *Investing in Climate, Investing in Growth (OECD, 2017)*, built directly on the IEA and IRENA report and concluded that on a broader economy-wide level, the incremental investment needed to ensure that infrastructure is low-carbon is also modest. The OECD study also investigated the macroeconomic implications of investment related to the low-carbon energy transition. It concluded that while the energy transition carries direct costs for the economy relative to a continuation of current trends, the transition could have a positive impact on economic growth over the long term, provided that the push for low-carbon investments is carried out in parallel with strong pro-growth structural reforms, themselves strongly aligned with climate objectives.

Another key finding of the IEA contribution to the IEA and IRENA report was that the necessary increase in energy investment would not be equal across the demand and supply sides of the sector. Demand-side investments would need to increase considerably from today's levels, in particular to improve energy efficiency across the global economy. The result of those efficiency gains is that total investment in the supply side would remain at nearly the same level of investment as today. However, supply-side investment would be significantly reoriented away from fossil fuels towards renewable energy resources.

Understanding the nature of these demand-side investments, in particular for energy efficiency, and successfully mobilising the necessary financing are essential to trigger an accelerated energy sector transition. To that end, the German government requested the IEA to carry out a follow-up study to take stock of progress towards a low-carbon energy sector and provide further insights on the role that efficient energy end-uses can play in achieving deep decarbonisation. This report focuses on the role of energy efficiency as a critical enabler of the clean energy transition in the buildings, transport and industry sectors.

Structure of the report

This report employs three scenarios to analyse the outlook to 2050. First is the **New Policies Scenario** – the main scenario of the *World Energy Outlook* (IEA, 2017) – that is based on the policies formally adopted and announced today, broadly in line with the NDCs, and which serves as a benchmark for gauging other scenarios. The **Sustainable Development Scenario** is an integrated scenario that combines the low-carbon energy transition with meeting energy access goals and reducing air pollution, seen through the lens of the SDGs. The **66% 2 °C Scenario** represents a low-carbon transition of exceptional scope, depth and speed to meet climate goals – a global CO_2 trajectory with a high chance of meeting long-term temperature targets without relying on global CO_2 emissions becoming negative this century (though its compatibility with other sustainability goals has not been assessed). The latter two scenarios are referred to as the clean energy transition scenarios in the discussion.

Chapter 1 introduces the scenarios, and discusses the role of energy efficiency and the required investment to achieve climate goals across these scenarios. Analysis of the two clean energy transition scenarios identifies the importance of energy efficiency for the low-carbon transition across end-use sectors and finds that the efficiency component in both scenarios is similar. Comparing this with the New Policies Scenario highlights the gaps in current policy ambition and technology status which provides a basis for policy recommendations.

Chapter 2 provides detailed insights on the needed energy efficiency investment by sector. Given the similar energy efficiency contributions in the two clean energy transition scenarios, it focuses on the 66% 2 °C Scenario. The chapter presents the outlook for energy intensity in the period to 2050 by way of detailed analysis by end-use sectors. It draws new findings on payback periods in the sectors and across time periods. The analysis then zooms out to shed light on how efficiency is characterised at a systems level.

Chapter 3 provides policy insights based on the analysis. It focuses on how specific policy measures can be tailored to improve energy efficiency across end-use sectors and explores broad strategic approaches to increase energy efficiency.

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Chapter 1. Setting the scene: Scenarios to 2050

Highlights

- Energy efficiency is an integral part of countries' climate change strategies. Nearly two-thirds of the Nationally Determined Contributions (NDCs) pledged under the Paris Agreement contain specific energy efficiency targets. In 2016, 31.5% of global energy consumption was regulated by mandatory efficiency standards, up from 11% in 2000. Energy efficiency investment is growing faster than investment in other parts of the energy sector: in 2016, it reached around USD 230 billion, an increase of 9% on the previous year, and equivalent to about 15% of the total energy sector investment of nearly USD 1.7 trillion.
- Existing and announced policies lead global energy demand to grow nearly 40% by 2050 in the New Policies Scenario. Without those measures, energy demand growth would be nearly twice as large. Nonetheless, significant energy efficiency potential remains untapped. Two scenarios are used to illustrate the role of energy efficiency in the clean energy transition: the Sustainable Development Scenario, which simultaneously achieves universal energy access, a reduction in air pollution and a rapid decline in carbon dioxide (CO2) emissions; and the 66% 2 degree Celsius (2 °C) Scenario, which focuses specifically on the low-carbon transition. Widespread adoption of energy efficiency measures is central to both scenarios, despite their differing objectives.
- Progressively stronger energy efficiency policies see the energy consumed per dollar of GDP decline by an annual average rate of 2.1% in the New Policies Scenario. This rate is significantly accelerated in the two clean energy transition scenarios to nearly 3% per year through 2050, emphasising the importance of energy efficiency. As a result, energy demand in both scenarios remains broadly flat between 2016 and 2050, even as the global economy triples and the population expands by nearly 2.3 billion. Renewable energy sources grow rapidly in both scenarios and there is a near-term peak and rapid decline in both coal and oil demand, whereas the New Policies Scenario sees steady growth in both coal and oil.
- In both clean energy transition scenarios, energy-related CO2 emissions peak before 2020 then fall rapidly in the period to 2050. Energy efficiency, including the contribution of electric vehicles, provides around a third of the emissions abatement in both scenarios, relative to the New Policies Scenario. Renewable energy is the other major pillar of emissions abatement accounting for nearly 70% of global electricity generation in both scenarios in 2050 (up from around 25% today), as well as a marked increase in biofuel consumption. This underscores the critical role of both renewables and energy efficiency, regardless of the precise pathway.
- The New Policies Scenario requires an annual average investment of USD 2.7 trillion (United States dollar) in the energy sector between 2017 and 2050, well above current levels. Incremental investment required by the clean energy scenarios is relatively modest, but does require a major reallocation towards clean energy on the supply side, as well as to investment in end-use sectors. In particular, annual average investment in energy efficiency in both scenarios is around USD 1 trillion through 2050, about four-times the current level.

This chapter briefly presents recent developments relevant to the low-carbon transition of the global energy sector. It explains the scenario approach used by the International Energy Agency (IEA) and details how the outlook to 2050 in the scenarios can inform energy sector decision making in the short term. In particular, the chapter looks at the crucial role of energy efficiency in the main IEA low-carbon scenarios, concluding that energy efficiency investments are similar in both an integrated sustainability scenario and in a climate-focused accelerated transition scenario.

Recent developments

Recent years have seen important energy sector developments with ramifications for its transition towards a low-carbon footprint. Changes in policy, technology costs and macroeconomic conditions have influenced how energy sector investment and operations are evolving. This section reviews these developments and examines the consequences for energy-related CO_2 and air pollution emissions.

Global energy investment trends

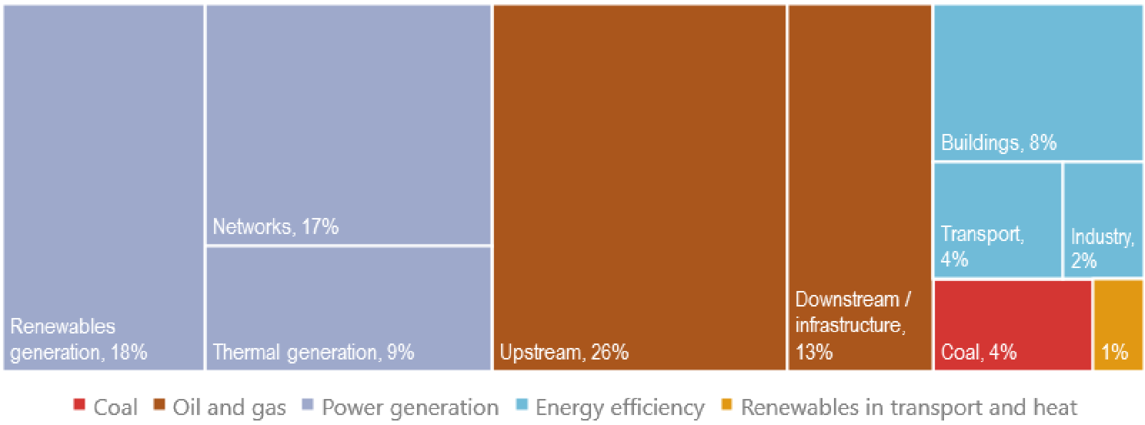
In 2016, total energy investment worldwide decreased 12% in real terms from the previous year, to around USD 1.7 trillion, having already decreased by about 8% from 2014 to 2015 (IEA, 2017a) (Figure 1.1). The biggest declines have been in upstream oil and gas, down 36% in the two years to 2016. However, the overall downward trend in oil and gas and also in the power sector is partly explained by falling unit capital costs which means that the same financial investment can deliver more in capacity terms.

Declining investment in oil and gas, particularly in the upstream, resulted in the electricity sector being the largest recipient, for the first time, of worldwide energy investment in 2016. Total investment in the power sector also declined by around 1% relative to the previous year, due to both lower thermal power generation investment and continued falling capital costs for renewables, notably solar photovoltaics (PV). However, lower capital costs mean that the total investment numbers belie strong capacity increases in renewables. For example, solar PV capacity additions reached more than 74 gigawatts (GW) in 2016, a 50% increase from the previous year.

Investment in electricity networks – an important enabler for the clean energy transition – continued to rise in 2016, as it has for the past several years. Investment in the expansion, modernisation and digitalization of networks and storage amounted to USD 277 billion, 30% of which was in the People’s Republic of China (hereafter “China”). As a result, renewables and networks increased their share of power investment to 80%. The combination of low-carbon generation and electricity networks saw their investment share grow by twelve percentage points to 43% from 2014 to 2016, closer to the total for fossil fuel supply investment.

Taken together, investment in clean energy sources – including renewables and other low-carbon power generation, energy efficiency and electricity networks – totalled USD 850 billion in 2016, accounting for over half of total energy investment. An increasingly important component of this trend is energy efficiency.

Figure 1.1 Global energy investment, 2016



Notes: Coal supply here includes mining and transport infrastructure; electricity networks include transmission and distribution lines, and grid-scale storage. Energy efficiency covers the incremental investments of efficient systems over less efficient alternatives (see Box 1.5).

Source: IEA (2017a), World Energy Investment 2017

Today electricity is the largest component of global energy investment and, together with efficiency, accounts for well over half of total investment.

Even with persistent low energy prices, energy efficiency was the fastest growing element in terms of energy investment in 2016. Global energy efficiency investment rose to USD 231 billion, an increase of 9% on the previous year. Europe remains the largest region for energy efficiency investment though China is catching up rapidly as the fastest growing region accounting for 62% of growth in energy efficiency investment. Defining energy efficiency investment is challenging. Consistent with recent IEA reports, an energy efficiency investment is defined here as the incremental spending on relatively efficient equipment or on building refurbishments that reduce energy use. The intention is to capture spending that leads to reduced energy consumption.[2]

The buildings sector continues to be the largest recipient of energy efficiency investment, making up more than half of the total and growing by 12% in the year to 2016. Improved building envelopes, including insulation, accounted for nearly half of total investment in efficiency in the buildings sector, while the other half was spread fairly evenly across heating, ventilation and cooling (HVAC), lighting and appliances.

In the transport sector, combined investment in electric vehicles – which can be considered an efficiency technology – and more efficient conventional vehicles increased 5% in 2016 from the previous year. Around one-third of the growth was for electric vehicles, while the remainder was largely attributable to investment in more efficient passenger vehicles in China. Investment in other regions, on average, was broadly flat with lower overall vehicles sales acting to mask an increased share of efficient vehicles. While vehicles within comparable classes are becoming more efficient, there is a consumer preference trend in most countries for larger vehicles.

[2] The numbers reported here are estimates of the incremental investment required for equipment that consumes less energy relative to a lower cost but less energy-efficient equivalent. A fuller discussion of defining efficiency investments, including for projections of future investment is in Box 1.5.

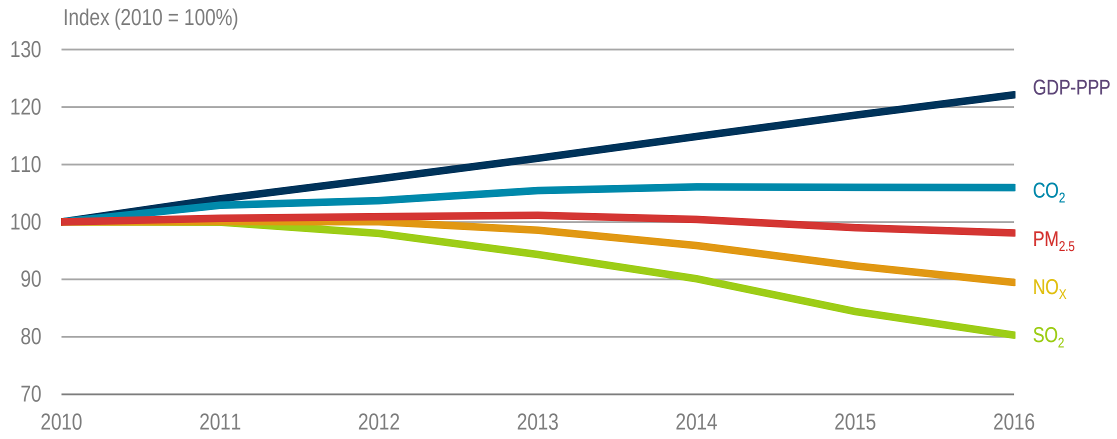
Total investment in energy efficiency in 2016 in the industry sector rose by 5% from the previous year. This was in line with increased production and brisk spending on industrial energy management systems, including software, especially in emerging and developing economies.

Research and development (R&D) is a critical element of energy investment as it is essential for the innovation required to transform the sector. The IEA has undertaken an estimation of private sector spending on energy R&D worldwide, in addition to its historical estimates on public spending. It is estimated that total global spending on energy R&D was USD 65 billion in 2015. Spending on R&D for general energy technology or specific for clean energy technology has not increased in the past four years.

Trends in energy-related CO_2 and air pollutant emissions

Shifts in the allocation of energy investment worldwide have slowed the rate of growth of global energy-related CO_2 emissions over the past decade. Following a resumption of strong growth after the financial crisis in 2008-09, CO_2 emissions growth tempered after 2010, and was flat for three consecutive years (2014-16). Over the period 2010-16, CO_2 emissions increased by only 6% while global gross domestic product (GDP) expanded, increasing by more than 20% during the period (in purchasing power parity [PPP] terms) (Figure 1.2). Despite this encouraging trend, global energy-related CO_2 emissions resumed growth in 2017, increasing 1.4% over the previous year (IEA, 2018).

Figure 1.2 CO_2 emissions growth relative to GDP and air pollutants



Notes: PM_{25} = particulate matter of size up to 2.5 µm; NO_x = nitric oxide and nitrogen dioxide; SO_2 = sulfur dioxide.

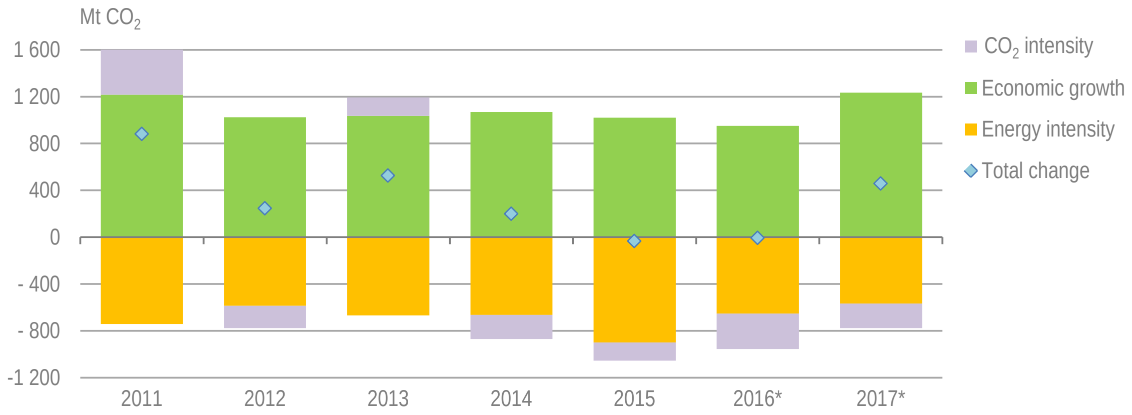
There are encouraging signs of a decoupling between economic growth and CO_2 emissions, which is even more apparent for emissions of air pollutants.

Notably, emissions of major energy-related air pollutants declined over the 2010-16 period. The energy sector is the main source of many air pollutants that can lead to severe human health consequences, as well as local and regional environmental damage. The three main categories of energy-related air pollutants are nitric oxide and nitrogen dioxide (together denoted as NO_X), sulfur dioxide (SO_2) and fine particulate matter ($PM_{2.5}$). Global emissions of all three have fallen in absolute terms since 2010. However, the link between pollution and its consequences for health is complex, depending on local factors as well as the nature of peoples' exposure to poor quality air. This means that premature deaths associated with outdoor air pollution are still increasing, despite the reductions in pollutant emissions (IEA, 2017b).

These trends point to an encouraging decoupling of economic growth from energy-related emissions. Dampening the rise of global CO_2 emissions in a period of accelerated global economic growth is a positive indicator. However, it is not sufficient to deliver the internationally agreed climate change goals of the Paris Agreement, especially given the resumption of growth in 2017. We examine this in our scenario analyses.

Energy efficiency is an important component in the decoupling of economic growth and energy-related emissions. It is useful to look at the metrics of energy consumed per unit of economic output (energy intensity) and the CO_2 emitted per unit of energy.[3] While energy intensity can be taken as a proxy for energy efficiency improvements, it is not a perfect indicator as it is also influenced by changes in economic structure, such as a shift from energy-intensive manufacturing to less energy-intensive services. Energy intensity improvements have played a strong role in the slowing growth of CO_2 emissions. Global energy intensity has been decreasing steadily since 2000, with marked improvements in the period 2013-15 (Figure 1.3). Recently, however, the trend on a global basis has slowed significantly, with energy intensity in 2017 improving by only 1.7%, much less than the 2.8% improvement in 2015. This slowdown was a key contributor to the rise in CO_2 emissions in 2017.

Figure 1.3 Change in global energy-related CO_2 emissions by driver, 2011-17



*2016 and 2017 data are estimates.
Note: Mt = million tonnes.

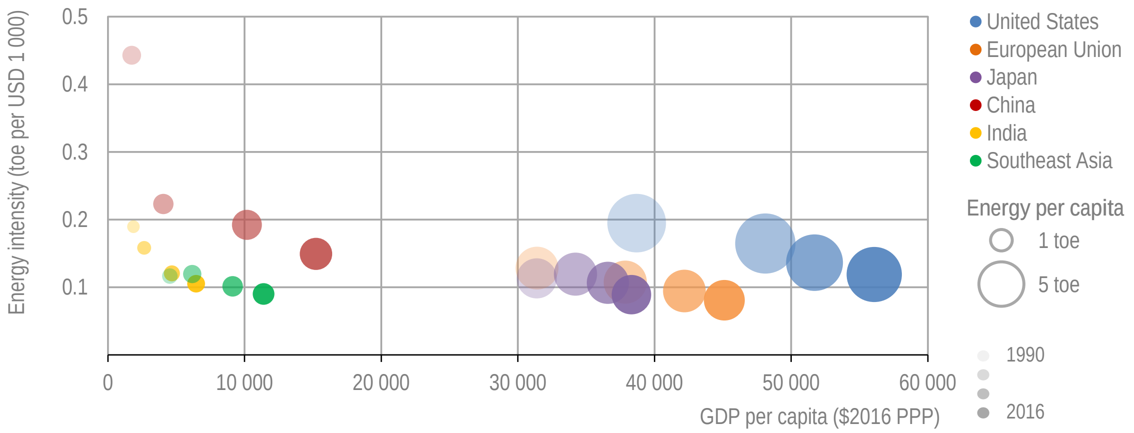
Energy intensity plays an important role in global CO_2 emissions trends.

Trends in energy intensity vary considerably by country. National contexts, including economic structure, level of development and cultural preferences, have important implications for how energy efficiency measures contribute to energy intensity improvements. For example, energy intensity across the world's largest economies (the G20 group) continued to improve in 2016, with intensity falling by 2.6% on the previous year, to 116 tonnes of oil equivalent (toe) per million dollars of GDP (USD 2016 PPP). This was driven in part by China's continued rapid improvements in energy intensity, highlighted in Figure 1.4. While energy intensity is improving in most countries,

[3] Economic growth can be further split into GDP per capita multiplied by population, resulting in the Kaya Identity: CO_2 emissions = population * per capita GDP * energy intensity * carbon intensity.

the rate of change is linked to both GDP per capita and energy use per capita, which has implications for policy (discussed below and in Chapter 3).

Figure 1.4 Energy intensity trends in selected regions



Note: toe = tonnes of oil equivalent; PPP = purchasing power parity.

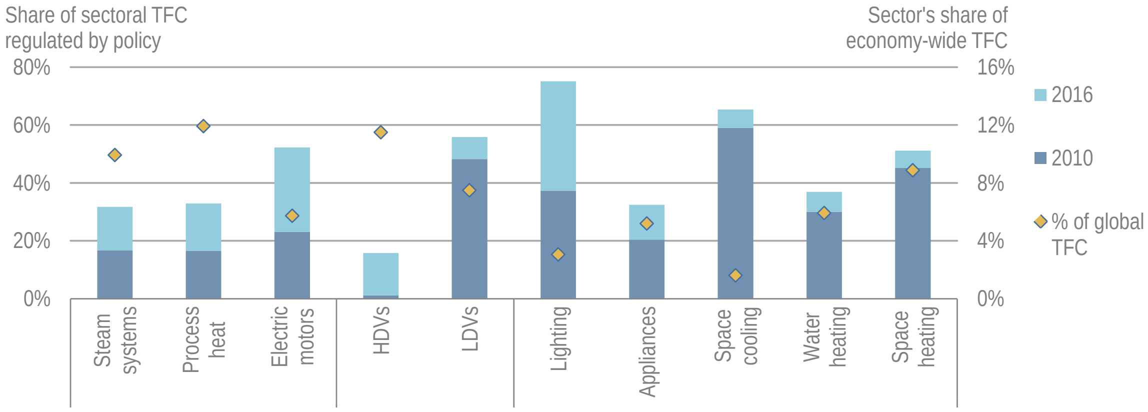
Trends in energy intensity reflect national contexts.

Developments in energy efficiency policy

The importance of energy intensity and carbon intensity in determining CO_2 emissions underscores the need for policy measures that influence both factors in the short and long term. Energy efficiency needs to be an integral part of climate change policy packages. Energy efficiency takes many forms and can be applied at many levels (Box 1.1).

At the heart of the Paris Agreement are countries' pledges in the form of their NDCs. Almost all NDCs include coverage of energy sector emissions, sometimes accompanied by targets or measures to address them. The most common energy-related ones are increased renewable energy deployment and nearly two-thirds of the NDCs mention specific plans to improve energy efficiency. Countries are taking steps to implement their pledges. However, many NDCs are not yet fully aligned with domestic energy policies. Governments increasingly value that energy efficiency measures can deliver multiple benefits to the economy, including cost savings, improved productivity and energy security. A good illustration is the proportion of global final energy consumption covered by mandatory efficiency standards that expanded from 11% in 2000 to 21% in 2010 and climbed to 31.5% in 2016 (Figure 1.5).

Figure 1.5 Share of global final energy consumption covered by mandatory efficiency standards by selected end-uses



Note: TFC = total final energy consumption; HDVs = heavy-duty vehicles; LDVs = light-duty vehicles.

Mandatory energy efficiency standards have been increasingly adopted in recent years, though the coverage varies considerably among end-use categories.

Box 1.1 What is energy efficiency?

Energy efficiency means achieving the same level of service (measured as economic output, production quantity or distance travelled) while consuming less energy. Typically, energy efficiency is considered in the end-use sectors (transport, buildings, industry). For example, if a new model of a gasoline car uses less fuel than the previous model to drive the same distance, the new car is more energy efficient.

Energy efficiency can also be considered more widely. For example, energy efficiency is also considered in the energy supply sector (power generation, oil and gas extraction and refineries). Furthermore, there are many ways to improve end-use energy efficiency, including both switching to more efficient technologies and employing behavioural and operational changes that make smarter use of existing technologies. This report’s main focus is technology improvements in end-use applications, though the potential for efficiency savings based on behavioural and operational changes and supply-side energy efficiency are addressed for context.

The digitalization of the energy system offers further opportunity for energy efficiency improvements. For example, ships and planes are being equipped with thousands of sensors that enable big data analytics for route planning and fuel reduction (IEA, 2017c). In road transport, global positioning systems coupled with real-time traffic information facilitate route optimisation, on-board monitoring safely reduces gaps between platooning trucks to improve fuel economy, and data sharing between companies across a supply chain allow them to ship more goods with fewer trips (IEA, 2017d). In intelligent buildings, automatic centralised control of HVAC, lighting, and appliances ensures that energy is consumed when and where it is needed, enabling more precise demand-side.

Energy efficiency is challenging to measure. Energy intensity – a measure of energy use per unit of production or economic output - is frequently used as a proxy for energy efficiency, though where data are adequate, more detailed indicators can provide useful metrics. It is also challenging to quantify the contribution of energy efficiency to aggregate energy savings and emission reductions: this entails a decomposition analysis to consider what the case might have been in the absence of more efficient technology or practice.

Coverage of energy efficiency policy (defined as the share of total final energy use covered by mandatory policy measures such as standards) varies across sectors. Energy efficiency standards for equipment used in the non-residential portion of the buildings sector applied to 45% of the sector's energy demand in 2016. In industry, efficiency standards applied to equipment representing 39% of the sector's energy use in 2016, an increase from only 2% in 2000 (IEA, 2017e). In addition to extending the coverage of energy efficiency standards to a wide array of products and processes, over time the levels of standards need to be assessed and adjusted if needed to spur technological innovation and the reap benefits of energy efficiency. For example, efforts to implement more ambitious standards for light-duty vehicles have delivered efficiency gains. Table 1.1 summarises a sample of recently announced and updated energy efficiency policy developments in selected countries.

While mandatory energy efficiency policies have been applied more broadly in the last decade, the increase in both coverage and stringency appears to have slowed in recent years. In 2016, incremental progress was slow with new policies accounting for only 1.5% of the increase in policy coverage of global final energy consumption. Coverage otherwise only increased via planned expansion from existing policies. In G20 countries, a number of end-uses, such as industrial process heat and steam, as well as buses and non-road transportation, were not addressed by any notable new efficiency policies in 2016. This indicates a need for enhanced action.

In addition to standards, regulations and other policies specifically targeting energy efficiency, a variety of other policies also directly or indirectly affect energy efficiency. End-use energy prices have an important influence on energy use and can supplement energy savings measures. Pricing measures can take a number of forms including raising energy taxes, implementing or strengthening a CO_2 price and phasing out energy subsidies. While CO_2 pricing measures have been expanding globally, price levels are generally low (OECD, 2016). In addition, other overlapping measures such as energy subsidies can counteract the effects of a CO_2 price. Policy coherence is essential. Where elements of fiscal and economic policies are misaligned with climate change objectives, even the best-designed policy measures for reducing CO_2 emissions can be ineffective (OECD-IEA-NEA-ITF, 2015). Subsidies for fossil fuel consumption are a prime example. Reflecting continued efforts at reform and lower prices for the main fuels, the estimated value of fossil fuel consumption subsidies continued its decline by 18% in 2016 from the previous year to USD 260 billion worldwide (IEA, 2017b). Subsidies for oil products saw the largest decrease (notably in the Middle East, where subsidies dropped sharply from about USD 55 billion in 2015 to USD 39 billion in 2016). In 2016, for the first time, the largest share of global subsidies went to electricity with 41% of the total. Subsidy schemes to meet the basic needs of vulnerable households are justifiable, but in practice subsidies to the residential sector are often not targeted, such that they disproportionately benefit better-off households. Electricity price and subsidy reforms are on the agenda in many countries.

Table 1.1 Selected recent energy efficiency policy measures

Country/ region	Policy	Year agreed/ updated
Argentina	Strengthened MEPs for cooling devices, washing machines and fluorescent lamps.	2014
Australia	National Energy Productivity Plan to improve energy productivity by 40% by 2030.	2015
Brazil	Increased funding for the National Electricity Conservation Programme.	2015
	Efficiency certification for all public lighting and a ban on incandescent bulbs.	2016
Canada	Energy performance standards for 20 product categories (including lighting, appliances, water heaters, electric motors).	2016
	Federal building energy codes for 2022 published in support of the Pan-Canadian Framework on Clean Growth and Climate Change, as guidance for provinces.	2016
China	13th Five-Year Plan goals for 2020: non-fossil fuels to reach 15% of total primary energy demand and energy intensity at 15% below 2015 levels; carbon emissions per unit of GDP at 18% below 2015 levels; NO_X and $PM_{2.5}$ emissions reduced by 15%.	2016
	Corporate average fuel consumption limit for new cars of 5 litres/100 km in 2020 and ambitions for 4 litres/100 km by 2025.	2017
European Union	Overall EU target is an increase in energy savings by 27-30% by 2030. Energy suppliers are obligated to improve energy efficiency by 1.5% per year as from 2020.	2017
	Tentative agreement on updates to the Energy Performance of Buildings Directive requiring existing buildings to be nearly zero-energy by 2050. All new public buildings to be nearly zero-energy buildings by 2019; all other buildings by 2021.	2018
France	Energy transition law includes a target to reduce final energy consumption 20% by 2030 and halve final energy consumption by 2050 from 2012 levels.	2015
Germany	Upgrades to energy efficiency schemes: enhancement of building modernisation programme; support for efficient heating systems; competitive tenders for electricity saving projects; support for cross-cutting technologies and waste heat recovery in industry; and, a pilot programme for advanced digital meters.	2016
	From 2016 to 2020, EUR 17 billion of public funding dedicated to energy efficiency.	2016
India	National Mission on Enhanced Energy Efficiency including Perform Achieve and Trade, a market-based scheme targeting energy-intensive industries and facilities.	Cycle III: 2017
	Voluntary building energy codes.	2017
	Light-duty vehicle CO_2 standards and heavy-duty vehicle fuel-economy targets.	2018
Indonesia	Goal to reduce energy consumption by 17% by 2025 compared to BAU, to be achieved through energy efficiency measures.	2016
Japan	Mandatory efficiency benchmarking for 70% of energy demand in the services and industry sectors by 2018.	2015
	Established the New Strategic Energy Plan, including actions to improve energy efficiency, e.g. electric motors included in the Top Runner Program.	2015
	Building Energy Efficiency Act, for new large-scale non-residential buildings, renovations, and extensions. Net-zero energy by 2030 for all new construction.	2016
Mexico	MEPS for split-type air conditioners and other appliances to reduce stand-by power.	2015
Saudi Arabia	Vision 2030 reform includes the Fiscal Balance programme to initiate a low-emissions transition and increase domestic fuel prices.	2016
South Africa	Draft National Energy Efficiency Strategy promoting energy efficiency as the “first fuel” to achieve a 29% reduction in final energy consumption by 2030.	2016

United Kingdom	Requirement for privately-owned rented buildings to achieve minimum energy performance rating of "E" on an Energy Performance Certificate, taking effect in 2018.	2017
United States	State-level renewable portfolio standards with the option of using energy efficiency as a means of compliance.	Various
	Energy Efficiency Improvement Act including voluntary certification programme for building owners and tenants, regulation of electric-resistance water heaters and requirement for federal government leased buildings to disclose energy usage data.	2015

Notes: MEP = minimum energy performance standards; BAU = business-as-usual.

Energy and emissions trends to 2050

A scenario-based approach is a powerful tool to analyse where existing policies and markets seem to be taking the energy sector and to illustrate how the course of the energy system might be affected by changing some of the key variables, including energy policies adopted by governments around the world. The analyses are underpinned by a system-wide modelling approach that covers all fuels, technologies and regions.[4]

This report examines three scenarios. The **New Policies Scenario** describes where existing policies and announced intentions might lead the energy system, in the anticipation that this will inform decision makers as they seek to improve on this outcome. It takes into account the energy components of countries' NDCs provided that policies are in place to support them and implementing measures have been clearly defined. The New Policies Scenario is not a forecast; rather it provides a sound basis to consider the key choices, consequences and contingencies in the energy path ahead and what adjustments may be needed to achieve desired outcomes.

The other two scenarios depict pathways towards a clean energy transition. The **Sustainable Development Scenario** is an integrated scenario that shows how the energy sector needs to change to meet three energy-related sustainable development goals as specified in the UN SDGs. In addition to an imminent peak and rapid decline in CO_2 emissions in line with the Paris Agreement, these include achieving universal energy access and reducing harmful air pollution (Box 1.2).[5]

A different energy sector pathway is depicted in the *66% 2 °C Scenario*. Developed by the IEA for IEA/IRENA (2017) and further analysed for the purposes of this report, the scenario focuses specifically on the climate change objective and thereby offers another important point of orientation for achieving long-term climate goals. Its main objective is an exceptionally rapid transition towards a low-carbon outcome, laying out technology and investment needs to stay within a specific carbon budget to 2100, assuming that global CO_2 emissions may not turn net negative in the second-half of the century.[6] While this assumption removes technical uncertainty about relying on the feasibility of negative emissions technologies, it serves to shift a greater

[4] For details on the IEA's World Energy Model, see www.iea.org/weo/weomodel.

[5] For full details of the Sustainable Development Scenario projection to 2040, see IEA (2017b). For the current report, a high-level assessment of the Sustainable Development and New Policies Scenarios has been carried out to 2050, solely for the purpose of understanding the role of energy efficiency in these scenarios. The results therefore do not reflect a detailed analysis to 2050 for these scenarios and are indicative only.

[6] For details of the assumptions in this scenario, see IEA/IRENA (2017). This scenario is also referred to as the Faster Transition Scenario in IEA (2017b)

emphasis onto near-term emissions reductions. The result is that the 66% 2 °C Scenario – so named because it is based on a carbon budget originally calculated to provide an estimated two-in-three chance of holding global temperature rise below 2 °C by 2100 – portrays an energy sector transition of exceptional scope, depth and speed.

Box 1.2 Energy and the Sustainable Development Goals

Energy is at the heart of sustainable development. Access to modern energy services – both electricity and facilities for clean cooking – is a fundamental prerequisite for social and economic development in countries where people still lack access. Where modern energy services are in place, minimising the environmental and health impacts of energy production and transformation is a critical part of sustainability. This is true for local and regional factors, such as health impacts arising from air pollution, as well as global implications such as the role of energy sector emissions in driving climate change.

The UN SDGs provide a comprehensive framework for measuring progress towards sustainable development. The 17 goals, comprising 169 specific targets, cover many aspects of social, economic and environmental development. The SDGs integrate multiple policy objectives within the framework, recognising, for example, that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs, while also tackling climate change and strengthening environmental protection.

While energy underpins many of the social and economic SDGs, it is fundamental for three goals in particular. SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. SDG 3 on health, and specifically SDG target 3.9, seeks to substantially reduce the number of deaths and illnesses from air pollution, of which the energy sector is the major contributor. SDG 13 aims to take urgent action to combat climate change and its impacts, where the energy sector is again the major contributor to GHG emissions.

The IEA is heavily engaged with the SDGs, notably as the lead custodian for tracking progress on the SDG indicators 7.2.1 (share of renewables in energy consumption) and 7.3.1 (rate of improvement in energy intensity). In addition, the IEA has been tracking developments in household access to electricity and clean cooking facilities since 2002 (IEA, 2017f). The IEA continues to support achievement of the targets, including through providing technical and policy inputs to the official United Nations review of SDG 7 in 2018.

The global energy transition should be seen in the context of these energy-related SDGs. Much attention has focused on action to tackle climate change, the importance and urgency of which is recognised in the Paris Agreement as well as within the SDGs. Most countries, including the G20, have made pledges towards tackling climate change in their NDCs to the Paris Agreement. However, climate change is one of many energy-related policy priorities and many countries – including G20 members – frame their climate contributions also in the context of other such policy goals, including ending poverty and reducing air pollution. IEA's new Sustainable Development Scenario, introduced in the WEO-2017, recognises these multiple priorities and illustrates an integrated approach to achieve the energy-related aspects of the SDGs: determined action on climate change; universal access to modern energy by 2030; and a dramatic reduction in air pollution (IEA, 2017b).

The intentions, and hence the outcomes, of the 66% 2 °C Scenario differ from those of the Sustainable Development Scenario, due to the respective nearer-term pace of the transition in each scenario and because of the latter's integrated approach to climate change, energy access and air pollution. Within the 2050 timeframe, both scenarios are in line with the long-term global objectives of the Paris Agreement, as they achieve a near-term peak in energy-related GHG emissions and a rapid decline thereafter. The ultimate temperature outcome will depend on further energy sector decarbonisation after 2050 and the time at which net-zero emissions are reached; the extent to which action is taken to reduce GHGs outside the energy sector and for other (non-CO_2) climate forcers; and possibly further refinement of the science of carbon budgets (Box 1.3).[7] The rest of this chapter compares and contrasts the evolution of the energy sector under existing and planned policies (the New Policies Scenario) with the outcomes of the two clean energy transition scenarios. The relative importance of emissions mitigation actions and different elements of the energy sector transition are assessed across the scenarios. Areas of commonality across scenarios can then be considered as priority areas for which insights are most urgently required.

Box 1.3 How emissions pathways affect long-term temperature outcomes

Climate studies have indicated that global temperature rise is almost linearly proportional to cumulative emissions of CO_2. This relationship has resulted in the concept of a remaining global "CO_2 budget", the cumulative amount of CO_2 that can be emitted over a given timeframe to stand a good chance of the temperature rise remaining below a chosen threshold (IPCC, 2014). While the CO_2 budget concept is relatively simple, multiple assumptions are necessary, meaning that carbon budgets should be used and interpreted with care.

First, the process for relating GHG emissions to future temperature rises is subject to multiple complexities. The process for doing so is generally undertaken in stages. GHG emissions are first related to changes in atmospheric concentration of GHGs, then to changes in the Earth's radiative forcing, and then to a temperature change. There are multiple feedbacks within this process, whose magnitudes cannot be directly observed, and each is subject to a variety of uncertainties. As a result, climate change can only be discussed in terms of the probability of staying below a specific temperature rise. Seemingly small changes in the probability attached to a particular temperature goal can have a major impact on the CO_2 budget: for example the remaining CO_2 budget for a scenario with a 66% chance of limiting the temperature rise to 2 °C in 2100 is around 250 gigatonnes (Gt) smaller than in a scenario with a 50% chance.

Second, non-CO_2 forcers, such as methane (CH_4), nitrous oxide (N_2O) and aerosols, also have a major impact on the temperature rise. These include energy sector emissions, such as methane leakage in oil and gas operations, as well as non-energy emissions such as those from land-use change. A specific CO_2 budget can only be associated with a temperature rise by making assumptions about the rates and levels of non-CO_2 emissions. Many non-CO_2 forcers have much shorter atmospheric lifespans than CO_2, complicating this calculation.

Third, different historical baseline temperatures can be used when assessing the temperature rise. The Paris Agreement refers to limiting the temperature rise relative to "preindustrial levels", but stops short of defining what this means in terms of either temperature or time period. Different historical periods have been used to assess temperature rise. The International Panel on Climate Change's (IPCC) Fifth Assessment Report, for example, reports temperature rises relative to the 1850–1900 period average, Hawkins et al. (2017) recommend using 1720–1800, while Schurer et al. (2017) focus on the period 1401–1800, pointing out that the period 1850–1900 could be as much as 0.2 °C warmer than the period 1401–1800. This small difference has a major impact: a 0.2 °C difference would reduce the remaining CO_2 budget by as much as 450 Gt.

[7] See also the discussion in Chapter 3 of World Energy Outlook-2017 (IEA, 2017b) and the online commentary at www.iea.org/newsroom/news/2017/november/a-new-approach-to-energy-and-sustainable-development-the-sustainable-development.html.

Fourth, budgets for total remaining CO_2 allowable emissions are generally derived by starting with the total CO_2 budget for cumulative emissions since a historical base year, and then subtracting the cumulative CO_2 emissions already emitted between the base year and the present. With a lack of reliable records of historic CO_2 emissions, estimates are made based on records of historic atmospheric concentration of CO_2. This process of converting concentration to emissions is subject to a high degree of uncertainty, meaning that cumulative CO_2 emissions up to 2015 could range from between 1 750 Gt to 2050 Gt, with corresponding implications for the remaining carbon budget.

In addition, whether or not the average global surface temperature rise can temporarily exceed the chosen threshold has important implications for the timing of mitigation efforts. Achieving a temperature overshoot would necessitate the widespread use of negative emissions technologies that can remove CO_2 from the atmosphere: any emissions above the CO_2 budget would need to be offset by negative emissions at a later date. While such technologies could include, for example, direct air capture of CO_2 or the use of bioenergy with carbon capture and storage, none has yet been demonstrated commercially at scale.

The IEA approach to CO_2 budgets is to rely on the climate model MAGICC. The model, widely used in studies assessed in the IPCC reports (IPCC, 2014), generates a probability distribution for the temperature rise over time. The scenarios presented here use 1765 as the baseline year and take non-energy emissions of non-CO_2 GHGs derived from the most appropriate scenarios produced by the longer term models assessed in the IPCC reports. The resulting remaining CO_2 budget for the 66% 2 °C Scenario is 880 Gt. This scenario assumes that there will be no overshoot in global temperature rise and no global net negative emissions. If CO_2 emissions from the energy sector were to follow the trajectory set out in the 66% 2 °C Scenario (for example) up to 2070 but were then to turn negative rather than remain at zero, then this would increase the chances of a lower temperature rise.

Our CO_2 budget for the 66% 2 °C Scenario lies towards the middle of the 590 – 1 240 Gt CO_2 range discussed in a study of CO_2 budgets commensurate with a 66% chance of staying below 2 °C (Rogelj et al. 2016). However there is an ongoing debate surrounding the CO_2 emission budget ranges associated with these temperature rises. On the one hand, recent papers by Millar et al. (2017) and Goodwin et al. (2018) provide CO_2 budgets that are considerably larger than the ranges indicated by Rogelj et al. (2016). Millar et al. (2017) suggest a remaining CO_2 budget to provide a 66% chance of limiting the temperature rise to 1.5 °C of around 730 – 880 Gt CO_2, and Goodwin et al. (2018) suggest a CO_2 budget to provide a 66% chance of limiting the temperature rise to 2 °C of 1 550 – 1 750 Gt CO_2. On the other hand, a recent study by Rogelj et al. (2016) suggests a remaining CO_2 budget (from 2015 to 2100) of between -140 Gt CO_2 and 510 Gt CO_2 to limit the temperature rise to 1.5 °C with a 50% probability. Since understanding of CO_2 budgets in the scientific literature is continuing to evolve and a scientific consensus has yet to emerge on this topic, we continue to rely on the method used in IEA/IRENA (2017), which is in line with the approach and results of IPCC (2014).

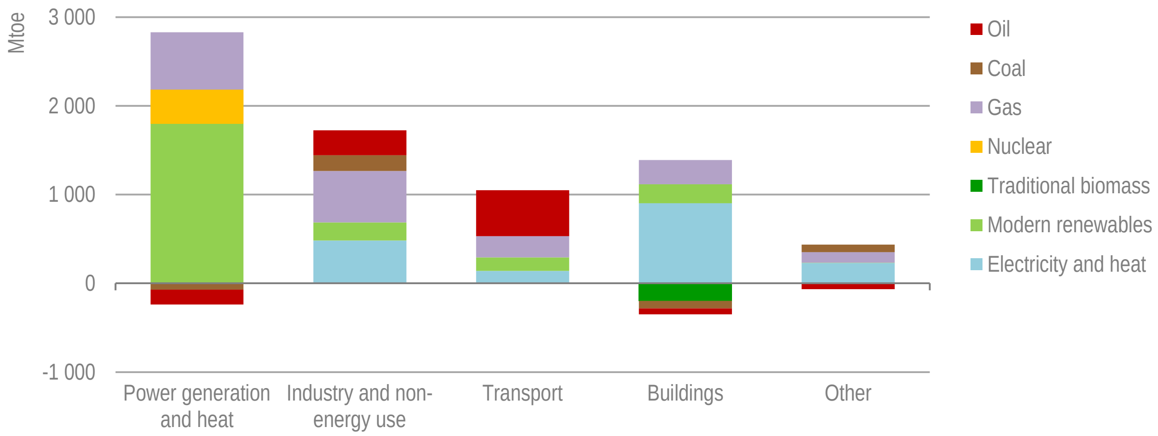
Trends in the New Policies Scenario

Primary energy demand growth in the New Policies Scenario is substantially lower than in past years: global energy demand experienced average annual growth of 2% in the period 2000-16 while this drops to less than 1% average annual in the period 2016-50 in the New Policies Scenario. Energy efficiency plays a strong part even in this scenario, supported by the transition towards less energy-intensive forms of economic activity (such as services and light industry) in emerging economies (most notably China), and slower economic and population growth. Energy efficiency is expected to be a cornerstone feature of energy sector developments. Indeed, in the absence of current and planned efficiency measures, global final energy demand would be more than twice as large (incremental final demand of over 8 500 million tonnes of oil equivalent [Mtoe] without efficiency measures relative to 3 850 Mtoe with the efficiency measures).

Efficiency measures in the industry sector account for almost 50% of the avoided energy demand in the New Policies Scenario in 2050. This reflects the addition of new capacity which brings down the overall intensity of the sector (new capacity tends to be more efficient than existing stock) and regulatory measures and standards that ensure efficient processes and technologies are adopted widely (e.g. preheating and pre-calcining equipment for cement kilns, low energy steel production routes and process integration in chemicals production).

While the rate of growth of energy demand slows, primary energy demand for all fuels increases through to 2050, with the exception of traditional biomass,[8] which declines as energy access policies bring cleaner cooking technologies to more households (Figure 1.6). Renewables collectively account for slightly more than 45% of demand growth, natural gas for just over 35%, oil for 10%, nuclear for 8% and coal for 2%. Oil demand growth slows notably over the outlook period. There is almost no growth in coal over the projection period, with demand drops of nearly 40% in advanced economies between 2016 and 2050 being offset by growth in the rest of the world, most notably in developing countries in Asia. On a global basis, coal fuels around 20% of global electricity generation in 2050, around 16 percentage points less than today. Natural gas surpasses coal in the global energy mix shortly after 2030 and rivals oil, as the second-largest fuel in the energy mix in 2050. Power generation remains the largest user of natural gas throughout the outlook period, though demand from the industry sector grows strongly. The net effect of these trends is that the share of fossil fuels in the global energy mix drops from 81% today to 72% in 2050.

Figure 1.6 Change in energy demand by fuel and sector in the New Policies Scenario, 2016-50



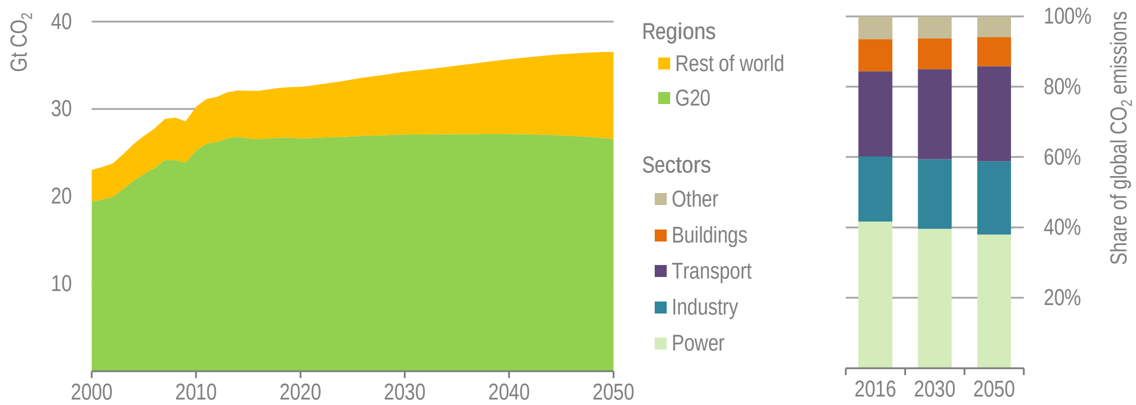
Notes: Mtoe = million tonnes of oil equivalent. *Other* includes agriculture and other energy sector.

While nearly all energy sources expand in the New Policies Scenario, modern renewable sources take the largest share of growth.

[8] The use of solid biomass for cooking and heating, typically using inefficient stoves in poorly ventilated spaces.

This pattern of demand growth means that energy-related CO_2 emissions continue to grow in the New Policies Scenario to 2050, albeit at a much slower rate than that seen in recent decades. Emissions increase on average by around 130 million tonnes of carbon dioxide (Mt CO_2) each year such that emissions in 2050 are around 15% higher than today's level (Figure 1.7), compared with the average annual growth rate of 450 Mt CO_2 in the period 1990 to 2016. Cumulative energy sector CO_2 emissions over the period 2016 to 2050 are around 1 210 Gt. Energy-related CO_2 emissions in the G20 group of countries peak around 2040 at 26.5 Gt before falling slightly to just under 26 Gt in 2050, although national emissions paths vary widely. G20 countries account for about three-quarters of global CO_2 emissions in 2050 in the New Policies Scenario. Overall, while the implementation of new and announced policies embodied in the New Policies Scenario helps to slow the growth in global CO_2 emissions, the projected emissions increase shows that they fall well short of moving the energy sector onto a pathway consistent with the goals of the Paris Agreement. This would require emissions to enter a steep decline towards net-zero emissions.

Figure 1.7 Energy sector CO_2 emissions in the New Policies Scenario



Notes: *Rest of world* includes international bunkers. *Other* includes agriculture and other energy sector.

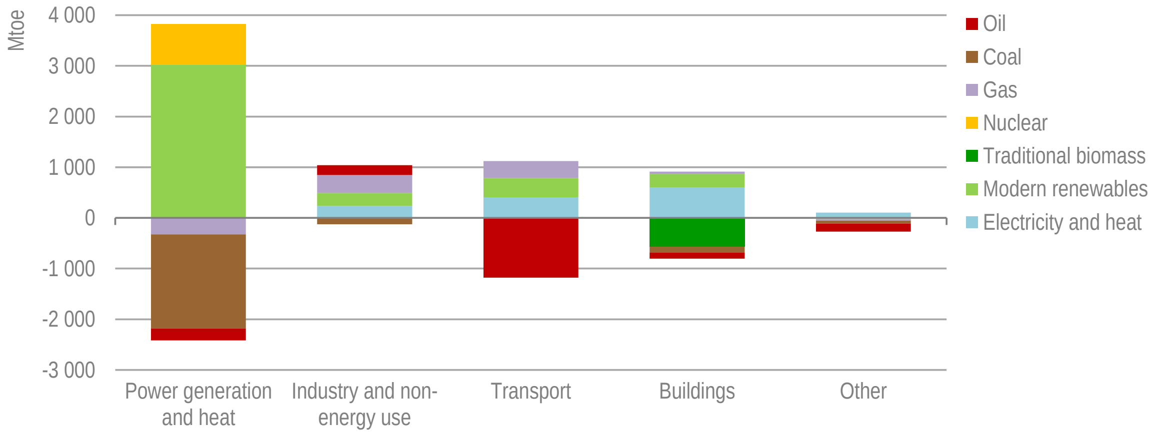
CO_2 emissions continue to rise in the New Policies Scenario though at a lower rate than experienced since 2000 and the G20 countries account for three-quarters of the emissions.

Trends in the Sustainable Development Scenario

The Sustainable Development Scenario starts from a view of where the energy sector needs to go to meet three major elements and then works back to the present. It describes a pathway to achieve universal access to modern energy services by 2030, meaning that 1.3 billion people gain access to electricity and 3.2 billion people gain access to clean cooking. It sets a route that is consistent with the direction to achieve the objectives of the Paris Agreement, including a peak in emissions as soon as possible, followed by a substantial decline. Third, it shows a large reduction in other energy-related pollutants, consistent with a dramatic improvement in global air quality and associated health benefits. There are significant reductions in local pollutants: $PM_{2.5}$ and SO_2 emissions both fall by around 60% from today's levels by 2030 (the time frame of the SDGs), while NO_X emissions drop by 40%. One clear opportunity that can simultaneously address air pollution, aid energy access and reduce CO_2 emissions is energy efficiency. The widespread adoption of more energy efficiency measures leads to a steep average annual decline of 2.8% in the energy intensity per unit of economic output over the period, such that total energy demand in 2050 is barely more than today's level.

The share of fossil fuels in the energy mix falls significantly in the Sustainable Development Scenario. Among the fossil fuels, coal falls by the largest degree: coal demand peaks before 2020 and falls by nearly 60% between 2016 and 2050 (Figure 1.8). This decline is most pronounced in the power sector, which sees an 80% drop over the outlook period, and by 2050 there is almost no electricity generated using unabated coal-fired power plants. By 2050, more than 250 GW of coal-fired generation capacity is fitted with carbon capture and storage (CCS), though it is concentrated in a small number of countries with China accounting for more than 60% of global CCS capacity.

Figure 1.8 Change in energy demand by fuel and sector in the Sustainable Development Scenario, 2016-50



Note: *Other* includes agriculture and other energy sector.

Overall energy demand is broadly flat in the Sustainable Development Scenario with the growth in renewables roughly offsetting declines in coal and oil.

In the Sustainable Development Scenario, oil demand peaks soon after coal and, by 2050, consumption is around 35% below today's level. A single sector, the transport sector, accounts for the vast majority of oil's decline. This is owing to several factors. The number of electric vehicles is expanding rapidly, from around 2 million electric cars on the road today to 1 400 million in 2050, cars and trucks becoming much more fuel efficient (the fuel economy of the average heavy freight truck improves by around 50% between 2016 and 2050), and a substantial increase in biofuel consumption, the transport sector sees a near 50% drop in oil demand over the period to 2050. The only sector to exhibit any growth in oil demand in this scenario is petrochemicals, where growth is connected to increased demand for plastics and chemical-based products.

Natural gas is the only fossil fuel that grows above today's levels in the Sustainable Development Scenario, partly because its combustion emits not only lower levels of CO_2 than coal and oil, but also much lower air pollutant emissions: virtually no sulfur dioxide (SO_2) and small levels of fine particulate matter ($PM_{2.5}$). Overall, gas demand worldwide grows by nearly 20% between 2016 and 2030 before declining slightly thereafter, becoming the largest single fuel in the global energy mix to 2050. Industry accounts for the largest share of natural gas demand growth given the more limited number of low-carbon options for the provision of high-temperature heat. In transport, natural gas helps reduce CO_2 and air pollutant emissions in sectors where electrification is a less viable option. In the power sector, baseload gas-fired generation continues to grow where there is still scope to displace coal. Yet the main role for gas-fired power is to provide operational flexibility to help integrate high levels of variable renewables.

Renewable sources of energy grow substantially in the Sustainable Development Scenario. In the power sector, renewables provide 70% of total electricity generation in 2050, with wind and solar PV each providing around 20% of global electricity generation, accompanied by slower growth in generation from hydro and geothermal sources. The direct use of renewables also increases in the industry and buildings sectors and, in 2050 around 20% of their heat demand is directly supplied from renewable sources. Nuclear development in this scenario is limited to those regions with existing or planned nuclear power plants. Global nuclear electricity generation more than doubles in the period to 2050 and provides close to 15% of electricity generation in 2050.

The traditional use of biomass for cooking in developing countries declines by 80% in the Sustainable Development Scenario, as a result of explicit policies to minimise air pollution while achieving universal energy access by 2030. These policies encourage the use of alternative fuels for cooking (including electricity, liquefied petroleum gas (LPG) and natural gas) and the use of advanced cook stoves (which reduce emissions of indoor air pollutants). In contrast, there is a significant increase in the modern use of bioenergy worldwide, consumption of increases by 150% between 2016 and 2050.

By far, the largest contributions to the reductions of CO_2 emissions in the Sustainable Development Scenario come from energy efficiency and the use of renewables in power generation, heat and transport. While emissions decline in all sectors, power sector emissions fall to the largest extent – an 80% drop between 2016 and 2050 – with the average CO_2 intensity of the power fleet falling to 45 grammes of carbon dioxide per kilowatt-hour (g CO_2/kWh) in 2050 (from around 500 g CO_2/kWh today). Given the difficulty in decarbonising road freight transport and shipping and aviation, the transport sector overtakes power generation to become the largest emitting sector shortly after 2030, although emissions from the transport sector still fall by around a third over the outlook period. All regions contribute to CO_2 emissions reductions in the Sustainable Development Scenario, but emissions in G20 countries peak earlier and decline at a faster pace than in other countries. The Sustainable Development Scenario also includes a dramatic reduction in all major sources of non-CO_2 gases from the energy sector, including methane emissions released during fossil fuel production (Box 1.4).

Box 1.4 Tackling oil and gas methane emissions in the clean energy transition scenarios

Natural gas fares best among the fossil fuels in the Sustainable Development and 66% 2 °C Scenarios. Natural gas results in fewer CO_2 emissions than coal or oil when combusted and so switching from coal or oil to natural gas can provide some emissions reduction benefits, particularly in sectors where low- or zero-carbon alternatives are less viable or will take longer to reach maturity. Natural gas-fired generation can also provide flexibility to help integrate high levels of variable renewables, However for gas to play these roles it is critical that the methane emissions that are released during its production, processing and transport are minimised. Methane is a potent non-CO_2 greenhouse gas and could easily erode any climate benefits from switching to natural gas unless it is carefully managed. A special focus in the WEO-2017 therefore examined in detail the current level of methane emissions from oil and gas operations and the policies, approaches, costs and benefits associated with mitigating these emissions (IEA, 2017b).

The current level of methane emissions from oil and gas operations is uncertain (see Dalsoren et al. (2018); Worden et al. (2017); Petrenko et al. (2017); Schwietzke et al. (2016); and Saunois et al. (2016)). WEO-2017 estimated global oil- and gas-related methane emissions in 2016 to be around 76 Mt, with just over half of these emissions coming from natural gas operations. A variety of mitigation options and technologies are possible to reduce these emissions and in many cases these measures can end up paying for themselves, because the recovered methane can often be sold. WEO-2017 estimated that methane emissions from oil and gas operations could be reduced by 40-50% just by implementing approaches that have no net costs. But implementing these technologies and measures will not be sufficient in the two clean energy scenarios; further action to realise the full technical mitigation potential is required, with the result that emissions fall by 75% between 2016 and 2030. Failure to achieve these reductions would make the climate objectives of the Sustainable Development and 66% 2 °C Scenarios harder to achieve and severely impede the role that natural gas can play in the energy sector transition envisaged in these scenarios.

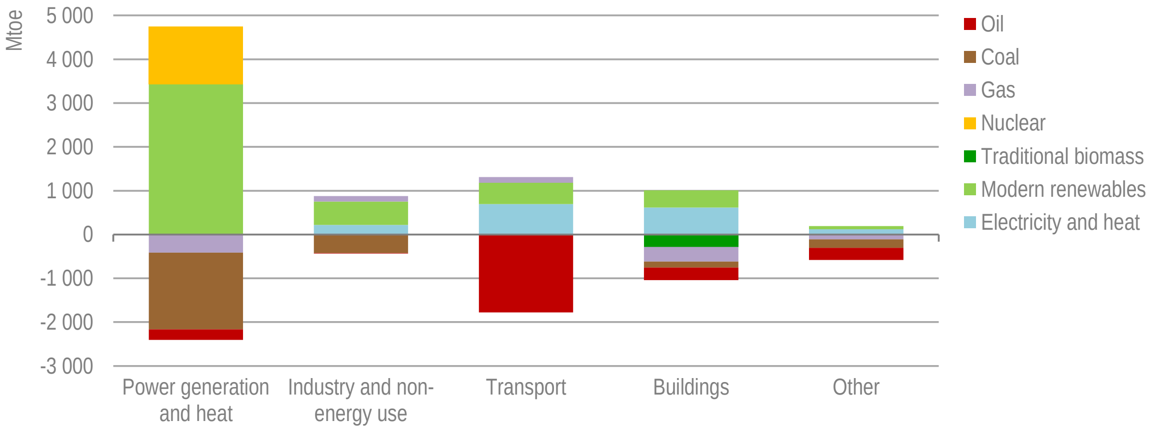
Trends in the 66% 2 °C Scenario

The 66% 2 °C Scenario would represent an energy transition of exceptional scope, depth and speed. Global primary energy demand in the 66% 2 °C Scenario would remain broadly flat in the period to 2050, even with a near-tripling of the global economy. The energy intensity per unit of economic output would decline by nearly 3% on average each year between 2016 and 2050 (twice the average annual decline seen over the past 25 years). This would occur not only through the immediate and widespread implementation of strict energy efficiency standards but also by extending efficiency measures to the production and use of materials. This would include light-weighting of products such as plastic bottles, paper and cars, and increased recycling and re-use of materials; these measures are not included in the New Policies or Sustainable Development Scenarios. The energy efficiency potential of the 66% 2 °C Scenario is discussed in detail in Chapter 2.

The share of fossil fuels in the 66% 2 °C Scenario in the overall primary energy fuel mix would plunge from 81% today to just under 40% in 2050. Coal use would fall throughout the outlook period at a particularly rapid rate and, in 2050, demand would be 65% below today's level; this drop would be led by declines in the power sector (Figure 1.9). End-use oil consumption would peak before 2020, with the decline in demand accelerating over an extended period such that in 2050 demand would be 60% below today's level. Despite the adoption of material efficiency displacing a substantial amount of plastics, the only sector in which oil demand would increase is again the petrochemical industry, albeit by less than in the Sustainable Development Scenario.

Although natural gas would fare better than coal and oil in the 66% 2 °C Scenario, demand would still be 20% lower than today by 2050. However, natural gas demand would increase in the shorter term, by around 15% between 2016 and 2025. There would be growth in natural gas demand in road transportation, as a marine bunker fuel and as a petrochemical feedstock, but during the period to 2025, most of this growth would stem from the power sector. During this period, generation from variable renewable electricity technologies would increase rapidly. However, this would still not be fast enough to offset entirely the loss of generation from coal-fired power plants. Gas-fired generation would be the key mechanism to fill the remaining gap. After 2025, with coal increasingly removed from power systems and an ever-increasing CO_2 price, the tide would turn against the use of gas-fired generation to provide baseload electricity, and gas demand in the power sector would start to drop. With natural gas also steadily displaced from the buildings sector after 2025 as efficiency measures and low-carbon alternatives would be adopted, total gas demand would start to fall.

Figure 1.9 Change in energy demand by fuel and sector in the 66% 2 °C Scenario, 2016-50



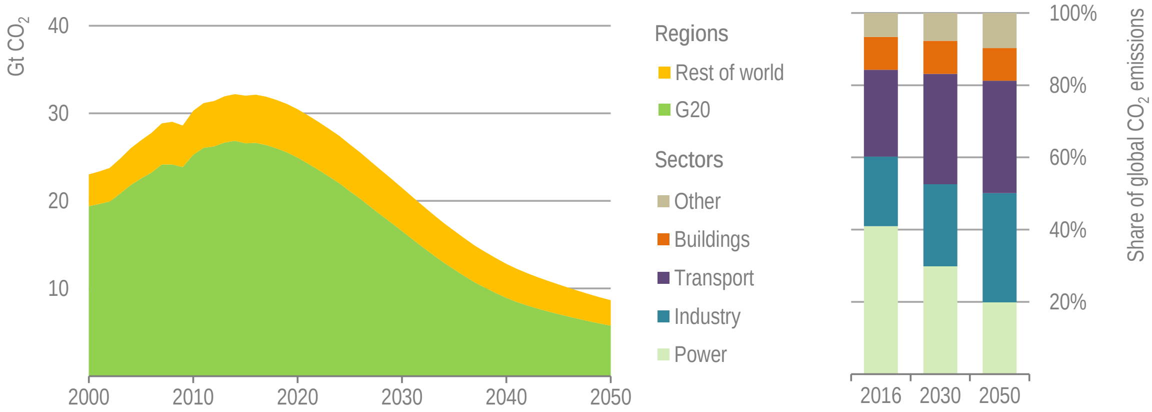
Note: *Other* includes agriculture and other energy sector.

Use of all fossil fuels would fall in the 66% 2 °C Scenario, with other energy sources meeting over 60% of global energy demand in 2050.

All low-carbon energy technologies, including renewables, bioenergy, CCS and nuclear energy, would expand rapidly in the 66% 2 °C Scenario. Growth in wind and solar PV would be most pronounced. By 2050, these two technologies alone would provide 35% of global electricity generation (compared with 5% today) despite the fact that total electricity generation would increase by 80% over this period. The modern use of bioenergy in 2050 increases by 250% compared to 2016, with consumption in 2050 far higher than that of oil and coal and broadly equal to the consumption of natural gas. In contrast, the traditional use of bioenergy would fall by more than one third between 2016 and 2050. Nuclear electricity generation would increase by a factor of three between 2016 and 2050 and account for 18% of global electricity generation in 2050. CCS capacity in both the power and industry sectors would expand rapidly after 2025; in 2050 just over 4.0 Gt CO_2 would be captured from these two sectors in roughly equal proportions. By 2050, there would be over 600 GW of coal- and gas-fired generation capacity fitted with CCS worldwide and nearly 50 GW equipped with bioenergy combined with CCS (known as BECCS). In the industry sector, CCS would be used to capture emissions both from heat generation and from industrial processes (the majority of which occur during cement production).

Energy-related CO_2 emissions would fall rapidly throughout outlook period in the 66% 2 °C Scenario with emissions less than 9 Gt in 2050 – around 70% below current levels (Figure 1.10). CO_2 emissions would fall fastest throughout the 2030s when on average they would drop by over 850 Mt each year. To place this in context, this pace of decline would be greater than the fastest sustained rate of growth ever seen in global CO_2 emissions: during the 2000s, energy sector CO_2 emissions increased on average each year by around 730 Mt. The average CO_2 intensity of the power fleet would drop rapidly from around 500 g CO_2/kWh today to 175 g CO_2/kWh in 2030 and to around 30 g CO_2/kWh in 2050. As a result, emissions from the power sector would fall by over 85% between 2016 and 2050, meaning that the electricity sector would account for less than 20% of total energy sector emissions in 2050.

Figure 1.10 Energy sector CO_2 emissions in the 66% 2 °C Scenario



Notes: *Rest of world includes international bunkers. Other includes agriculture and other energy sector.*

Global CO_2 emissions would fall to less than 9 Gt, with G20 countries responsible for two-thirds of emissions in 2050.

CO_2 emissions from buildings would fall by nearly 75% between 2016 and 2050 in this scenario. Stringent policies would be introduced in the buildings sector to achieve this, including: making end-use appliances as efficient as possible; ensuring buildings would be near zero-energy when they are constructed; undertaking deep retrofits on the entire existing building stock by 2050; and maximising the levels of heating in buildings provided through zero-carbon sources (including electricity, district heating and renewables). In the transport sector, the rapid deployment of electric vehicles (for all types of road vehicles), as well as fuel-efficiency standards and biofuel mandates, would have a sizeable impact on oil demand; total transport sector CO_2 emissions would fall by 65% between 2016 and 2050.[9] Emissions from the industry sector would fall by just under 60% between 2016 and 2050 as a result of the comprehensive exploitation of all energy and material efficiency potentials, extensive deployment of CCS, a 35% increase in the use of electricity and a focus on the direct use of renewables to provide heat. On a regional level, energy-related CO_2 emissions in the G20 countries would fall by nearly 80% from today to less than 6 Gt in 2050 in the 66% 2 °C Scenario. Emissions would peak slightly later in non-G20 countries and fall by a lesser extent (about half between 2016 and 2050); but, in 2050, the group of G20 countries would still account for two-thirds of global emissions and over three-quarters of the 720 Gt cumulative global CO_2 energy sector emissions between 2015 and 2050.

Comparison of energy trends between scenarios

The future of the energy sector depicted by the three scenarios differs in several ways. The speed of the transition towards low-carbon energy sources is a principal factor, in particular between the New Policies Scenario and the two "clean energy transition scenarios" i.e. the Sustainable Development Scenario and the 66% 2 °C Scenario. But this is not the only reason. The Sustainable Development Scenario contains the additional goals of achieving universal energy access by 2030 and minimising air pollutant emissions, and this helps to explain some of the differences between this scenario and the 66% 2 °C Scenario. While many technology options can concurrently help avoid air pollution and CO_2 emissions, in some cases, especially in seeking to secure universal energy access by 2030, there may be trade-offs involved or certain technologies may be more appropriate for achieving multiple objectives simultaneously. One particular example is in the power sector, where decentralised renewable technologies are often better suited to achieve the multifarious objectives of the Sustainable Development Scenario rather than centralised power generation facilities.

The degree to which governments introduce and tighten energy efficiency policies is a clear differentiator between the New Policies Scenario, and the two clean energy transition scenarios. While the global economy nearly triples in size between 2016 and 2050 in each scenario, primary energy demand is broadly flat in both clean energy transition scenarios. This demonstrates that there is no inherent need for energy demand to increase in the future but that this will depend upon sustained and concerted policy efforts to ensure that efficiency measures are adopted and effectively implemented across all end-use sectors.

Differences in the outlook for oil and coal consumption between the scenarios are striking. For coal, there is a slow but steady rise in overall coal demand in the New Policies Scenario while there is a near-term peak and rapid decline in both of the clean energy transition scenarios. A divergence in the evolution of the power sector is overwhelmingly responsible for these differences in outlook: while in the New Policies Scenario generation from coal remains broadly flat, in the clean energy transition scenarios, unabated coal is quickly phased out in favour of low-carbon sources of electricity.

[9] Modal shifts – such as a move away from personalised motorised transport – could contribute further to emissions reductions but are not modelled here.

For oil, again there is no peak in overall demand in the New Policies Scenario but steady declines in both of the clean energy transition scenarios; by 2050 oil demand is respectively 40% and 65% lower in the Sustainable Development and 66% 2 °C Scenarios than the New Policies Scenario. This is largely because of policies and measures to increase efficiency and encourage the adoption of electric vehicles in the transport sector. The only sector to exhibit growth in oil demand in the clean energy transition scenarios is petrochemicals. Indeed the growth between 2016 and 2050 in the Sustainable Development Scenario (5.2 million barrels per day [mb/d]) is only marginally smaller than in the New Policies Scenario (6.2 mb/d) given the absence of substitution options away from oil. Growth in the 66% 2 °C Scenario would be more muted (1.9 mb/d over the same period) given the additional measures going beyond energy efficiency to encourage material efficiency, such as light-weighting of end-user products (e.g. plastic bottles, paper and cars) and increased recycling and re-use of materials.

Natural gas is the only fossil fuel that sees strong divergence between the two clean energy transition scenarios. Global gas demand in 2050 is 10% higher than today in the Sustainable Development Scenario, while in the 66% 2 °C Scenario it would be 20% lower. This is partly because of the additional decarbonisation efforts required in the 66% 2 °C Scenario, which means that the tide turns against the unabated use of natural gas sooner than in the Sustainable Development Scenario. But it is also caused by the additional energy access and air pollution goals of the Sustainable Development Scenario. In the buildings sector, for example, natural gas helps in achieving universal energy access by 2030, most notably in urban areas; LPG that is currently used in many urban areas for cooking then becomes available to be used in modern cookstoves in rural locations where it displaces the traditional use of biomass. In the transport sector, switching to natural gas offers a way to reduce both air pollution and, in some cases, CO_2 emissions where electrification is a less viable option (such as the maritime sector).

Another major difference between the two clean energy transition scenarios is in levels of bioenergy consumption. The use of bioenergy in modern applications increases more rapidly in the 66% 2 °C scenario: 250% increase between 2016 and 2005, compared to 150% in the Sustainable Development Scenario. Even in modern applications, biomass combustion gives rise to emissions of $PM_{2.5}$, which need to be removed to minimise health impacts. This requires using post-combustion filters (where applicable and cost-effective against other options), which holds back further deployment in the Sustainable Development Scenario. Since tackling air pollution is not a core tenet of the 66% 2 °C Scenarios, and given the intended faster emissions reductions in this scenario, modern bioenergy use in 2050 is therefore 40% greater than in the Sustainable Development Scenario. Nevertheless, in both scenarios, for biomass to contribute successfully to GHG emission reductions, it must be cultivated and harvested in a way that does not lead to additional emissions from direct or indirect land-use change. There is also a large difference between the scenarios in the levels of bioenergy used in traditional applications. Securing universal energy access by 2030 and bringing about a major reduction in air pollutants in the Sustainable Development Scenario means that the traditional use of bioenergy falls by nearly 80% between 2016 and 2030. Since the 66% 2 °C Scenario does not require achieving these additional objectives the drop in traditional bioenergy over the same period is only 10%.

Overall levels of renewable electricity generation are somewhat similar in the two clean energy transition scenarios. Indeed, within the power sector, the rapid roll out of renewable sources of electricity generation is common across all three of the scenarios analysed. The key differentiating factor is the speed of this deployment. In the New Policies Scenario, generation from wind and solar PV grow by a factor of eight between 2016 and 2050, while in the clean energy scenarios they grow by a factor of twelve. In addition, the 66% 2 °C Scenario would see around 35% more nuclear generation than the Sustainable Development Scenario; in the latter, policies supporting energy access favour the use of distributed low-carbon technologies over centralised solutions, which somewhat inhibits the deployment of nuclear facilities.

Across the end-use sectors another common theme is the rise of electrification. Again, however, the two clean energy transition scenarios require a much faster shift than is seen in the New Policies Scenario. Today just under 20% of energy consumed in end-use sectors is electricity; in 2050 this increases to 25% in the New Policies Scenario, to nearly 30% in the Sustainable Development Scenario, and to 35% in the 66% 2 °C Scenario. Despite the higher share of electricity consumption in end-use sectors in Sustainable Development and 66% 2 °C Scenarios, the absolute level of electricity demand growth in the two clean energy transition scenarios is actually lower in the industry and buildings sectors than in the New Policies Scenario. In the industry sector electricity demand grows by just over 3 000 terawatt-hours (TWh) between 2016 and 2050 in the clean energy transition scenarios and by about 5 500 TWh in the New Policies Scenario. Similarly, in the buildings sector, electricity demand growth in the New Policies Scenario is nearly 50% higher than the growth in the clean energy transition scenarios. These differences arise as a result of the extraordinary efficiency policy efforts implemented in both the clean energy transition scenarios that stimulate the much wider adoption of efficient technologies and measures than in the New Policies Scenario.

There is a major difference in electricity consumption growth in the transport sector between the two clean energy transition scenarios. In the Sustainable Development Scenario, electrification of the vehicle fleet is largely confined to passenger cars: by 2050 there are 1 400 million electric passenger cars on the road (around 65% of the passenger car fleet at that time). In contrast, the extent of electrification of trucks is much lower. In the 66% 2 °C Scenario, the rise of electric passenger cars would be even more rapid – by 2050 there would be 1 750 million electric passenger cars on the road (70% of the passenger car fleet) – but electrification also extends to the freight sector. The number of electric trucks would expand rapidly with almost 50% of trucks on the road plug-in hybrid or full battery electric vehicles in 2050.

The largest contributions to global energy-related CO_2 emissions abatement between the New Policies Scenario and the 66% 2 °C Scenario would come from efficiency, electric vehicles and the use of renewables (Figure 1.11). The contribution from efficiency includes energy efficiency measures, the use of electric vehicles[10] and material efficiency measures. As discussed, electrification is the primary mechanism to reduce emissions in the road transport sector, with the majority of cars and around half of trucks electrified by 2050. For all remaining vehicles, as well as the maritime and aviation sectors, stringent fuel-efficiency and emissions standards are critical

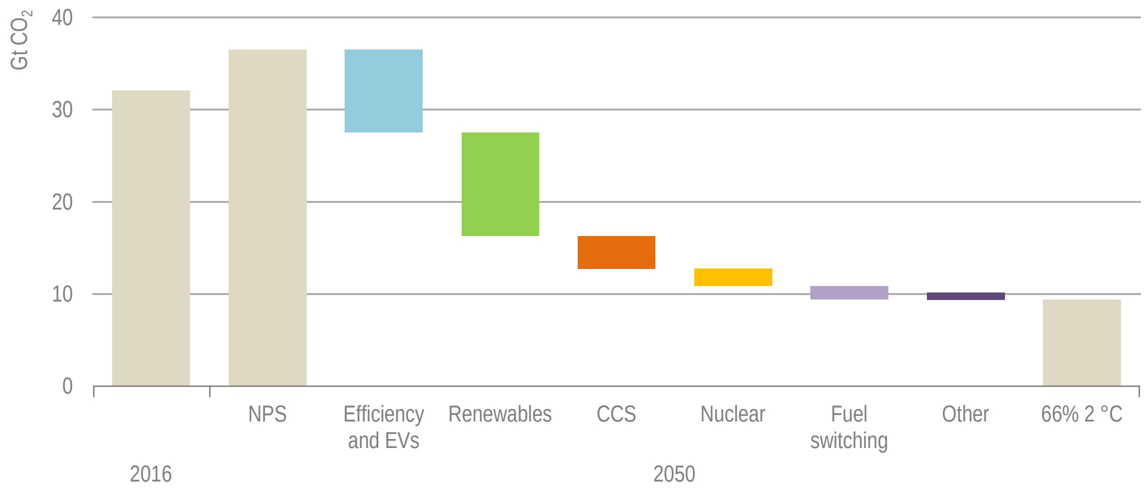
[10] Motors in electric vehicles are generally much more efficient than internal combustion engines and so investment in electric vehicles can also sometimes be considered an efficiency investment, (see Box 1.5).

(such as differentiated vehicle taxation based on efficiency performance and improvements in air traffic management to minimise flight distances and aircraft waiting times).

In the buildings sector in the 66% 2 °C Scenario, it would require an unprecedented push for new buildings to be near zero-energy when constructed – around 40% of all new buildings built between today and 2050 would be zero-energy with the other 60% compliant with stringent buildings codes – along with deep retrofits of the entire existing building stock by 2050. In the industry sector, minimum energy performance standards (MEPs), along with the deployment of system-wide measures in industrial systems (such as predictive maintenance and proper systems sizing), would be critical to moderating energy demand growth in the 66% 2 °C Scenario. Emissions reductions would also be generated through the light-weighting of end-user products and increased recycling and re-use of materials (most notably steel and aluminium), which lowers the level of new materials that are required and so also reduces energy use in the industry sector. While it would be a major challenge to mobilise all of these stringent efficiency measures in such a short period of time, doing so would be critical to achieve the emissions reductions that are necessary.

Renewable energy technologies account for around 60% of the power sector CO_2 emissions reductions in the 66% 2 °C Scenario, relative to the New Policies Scenario. But renewables are also crucial in the transport sector, with nearly 12 mb/d of biofuels consumed in 2050 in the 66% 2 °C Scenario in road freight transport where electrification is more difficult as well as in aviation and shipping, and in directly producing heat in the industry and buildings sectors. CCS accounts for 10% of global CO_2 savings in 2050 in the 66% 2 °C Scenario relative to the New Policies Scenario, and is vital to reduce energy-related emissions in both the power sector and, just as importantly, the industry sector.

Figure 1.11 Global CO_2 emissions reductions in the 66% 2 °C Scenario relative to the New Policies Scenario, 2016-50



Notes: NPS = New Policies Scenario; SDS = Sustainable Development Scenario; EVs = electric vehicles; CCS = carbon capture and storage. Efficiency and electric vehicles have been combined here as policy measures relating to both are considered in Chapter 3.

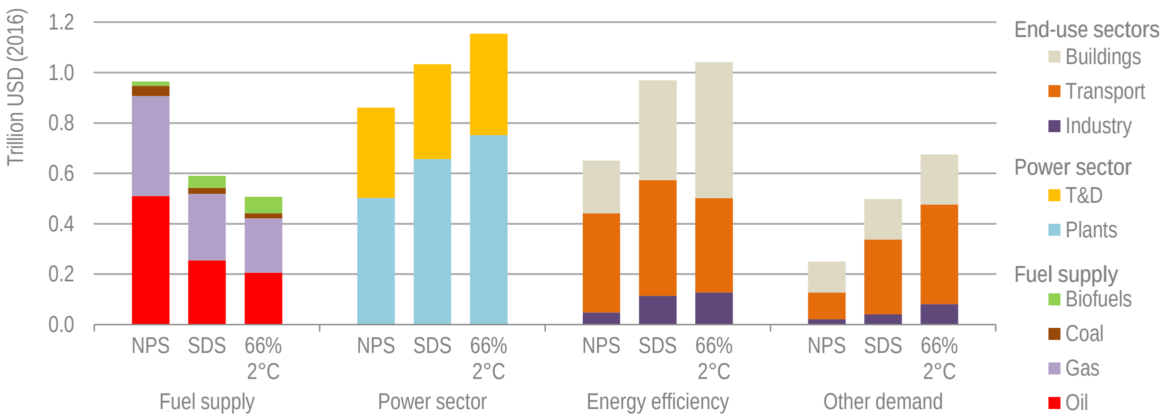
Efficiency measures, electric vehicles and renewables provide three-quarters of the CO_2 emissions reductions in the 66% 2 °C Scenario relative to the New Policies Scenario.

Investment needs to 2050

The New Policies Scenario requires an average of USD 2.7 trillion to be invested in the energy sector every year between 2017 and 2050 (Figure 1.12). The Sustainable Development Scenario requires around 15% more capital than the New Policies Scenario, while the 66% 2 °C Scenario requires almost 25% more. These are not marked increases in overall terms; however there are major differences in how capital is allocated between the sectors.

The largest share of capital expenditure in the New Policies Scenario (more than 35% of the total) is used to extract and supply fossil fuels. Investment into fossil fuels is required both to meet the increasing levels of oil, gas and coal demand in this scenario, but, more importantly, to offset the underlying declines in production from existing fields. In the Sustainable Development Scenario, average investment in fossil fuel extraction (nearly USD 550 billion per year) is over 40% lower than in the New Policies Scenario. Continued investment in fossil fuels nevertheless remains vital in the Sustainable Development Scenario. This is because there is around a 15% increase in natural gas demand between 2016 and 2050, and while oil demand falls throughout the outlook period, the decline is slower than the decline in existing oil fields. The 66% 2 °C Scenario would have even lower fossil fuel demand than the Sustainable Development Scenario and, so as would be expected, it would require less investment in fossil fuel extraction. Yet, more than USD 400 billion would be spent on average each year in the 66% 2 °C Scenario on fossil fuel supply. Continued investment in oil and gas extraction, albeit at very different levels, therefore remains a necessary feature of all of the scenarios analysed.

Figure 1.12 Annual average investment in the energy sector in the three scenarios, 2017-50



Notes: NPS = New Policies Scenario; SDS = Sustainable Development Scenario; T&D = transmission and distribution. *Plants* include all power generation technologies. *Other demand* includes demand-side investments not related to efficiency, including electric vehicles, use of renewables in buildings and CCS in industry.

The Sustainable Development and 66% 2 °C Scenarios require similar levels of investment in end-use sectors (including efficiency), much more than the New Policies Scenario.

Around 30% of total investment in the New Policies Scenario is required for electricity generation and the transmission and distribution networks necessary to deliver it. Renewables account for around 40% of the USD 860 billion annual average investment in the power sector in this scenario, with similar amounts for both wind and solar (including PV and concentrated solar power) generation.

In the Sustainable Development Scenario, annual average investment in the power sector to 2050 is over USD 1 trillion, 20% higher than in the New Policies Scenario, which largely reflects the transition from fossil fuelled power plants to low-carbon technologies. These are less expensive to maintain and operate once they have been constructed but in general are still more expensive to build. However significant cost reductions in renewables-based electricity generation over time alleviate some of the increase in power sector capital investment in the Sustainable Development Scenario. To give some examples: the average cost of solar PV in 2030 in the Sustainable Development Scenario is around 55% below today's levels; cost of CCS in the power sector are nearly 40% lower; and the cost of offshore wind is around 35% lower. There is also a modest increase (5%) in investment in electricity transmission and distribution networks above the level of the New Policies Scenario given that generation is more distributed in the Sustainable Development Scenario.

Annual average power sector investment in the 66% 2 °C Scenario between 2017 and 2050 would amount to around USD 1.15 trillion. This is nearly 12% higher than in the Sustainable Development Scenario, even though total electricity generation is only 8% higher, with part of this difference due to more nuclear capacity in the 66% 2 °C Scenario. Nuclear capacity is very capital intensive and does not enjoy major cost reductions over time in the scenarios. Even though the Sustainable Development Scenario contains major cost reductions in the cost of renewables and CCS, the additional deployment of renewables and CCS in the 66% 2 °C Scenario would lead to further cost reductions that help to moderate some of the overall increase in power sector investment.

The New Policies Scenario requires average annual investment of USD 880 billion in end-use sectors, of which USD 630 billion per year is for efficiency technologies that moderate energy use. The costs of deploying these technologies falls over time but the efficiency mandates included in the New Policies Scenario require, on average, spending of nearly USD 650 billion every year between 2017 and 2050. Box 1.5 discusses how efficiency investments are calculated. The remaining portion is for end-use technologies to help reduce energy-related CO_2 emissions directly, e.g. solar thermal in buildings, and the additional capital spent on electric or natural gas vehicles and trucks that displace the use of conventional vehicles.

The investment required in end-use sectors in the Sustainable Development Scenario is considerably higher, 60% more than in the New Policies Scenario, with average investment exceeding USD 1.4 trillion each year between 2017 and 2050. The largest share is for energy efficiency – requiring over USD 950 billion annual investment on average – and in particular more efficient technologies in the transport sector, where spending averages USD 460 billion per year (almost 20% more than in the New Policies Scenario). The proliferation of fuel-efficiency standards, for both passenger and freight vehicles, delivers a major improvement in average fleet efficiencies: by 2050, the global conventional car fleet is about 50% more efficient than today. There is also average annual spending of around USD 250 billion on electric vehicles between 2017 and 2050 (included in "other demand" in Figure 1.12). This investment ramps up over the course of the Sustainable Development Scenario as a result of the time it takes for electric vehicle sales to grow from today's low base and the need for infrastructure to be developed.

Investment in more efficient buildings, and the appliances used within them, averages just under USD 400 billion each year in the Sustainable Development Scenario (90% more than in the New

Policies Scenario). This is led by spending on more efficient household and office appliances, as well as more efficient forms of lighting, insulation, space heating and cooling. These measures are achieved through the introduction and strict enforcement of MEPS, stringent codes for new buildings and major programmes to retrofit existing buildings. Efficiency measures in the industry sector require annual investment of just over USD 100 billion over the course of the Sustainable Development Scenario (more than double the level of investment in industrial efficiency measures in the New Policies Scenario).

Energy efficiency investment in the 66% 2 °C Scenario, which averages USD 1 trillion annual each year to 2050, would be only marginally higher than in the Sustainable Development Scenario. However this masks sectoral some differences. The level of investment in efficiency measures in the transport sector, averaging USD 370 billion per year, is lower in the 66% 2 °C Scenario than in Sustainable Development Scenario (and indeed lower than in the New Policies Scenario). This is because improvements in efficiency are insufficient to generate the rapid emissions reductions that are required across the vehicle fleet in the 66% 2 °C Scenario. However electric vehicles are deployed much more rapidly in this scenario and are extended to other transport modes (notably freight vehicles), so there is a consequent large increase of spending in this area that offsets the decrease in efficiency spending. If electric vehicles were to be included as an energy efficiency investment, then total investment in the transport sector in the clean energy transition scenarios would be very similar (averaging USD 760 billion per year).

In the buildings sector, investment in efficiency measures would be around 35% larger in the 66% 2 °C Scenario than the Sustainable Development Scenario (and 150% more than in the New Policies Scenario). In the industry sector too there would be a higher level of investment in efficiency in the 66% 2 °C Scenario than in the Sustainable Development Scenario. However this increase of just over 10% is more modest than the relative increase in the buildings sector since nearly all possible energy efficiency measures in the industry sector are already deployed in the Sustainable Development Scenario. The additional spending would therefore mostly be related to the larger efforts to improve material efficiency. Around USD 28 billion would also be required each year in direct emissions-reduction technologies on the demand side, most notably for solar thermal and geothermal for space heating in buildings and CCS in the industry sector.

While the Sustainable Development and 66% 2 °C Scenarios do not have the exact same targets both set out a pathway to an important transition to a low-carbon energy future that can provide benefits to economies, communities and individuals. To make progress on this route, the urgency of shifting investment from fossil fuel supply towards improving energy efficiency performance and mobilising investment in efficiency across the main end-use sectors is a clear conclusion from this analysis. Given that the levels of efficiency investment are broadly similar in both of these clean energy transition scenarios, the rest of this report focuses on results in the 66% 2 °C Scenario, but what is clear is that achieving the reallocation of investment necessary to bring about the clean energy transition will require strong policy support that goes well beyond existing pledged ambitions.

Box 1.5 What is an energy efficiency investment?

There is no standardised definition of energy efficiency investment. Consistent with recent IEA reports, this report defines energy efficiency investment as the additional expenditure made by households, firms and governments to improve the performance of their energy-using equipment above the average efficiency level of that equipment in the base year of 2016. To calculate energy efficiency investment on this basis, we have made use of the extensive technology detail in the World Energy Model.

To illustrate, in the case of a passenger car, the efficiency improvement and cost increment of an efficient vehicle is calculated against a reference technology, such as an average gasoline car, and multiplied by the volume of sales. This increment collates the additional cost for technology that improves efficiency, such as direct injection, low friction tyres and design improvements. The same principle is used for appliances: for example, the reference technology for refrigerators is a 2016 A++ model, with future electricity savings and cost increments calculated relative to that model. For building construction, efficiency investment is the extra cost of erecting buildings that meet or exceed minimum performance standards or new regulations for energy efficiency compared with an older standard to which the market has already adapted. Similarly, for building refurbishments, the incremental cost of the efficiency part of the refurbishment is estimated. This method, combined with estimated stock turnover and the economic return required across sub-sectors in industry, across modes in transport and across end-uses in buildings, enables the projection of future investment needs for efficiency, by region and technology.

Energy efficiency investment covered in this report includes improvements achieved through more efficient technologies, better insulation of buildings and improved energy management in industrial processes. Energy savings resulting from fuel switching with a modal shift in transport or through behavioural change are not counted as energy efficiency investment in this report, even if, in practice, they increase the energy efficiency of the system. Capital expenditure for R&D of energy-efficient technologies is not included either. However, investment costs include labour costs directly related to installation of a product, as well as additional costs for the more efficient product, such as associated taxes, freight and administrative costs.

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Chapter 2. Efficiency in the clean energy transition

Highlights

- A decline in energy intensity of nearly 3% per year as projected in the 66% 2 °C Scenario would help to reduce final energy demand by 3 700 Mtoe (more than the People's Republic of China (hereafter, "China") and the European Union's combined energy demand today) in 2050 relative to the New Policies Scenario. Transport would account for around 40% of the savings, industry for almost 30% and the buildings sector for about one-quarter. Electricity demand would reach about the same level as in the New Policies Scenario thanks to efficiency policies. However, its share of total final energy demand would rise to 35% (25% in the New Policies Scenario) as electricity would overtake oil as the main final energy carrier by the late 2030s. Direct and indirect CO2 emissions from final energy demand would fall by a combined 25 Gt (or three-quarters), relative to the New Policies Scenario.

- In buildings, in the 66% 2 °C Scenario, energy demand in 2050 would be nearly one-quarter below that of the New Policies Scenario. Almost half the decline in energy demand would be from space and water heating, reducing gas demand in particular; in the 66% 2 °C Scenario, buildings gas demand would be nearly 740 bcm (or around two-thirds) lower than in the New Policies Scenario. Increasing the efficiency of technologies is as important as improving performance of building envelopes. All buildings existing today would need to be retrofitted by 2050 and around 40% of new residential constructions would need to be near zero-energy buildings.

- Energy intensity of the industry sector in 2050 in the 66% 2 °C Scenario would be about a quarter below the level of the New Policies Scenario (about half of today's level). Demand for all energy carriers except renewables would fall, particularly coal demand. Non energy-intensive industries (e.g. textiles, food processing) would contribute around 45% of the energy savings in 2050, relative to the New Policies Scenario. Energy-intensive sectors would also contribute to improved energy intensity and lower emissions, accounting for more than 60% of coal and oil savings in the industry sector in 2050.

- Transport energy demand in 2050 would be 40% lower in the 66% 2 °C Scenario, relative to the New Policies Scenario, contributing nearly 50 mb/d of the reduction in global oil demand in 2050. This would be partially offset by a factor-four increase of electricity demand. Energy efficiency improvements in conventional combustion engines would account for two-thirds of cumulative savings in energy demand, led by road (70%), aviation (17%) and shipping (11%). The role of such direct energy efficiency savings would diminish over time as electric vehicles make inroads in the road passenger and freight segments.

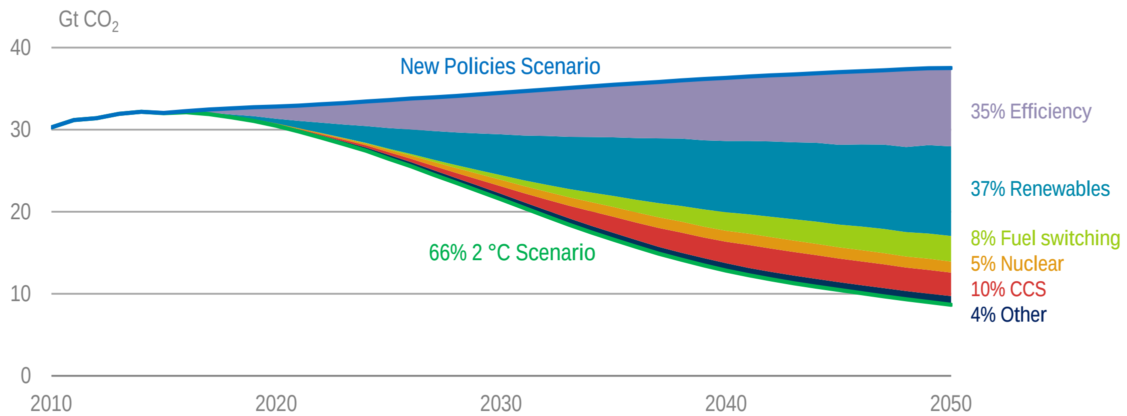
- Energy efficiency investment to achieve the targets of the 66% 2 °C Scenario requires an annual average of nearly USD 1 trillion (United States dollar) to 2050. This would typically be offset by fuel cost savings over the lifetime of most technologies, indicating an important economic benefit arising from energy efficiency in the clean energy transition. Nonetheless, across all end-use sectors, the payback period for the investment would rise over time as incremental efficiency improvements become costlier despite learning effects. In many cases, the payback period is well beyond what consumers or industries would typically accept.

Introduction

Energy efficiency is a critical enabler of the transition to a cleaner and more sustainable energy system. Two clean energy transition scenarios are analysed in this report (see Chapter 1, *Energy and emission trends to 2050*). In both, energy efficiency improves at a rapid pace to meet the outcomes that define the scenarios. The projected level of energy efficiency improvements varies somewhat between the two scenarios relative to their respective pace towards the clean energy transition. The difference is not substantial and the level of investment in energy efficiency required is similar.

In this chapter, we use the 66% 2 degree Celsius (2 °C) Scenario (i.e. the scenario with the slightly higher energy efficiency improvements among the two clean energy transition cases) to examine the energy efficiency details at the sector level. Improving energy efficiency is an essential pillar of carbon dioxide (CO_2) emissions reductions in this scenario, alongside renewable energy sources (Figure 2.1). First, we analyse the required energy efficiency improvements in the 66% 2 °C Scenario at the level of total final energy demand, followed by detail at sector and subsectoral levels. The intention is to unpack the energy efficiency levels required; to assess the associated investment needs; and to analyse the pace at which the energy efficiency investment may or may not pay back within the lifetime of individual technologies. This analysis provides the foundation to discuss in Chapter 3 the implications for policy makers and relevant stakeholders in the quest to unlock the potential of energy efficiency in a transition to a clean energy system.

Figure 2.1 Global CO_2 emissions abatement by technology and region in the 66% 2 °C Scenario relative to the New Policies Scenario, 2010-50



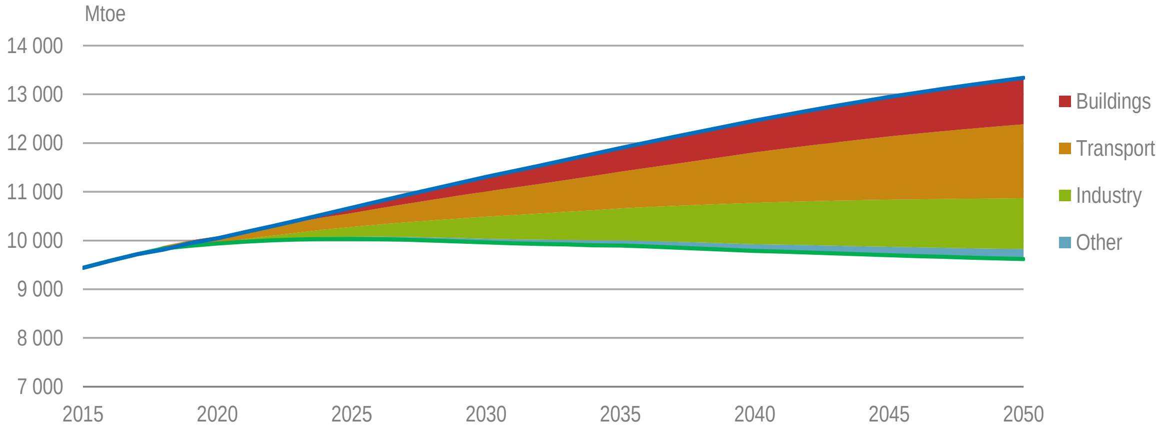
Energy efficiency is critical to achieve global emissions abatement.

Energy efficiency in the 66% 2 °C Scenario

The world's need for energy is driven by demand for energy services across the end-use sectors, mainly buildings, industry and transport. The buildings sector includes energy used in residential, commercial and institutional buildings, and is responsible for nearly one-third of final energy demand today and over half of global electricity demand. The industry sector is an important engine of economic growth and is responsible for almost 40% of final energy demand today. The transport sector includes personal as well as commercial activities by road, air, sea and rail, and today largely is fuelled by oil. Transport accounts for just below 30% of final energy demand today and almost two-thirds of direct oil use in end-use sectors.

With rising economic output and expanding population, demand for energy services from all end-use sectors is expected to continue to grow in our outlook period to 2050. These factors are expected to continue to push up demand in the buildings sector for modern energy services such as water heating, lighting, air conditioning and the electricity required by the increasing range and number of appliances and devices. The economic outlook also implies rising industrial output in monetary terms at an aggregate level, though deep structural changes in the sector are expected over the coming decades. Demand for mobility is also set to accelerate, both for individual and commercial activities, particularly in developing countries. In the New Policies Scenario, total energy consumption is significantly higher in 2050 compared with 2016; whereas energy use would decline somewhat in the 66% 2 °C Scenario (Figure 2.2). In 2050, the main driver for the differential between the two scenarios would be the large decline in energy consumption in the transport sector (1 500 million tonnes of oil equivalent [Mtoe]) in the 66% 2 °C Scenario). The industry sector would account for 1 000 Mtoe of the differential and the buildings sector for 950 Mtoe.

Figure 2.2 Savings in total final energy consumption in the 66% 2 °C Scenario relative to the New Policies Scenario



40% of the difference between the two scenarios is a result of lower energy consumption in transport.

Energy use in the buildings sector experiences a strong demand increase over the outlook period. A significant increase in residential floor area in 2050 compared with today and an increase in services value added of 150% drives up energy demand in buildings by one-third in 2050.[11] Better access to modern energy services in many parts of the developing world also contributes. Therefore, improving energy efficiency in buildings would require major efforts in terms of new policies and additional investment. In the 66% 2 °C Scenario, however, a stronger focus on efficiency efforts would be needed to counterbalance the increase in services demand. Key drivers of savings in the 66% 2 °C Scenario relative to the New Policies Scenario would include more

[11] Value added reflects the contribution of labour and capital to production. Value added by activity breaks down the total value added by sector, namely industry, services and agriculture.

efficient space heating and cooling, which are the result of both additional improvements in the average performance of building envelopes and higher average efficiency of the end-use equipment to deliver the space conditioning. A major factor in this regard would be an accelerated switch to heat pumps for space heating.

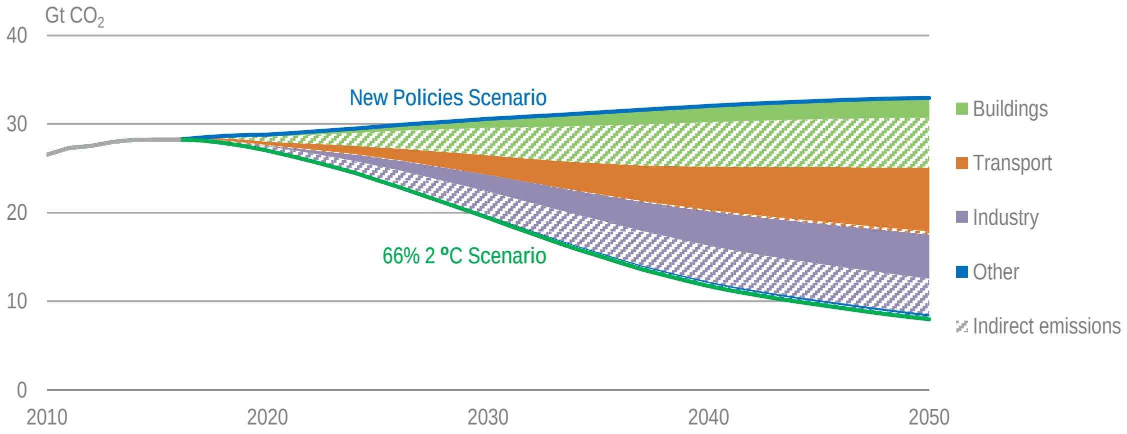
Heavy industries, such as steel and cement making, account for almost two-thirds of all energy consumption in the industrial sector. Over the outlook period, energy consumption in the New Policies Scenario is expected to increase by an average of 1.1% per year or almost 45% to over 5 000 million tonnes of oil equivalent (Mtoe) in 2050. This contrasts with the 66% 2 °C Scenario, where energy demand in industry would rise at a much lower average annual rate (almost 0.2%) or by less than 10% to 3 100 Mtoe. The key energy-intensive subsectors that would drive down energy demand in the 66% 2 °C Scenario are iron and steel and chemicals, accounting for 44% of the energy-intensive savings combined, while other energy-intensive subsectors would play a smaller part.

Oil accounts for more than 90% of energy use in the transport sector. In the outlook, rising incomes and growing trade drive demand for transport services, but there is a significant divergence between the scenarios in how this demand is satisfied. In the New Policies Scenario, oil demand in the transport sector rises by 0.5% per year on average over the period to 2050, but at a much higher rate between 2017 and 2030 compared to following years. In contrast, in the 66% 2 °C Scenario, oil demand would decline at an average rate of 3.7% per year to 2050, declining by 1.5% per year on average to 2030, but declining at a much faster rate (5.1%) thereafter as the effects energy efficiency improvements in engines and wider electrification take hold. Energy efficiency improvements in conventional internal combustion engines (ICEs) would account for two-thirds of cumulative savings over the period to 2050 most of which are in road transport.

Electricity demand increases from 21 000 terawatt-hours (TWh) in 2016 to just below 40 000 TWh in both scenarios. This similarity masks the complexity of changes in demand growth. In the New Policies Scenario, demand grows at an average annual rate of 2.1% to 2030 and slows thereafter to 1.6%, whereas in the 66% 2 °C Scenario, electricity demand growth would be maintained at an average annual rate of 1.8%. In the 66% 2 °C Scenario, electricity demand growth in industry would be slower than in the New Policies Scenario.

Attaining the CO_2 emissions reductions in the 66% 2 °C Scenario would require not only efforts to curb energy demand, but also a sea change in the way that demand is satisfied. By 2050, energy efficiency would account for more than a third of the savings and play the largest role in reducing CO_2 emissions from industry in the 66% 2 °C Scenario compared with the New Policies Scenario. Direct CO_2 emissions from the transport sector would see a large decline, to 2.7 gigatonnes (Gt) compared to 7.8 Gt today, in the 66% 2 °C Scenario (Figure 2.3). This would arise from both a steep decrease in oil demand and increased use of electricity in the transport sector. Indirect emissions would see an even larger decrease, falling to around 800 million tonnes of carbon dioxide (Mt CO_2) in 2050 from 5 500 Mt CO_2 today in the 66% 2 °C Scenario, and from 6 440 Mt CO_2 in 2050 in the New Policies Scenario. Improvements in the energy efficiency of electricity consuming end-use devices and the decarbonisation of the power sector would lower indirect emissions, although the power sector would contribute the most.

Figure 2.3 Global direct and indirect CO_2 emissions reductions by end-use sector in the 66% 2 °C Scenario relative to the New Policies Scenario



Note: Indirect emissions refer to the energy use in end-use sectors and account for the emissions associated with the upstream production of the end-use energy.

The transformation of energy demand in end-use sectors would contribute equally to direct and indirect CO_2 emissions savings.

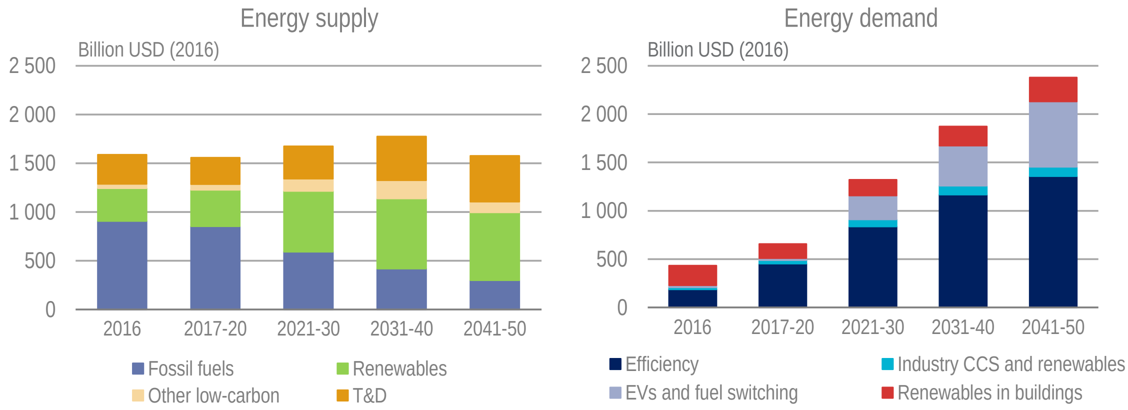
Investment in the 66% 2 °C Scenario

Chapter 1 compared the average annual investment needs to 2050 for the three scenarios. This section focuses on how the investment requirements of the 66% 2 °C scenario evolve over time.

The volume of annual supply-side investment would be broadly constant over the period to 2050 in the 66% 2 °C Scenario (Figure 2.4). There is a major shift, however, with expenditure planned for fossil fuels (including extraction and investment in fossil fuel plants without carbon capture and storage [CCS]) being reallocated to renewables and other low-carbon technologies (nuclear and CCS). In 2016, fossil fuels comprised almost 60% of supply-side investment, a share that would fall to less than 20% by 2050 in the 66% 2 °C Scenario. Indeed, by 2025, investment in renewables exceeds total investment in fossil fuels in the 66% 2 °C Scenario. The speed of this investment shift warrants consideration of whether certain energy sector assets could become economically stranded (Box 2.1).

Investment in end-use sectors would need to see an even more radical transformation over the period to 2050. Total demand-side investment in low-carbon technologies grows by a factor of almost six to around USD 2.5 trillion by 2050 in the 66% 2 °C Scenario. Demand-side investment to 2020 in the 66% 2 °C Scenario would be dominated by the need to enhance energy efficiency and to deploy low-carbon options in buildings, using technologies that are commercially available today. Between 2016 and 2020, investment into energy-efficient technologies is on average almost twice the level of 2016, and within ten years, the level of investment in energy efficiency measures exceeds the total level of spending on fossil fuel extraction in 2016. An array of policies and measures drives this boost in the 66% 2 °C Scenario, such as tighter minimum energy performance standards (MEPs) for a range of equipment, more stringent fuel-efficiency standards and a widespread push for near zero-energy buildings.

Figure 2.4 Average annual global investment in the 66% 2 °C Scenario



Note: T&D = transmission and distribution; CCS = carbon capture and storage; EVs = electric vehicles.

The level of supply-side investment would remain broadly constant, but shifts away from fossil fuels. Demand-side investment would ramp up significantly.

Facilitating the additional energy efficiency investment required in the 66% 2 °C Scenario would be an important challenge, but it would also open the door to considerable energy savings and resultant reductions in energy bills. The time required for expected financial savings to cover the additional investment cost is an important indicator of the attractiveness of energy efficiency investments to consumers. Energy efficiency investments with quick payback periods are more likely to be taken, while investments with longer payback periods are less attractive and therefore require effective policy frameworks to incentivise adoption of the most efficient technologies.

In the following sections, we take a closer look at energy efficiency requirements by end-use sector. In doing so, we calculate the payback period of a marginal improvement in the energy efficiency of the equipment sold, to encompass both the cost and benefit of energy efficiency from the consumer perspective. The payback period is the additional investment relative to a reference group of equipment, divided by the reduction in energy expenditure where expenditure is based on energy prices expected by the consumer. Payback periods are calculated for energy end-uses in buildings and by geographical region. The intention of the analysis is to put the required energy efficiency investments into the perspective of consumer benefits, thereby supporting the discussion of policy implications in Chapter 3.

Box 2.1 Stranded assets in the 66% 2 °C Scenario

Changes in government policy, market dynamics or the environment can diminish an asset's economic value as it becomes unusable or inaccessible earlier than its expected economic lifetime, meaning part of the capital invested cannot be recuperated, leading to a "stranded asset". The IEA's definition of stranded assets in the energy sector focusses on the effects of regulatory change on prior investment decisions: "the capital investment in infrastructure which ends up failing to be recovered over the operating lifetime of the asset because of reduced demand or reduced prices resulting from climate policy" (IEA, 2017a). Changes in government policy, market dynamics or the environment can diminish an asset's economic value as it becomes unusable or inaccessible earlier than expected.

One of the frequently discussed implications of ambitious climate policy is supply-side stranded assets. There is particular interest in the extent of fossil-fuel reserves that may not ultimately be produced. Here, however, it is important to distinguish between the full extent of fossil-fuel reserves that are left unexploited as a result of climate policy ("unburnable" fossil fuels) and the investment that is lost as a result. We estimate that the transition implied by the 66% 2 °C scenario would amount to stranded assets of around USD 400 billion from sunk costs in undeveloped oil reserves and USD 120 billion in undeveloped natural gas reserves, a small proportion relative to the total cumulative investments of USD 7.3 trillion in oil and USD 7.5 trillion in gas to 2050. These numbers are smaller than some other estimates, because we do not consider the value of the reserves themselves as potential stranded assets, only the exploration investment capital that is not recuperated (IEA, 2017a). Asset stranding from policy changes can also occur for transformation technologies dependent on fossil-fuel inputs, such as coal- or gas-fired power plants, part of an estimated USD 320 billion in stranded power sector assets in the 66% 2 °C Scenario. This totals about 12% of the USD 2.8 trillion cumulative investment in fossil-fuel generation to 2050. Most of the stranded assets are coal-fired plants as gas-fired plants continue to play an important role in helping to balance the high levels of variable renewables present in this scenario (IEA, 2017a).

More recently, the literature has started to explore whether stranded assets could also exist on the demand side. Buildings, vehicles and industrial machines could lose value because of sudden regulatory changes such as the implementation of very stringent new energy efficiency standards. This loss in the future revenue generated by an asset or asset owner or a reduction in the "remaining book value" of assets as a result of climate policy is an important factor to help understand the potential impacts of the low-carbon transition. However it is important to recognise that this is a distinct consideration from stranded assets as defined above. Another policy or economic risk is created by locked-in emissions, for example from buildings and transport. While locked-in emissions from the demand side are low compared to the supply side they nonetheless account for a reasonably large share in some regions. Previous IEA analysis estimated that the share of locked-in emissions from transport (9%) and buildings (6%) is relatively low, as the bulk of the energy consuming infrastructure in these sectors typically does not remain operational for more than around 15 years (IEA, 2013). In the United States, the transport sector was estimated to have a relatively high share (18%) of total locked-in emissions, since transport is responsible for a relatively high proportion of overall energy-related CO_2 emissions. Buildings accounted for 15% of locked-in emissions in the European Union, the highest share of all regions, owing to the importance of space heating in Europe's energy systems.

A further confusion often exists between "stranded assets" and the cost of decarbonising a particular sector or sub-sector. In the buildings sector, for example, the cost of paying for an upgrade to a building as a result of new building energy codes (such as mandated retrofits of least-efficient buildings before sale) is the capital cost of decarbonising a building, but does not create a stranded asset. In fact, such investments could reduce overall running costs, particularly if they lead to improved energy efficiency. A genuine stranded asset in the buildings sector could be imagined in cases where a retrofit is carried out but then needs to be carried out again at a higher level of efficiency because of an increase in climate policy ambition. This is difficult to quantify, but is avoided by early and clear policy signals such as those included in the 66% 2 °C Scenario.

In the transport sector, exclusions of diesel or gasoline vehicles from urban areas, either due to air pollution or fuel efficiency could impact the resale value of affected vehicles. One example of devaluation came after the government of the United Kingdom announced in July 2017 that sales of diesel vehicles would be banned by 2040 and popular diesel models lost around 6% in value between the first- and third- quarters of the year. However, this would again not be a stranded asset as defined above as the cars can continue to be used until the end of their economic lifetimes. In the 66% 2 °C Scenario, because the policies are known well in advance and because the economic lifetime of a car is generally quite short, stranded assets of vehicles themselves would be limited.

Forced early replacement of industrial equipment could in some cases be considered a stranded asset, including in the automotive sector. Vehicle manufacturing companies may see significant losses as the growing trends of automation, electrification and ride-sharing – trends which are not driven by climate considerations alone – combine to disrupt the industry due to lower demand for vehicles (as automated vehicles may have much higher utilisation rates than conventional cars). There are comparable cases of manufacturing machinery becoming "stranded" in the face of disruptive technology or regulatory shifts unrelated to climate policy. For example, recent estimates for the European automotive manufacturing sector suggest that up to EUR 163 billion (Euro) of property, plant and equipment, EUR 56 billion of capitalised research and development and further elements of production capability could be at risk in the event of a barrage of simultaneous disruptions, and assuming no other sales were possible (SEI, 2017). However, stranded assets in conventional vehicle manufacturing equipment may be tempered by manufacturers' ability to continue selling cars in areas of the world that remain unregulated. Further, efficiency or climate regulations are just one part of the shifting market and regulatory environment that influence investment decisions on industrial plant renewal, and are unlikely to be the key driver leading to investment capital in industrial production capacity not being fully recuperated.

Nevertheless, policy makers need to be aware of the potential impacts on asset values and to address the distributional impacts of climate-related regulations. In general, steady, long-term price signals allow consumers more time to adapt to a changing system and moderate the changes in assets' market value. Aligning short-term manufacturing and construction with long-term climate policy goals will minimise the risk of stranded assets, emissions lock-in and major reductions in asset values.

Energy efficiency in buildings

The direct combustion of fossil fuels meets 36% of energy demand in the buildings sector, resulting in direct CO_2 emissions of more than 2.9 Gt. Direct emissions represent only 35% of the sector's total emissions, however, while the generation of electricity and heat used in buildings resulted in more than 5.5 Gt of CO_2 emissions in 2016.

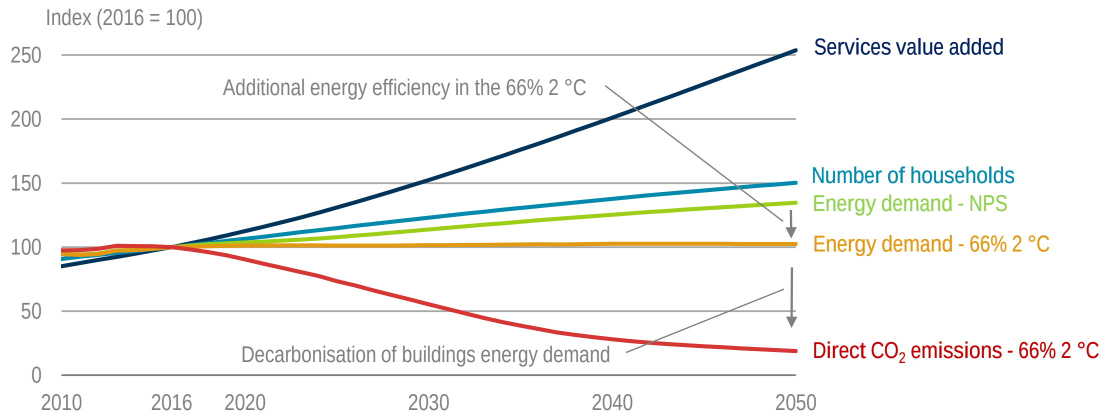
Population expansion and economic growth are the major underlying drivers of energy demand growth in the buildings sector. With the global population expected to reach around 9.7 billion by 2050 and gross domestic product (GDP) expected to nearly triple, demand for energy services in buildings increases rapidly. Through to 2050, the number of households is expected to increase by 50%, with residential floor area on a worldwide basis increasing even faster as average household size increases (Figure 2.5). Energy demand in services buildings (i.e. commercial and institutional buildings) is closely linked to the economic value added by the sector, and this is projected to increase to more than two-and-a-half times today's value by 2050, thereby driving energy demand growth. Increasing energy efficiency is central to decoupling energy demand growth from increases in sectoral value added and floor area.

The buildings sector is a major reservoir of energy efficiency potential: the ambitious pursuit of this potential in the 66% 2 °C Scenario would represent a dramatic break from the sector's energy demand trajectory in the New Policies Scenario. Despite energy efficiency efforts in the New Policies Scenario (that mirror current policy intentions), the increase in the number of households worldwide and in services value added drives up the buildings sector's energy demand from 3 000 Mtoe today to over 4 000 Mtoe in 2050. In the 66% 2 °C Scenario, however, the impact of additional energy efficiency efforts would be sufficient to almost completely offset the increases in services demand (Figure 2.5). Buildings sector energy demand in the 66% 2 °C Scenario is flat over the period at just over 3 000 Mtoe in 2050. By 2050, the cumulative energy savings in the

66% 2 °C Scenario, relative to the New Policies Scenario, would total around 15 800 Mtoe, equivalent to more than five-times the energy consumption of the buildings sector today.

Certain end-uses would contribute the bulk of savings relative to the New Policies Scenario. In particular, furthering the efficiency of space heating would contribute to more than one-third of the energy savings in 2050. Given demand growth projections of around 2.6% per year in the New Policies Scenario, improving the energy efficiency to meet cooling needs would play a major role in reducing energy demand in the 66% 2 °C Scenario, contributing almost one-quarter to total savings relative to the New Policies Scenario.

Figure 2.5 Decoupling of energy demand and CO_2 emissions from key drivers of demand growth in the buildings sector in the New Policies and 66% 2 °C Scenarios

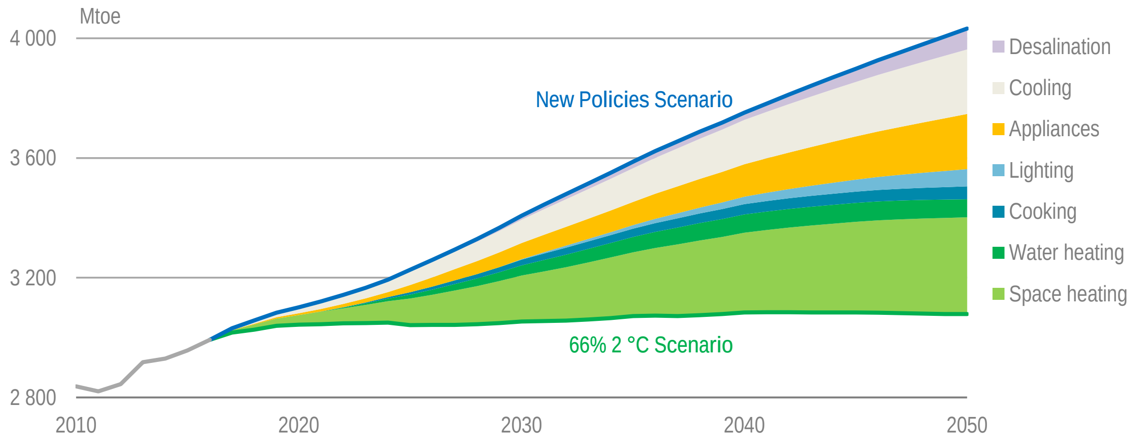


Additional energy efficiency in the 66% 2 °C Scenario would halt energy demand growth, despite a major increase in the demand for energy services in the buildings sector.

Savings in space heating and cooling energy demand would be a result of additional improvements in the average performance of building envelopes and more energy-efficient equipment. Universal adoption of mandatory and stringent building energy codes for new residential and services buildings would improve building envelope performance and provide the most significant difference in the 66% 2 °C Scenario relative to the New Policies Scenario. Appropriate building codes would facilitate wide deployment of efficiency measures for building envelopes such as insulation, improved glazing and solar passive design. As a result, 40% of residences built in the period to 2050 would be near zero-energy buildings (NZEB) meeting the strictest standards in terms of energy consumption for space heating and cooling as well as other end-uses. Moving to NZEBs is especially challenging in emerging economies where half of the world's new residences will be built in the coming 20 years. By 2050, the global share of NZEBs in new construction would reach at least 65% in the 66% 2 °C Scenario, while in many advanced economies it would be closer to 100%. (In addition to building material and equipment solutions, further digitalization of building energy use via electronic devices and home energy management systems would facilitate energy savings, though they are not included in our analysis.)

In order to achieve such ambitious reductions in energy demand for space heating and cooling, however, it would not be sufficient just to improve building envelopes in new construction. This is especially the case for space heating given the relatively slow turnover of building stock in countries with high space heating demand. The 66% 2 °C Scenario would see major efforts to rapidly improve the energy efficiency of existing buildings with measures to drive widespread deep retrofits across the entire building stock by 2050 to drastically reduce energy demand.

Figure 2.6 Avoided global energy demand by end-use in the buildings sector in the 66% 2 °C Scenario relative to the New Policies Scenario



Improving the energy efficiency of space heating and cooling would provide more than half of the incremental energy savings in the 66% 2 °C Scenario.

In addition to major improvements in building envelope performance, the 66% 2 °C Scenario would require an accelerated switch to heat pumps for space heating. Wide use of heat pumps would reduce energy demand for space heating by 25% in 2050 from current levels and 330 Mtoe compared with the New Policies Scenario (Figure 2.6). A switch to more efficient heat pumps for cooling would also play a major role in mitigating demand growth, with energy demand for cooling some 220 Mtoe lower than in the New Policies Scenario. Household and commercial appliances, such as refrigerators, washers, dryers, televisions and computers, would also contribute to lower electricity demand in the 66% 2 °C Scenario as MEPs and other policy measures incentivise accelerated adoption of the best available end-use technologies. By 2050, global electricity demand for appliances in the 66% 2 °C Scenario would be nearly 2 200 TWh less than in the New Policies Scenario, as the energy intensity of new appliances would drop considerably relative to today. Despite this improvement, electricity demand for appliances is 2 500 TWh higher than today owing to major increases in appliance ownership.

Enhanced energy efficiency in the 66% 2 °C Scenario would allow the energy intensity of buildings in both the residential and services subsectors to decline over the projection period. By 2050, the energy intensity of residential buildings per unit of floor area would decrease by 40% relative to today. The energy intensity of buildings in the services subsector, measured per unit of sectoral value added, would drop by more than 50% by 2050. Both represent a major improvement relative to the New Policies Scenario (Table 2.1). The aggressiveness of energy efficiency improvement in the 66% 2 °C Scenario would enable energy intensity to be reduced despite a major increase in the cooled floor area as millions of households in the developing world install air conditioners. This is in contrast to the New Policies Scenario, where the rate of increase in cooled floor area would outpace energy efficiency, causing an increase in the space cooling energy intensity of new buildings. This is also the case for refrigeration, cleaning and brown goods such as televisions and computers. The global average energy intensity of new equipment for these end-uses (measured in kilowatt-hours per average appliance per year) increases in the New Policies Scenario for two reasons: first, key developing markets with less stringent energy efficiency standards, and therefore less efficient technologies on the market, grow to represent a more important share of global sales; and second, households upgrade to larger, more energy consuming appliances. A common thread between the two scenarios is improved energy intensity of lighting in new buildings; thanks to the rapid decrease in the cost of light-emitting diodes (LEDs), they see widespread adoption without major additional policy support.

Table 2.1 Global energy efficiency indicators in the buildings sector by scenario

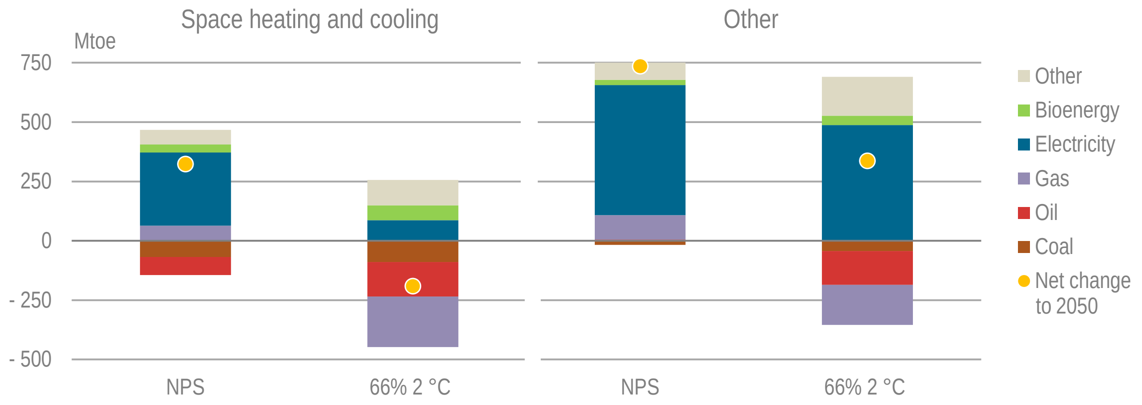
	2016	2050 New Policies Scenario	2050 66% 2 °C Scenario
Residential buildings average energy intensity (kWh/m^2)	88	75	52
End-use energy intensity in new residential buildings (index 2016 = 100)			
Space heating	100	26	13
Space cooling	100	164	31
Lighting	100	21	21
Water heating	100	74	55
Refrigeration	100	148	76
Cleaning	100	145	93
Brown goods	100	133	49
Services subsector average energy intensity of value added (kWh/USD 1 000)	198	123	93

Notes: kWh/m^2 = kilowatt-hour per square metre; kWh/USD 1 000 = kilowatt-hour per USD 1 000. Indexed end-use energy intensity for new residential buildings is expressed per unit of floor area for space heating/cooling and lighting; per person for water heating; and per average appliance for refrigeration, cleaning and brown goods (i.e. televisions, computers and home audio equipment).

Improving the energy efficiency of the global buildings sector in the 66% 2 °C Scenario would lead to major changes in the fuel mix used to meet the demand for energy services. The accelerated adoption of electric heat pumps for space and water heating, and the electrification of cooking, would lead to dramatic decreases in the use of fossil fuels in buildings. There would be an almost complete phase out of coal consumption with demand falling from around 130 Mtoe in 2016 to less than 2 Mtoe in 2050. In addition, the use of oil would decline by an annual average of 6.8%, dropping under 30 Mtoe by 2050, over 200 Mtoe lower than in the New Policies Scenario. Natural gas demand would decrease by more than 50% relative to today and by 2050, gas demand would be less than one-third of that in the New Policies Scenario.

Switching from fossil fuels to electric heat pumps for space and water heating would have an evident impact on electricity demand; even with major improvements in the efficiency of electric heating in the 66% 2 °C Scenario, electricity demand for these end-uses would be slightly higher in the 66% 2 °C Scenario than in the New Policies Scenario (Figure 2.7). The use of renewables, such as solar thermal, for heating would also increase markedly in the 66% 2 °C Scenario. For end-uses other than space heat or cooling, electricity is the dominant energy source. The shift away from fossil fuels for cooking and water heating would see a significant decrease in demand for oil and gas in the 66% 2 °C Scenario relative to today. Increased efficiency of appliances and cooling equipment would see electricity demand for these end-uses fall by a third, relative to the New Policies Scenario, while this would be partially offset by higher electricity demand for cooking of around 170 Mtoe in the 66% 2 °C Scenario in 2050.

Figure 2.7 Change in global energy demand in the buildings sector by main end-use and fuel, 2016-50



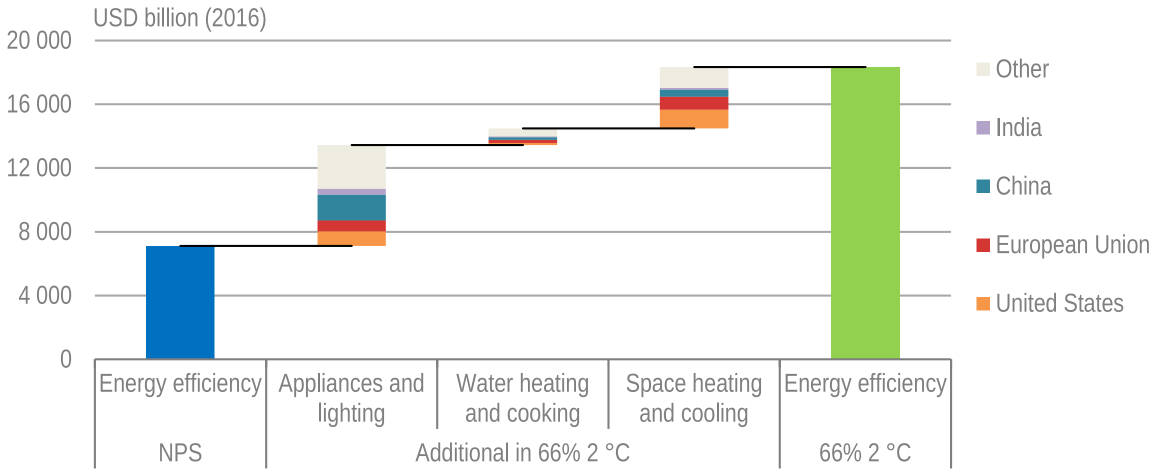
Enhanced energy efficiency would have the largest impact on oil and gas demand in the buildings sector. Increased electrification would offset some of the energy efficiency gains for electricity.

The divergence in trajectories between the New Policies Scenario and the 66% 2 °C Scenario would be even starker for CO_2 emissions. By 2050, total CO_2 emissions in the buildings sector in the 66% 2 °C Scenario would be less than one-fifth of emissions in the New Policies Scenario. Demand for all fossil fuels would decrease, driving down direct CO_2 emissions in the sector to around 25% of today's emissions. This means that by 2050, direct emissions of CO_2 in the 66% 2 °C Scenario would be around 775 Mt CO_2, compared to just over 3 000 Mt CO_2 in the New Policies Scenario. Although the switch to direct renewables such as solar, geothermal and modern biomass would contribute to lower direct CO_2 emissions, the main driver would be the additional energy efficiency in the 66% 2 °C Scenario.

Indirect emissions would see an even larger decrease, falling to around 800 Mt CO_2 in 2050 from 5 500 Mt CO_2 today, compared with 6 440 Mt CO_2 in 2050 in the New Policies Scenario. Both efficiency improvements in electric end-use devices and decarbonisation of the power sector would lower indirect emissions, although the impact of additional energy efficiency on indirect emissions would be partially offset by the increasing electrification of end-uses. As a result, global electricity demand in the buildings sector in the 66% 2 °C Scenario would be only 15% (300 Mtoe) lower than in the New Policies Scenario in 2050. Yet, lower demand would reduce indirect emissions by around 15%, while progress to decarbonise the power sector would contribute to the remainder of the decrease in indirect emissions relative to the New Policies Scenario in 2050.

Achieving the additional energy efficiency in the buildings sector in the 66% 2 °C Scenario would require an increase in investment of USD 11 trillion over the period 2017-50 (Figure 2.8). This would represent nearly 50% of total additional investment in energy efficiency across all end-use sectors. The largest share of additional energy efficiency-related investment in would be in appliances and lighting. Efforts to move towards the best available technologies, such as refrigerators with vacuum insulation, would require average annual investment of USD 190 billion. The important share of appliances and lighting would also be a result of the expected dramatic increase in the number of appliances being taken up over the outlook period, and the costs associated with ensuring that the average efficiency of appliances would be converging towards international best practice in all markets.

Figure 2.8 Additional average annual energy efficiency investment in buildings by end-use in the 66% 2 °C Scenario relative to the New Policies Scenario, 2017-50



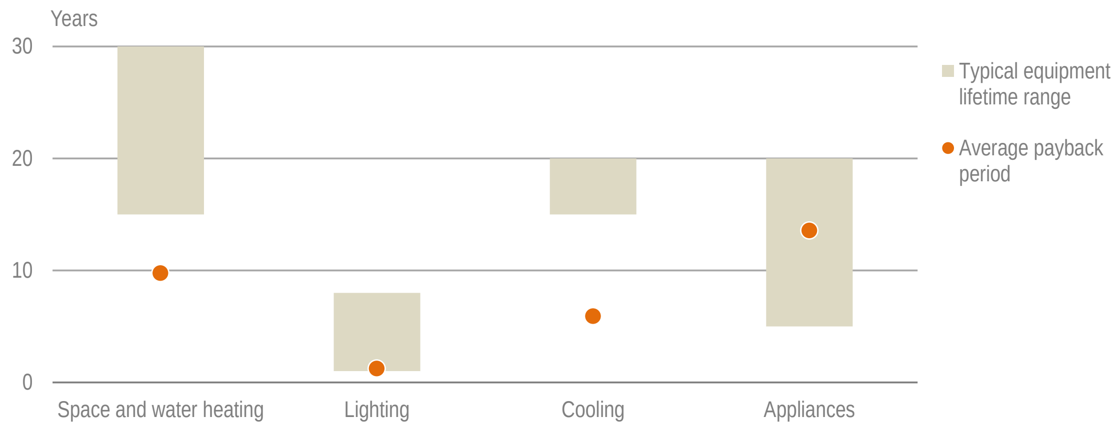
The largest share of additional investment in energy efficiency for buildings would be in appliances and lighting.

Increasing the energy efficiency of space heating and cooling would require additional investment in both building envelope performance and more efficient equipment. Owing to the importance of space heating needs in advanced economies, such as the United States and the European Union, as well as the costs involved with retrofitting the existing building stock, additional investment in the 66% 2 °C Scenario would be more significant in these regions. Improving the insulation of new and existing buildings would represent around 35% of the cumulative additional investment in space heating and cooling in the 66% 2 °C Scenario, with the remaining 65% directed towards more efficient equipment, such as heat pumps. Water heating and cooking would make up the smallest share of the additional investment required in the 66% 2 °C Scenario reflecting their lower energy demand profile and efficiency improvements embedded in the existing policies and measures of the New Policies Scenario.

Decisions to invest in energy-efficient materials, devices and practices are often based on an expectation of reducing energy costs. Our analysis indicates that the average payback period for more efficient space and water heating, and space cooling equipment would be between five to ten years in the 66% 2 °C Scenario, well below the range of the typical lifetime for such equipment (Figure 2.9). Payback periods for improving the efficiency of space heating have significant regional variations; unsurprisingly, they would be lowest for regions with high heating demands and high energy prices. Payback periods for more efficient space cooling equipment are lower than for space heating, underlining that shifting to the best available heat pump-based cooling equipment is economically attractive in almost all markets.

For appliances, moving to the most efficient technologies can often require a significant additional investment which increases the payback period. Taking refrigerators as an example, units with an A++ efficiency rating already represent an important share of sales in markets such as Europe, while A+++ appliances, such as vacuum cavity insulated refrigerators, are not yet cost effective in many markets. Shifting to the most efficient technologies, as projected in the 66% 2 °C Scenario, therefore may require a step up in investment, though the average payback period is less than the lifetime of the most efficient equipment for most types of appliances. Lighting presents a contrasting example; rapid declines in the cost of LEDs in recent years have seen the payback period fall dramatically, while the longer lifetime of LEDs ensures that adopting the most efficient technology is the most economically attractive option in all regions.

Figure 2.9 Average payback times of energy efficiency investment in buildings and range of typical lifetimes by category in the 66% 2 °C Scenario, 2030



Average payback periods for more efficient technologies would typically be less than the expected lifetime of the equipment.

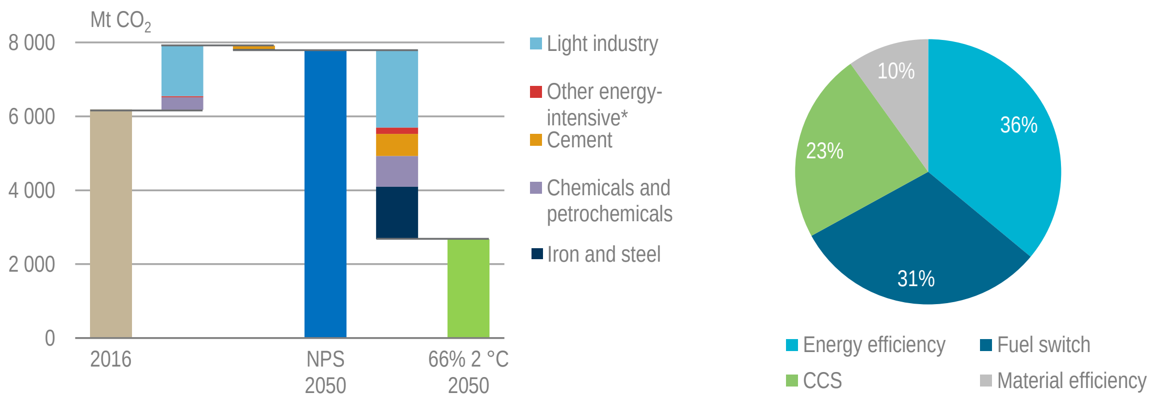
Existing energy efficiency policy frameworks in many countries with high space heating demand, combined with low payback periods, could facilitate near-term improvements in the energy efficiency of space heating in the 66% 2 °C Scenario. In the 2020s, the share of heat pumps in worldwide sales of space-heating equipment would expand as they move towards becoming the dominant technology. For space cooling, low payback periods would see a rapid transition towards more efficient equipment beginning in the 2020s, led by emerging economies. The low payback periods for efficient lighting would drive improvements in lighting energy efficiency as the share of LEDs in global lighting sales rises to 100% in almost all regions by 2040 in the 66% 2 ˚C Scenario.

Energy efficiency in industry

With projected growth in economic activity, its capital intensive and energy intensive nature, particularly in primary manufacturing with processes reliant on fossil fuels, the industry sector faces steep challenges to decarbonise. To meet the ambition of the 66% 2 °C Scenario, a wide range of low-carbon technologies and processes would need to be adopted at a faster pace and larger scale than seen to date.

Energy efficiency gains would play the largest role in reducing CO_2 emissions from the industry sector worldwide in the 66% 2 °C Scenario relative to the New Policies Scenario, complemented by more shifts to low-carbon fuels (mostly bioenergy, direct heat from renewables and decarbonised electricity supply), CCS and material efficiency (Figure 2.10). Material efficiency, or delivering the same level of material service with less overall use of materials, is closely linked with energy efficiency. Greater material efficiency would, for instance, contribute to the stabilisation of CO_2 emissions from primary steel and cement production to 2050 (Box 2.2).

Figure 2.10 Global industry sector direct CO_2 emissions by subsector and scenario, and factors contributing to cumulative abatements in the 66% 2 °C Scenario, 2016-50



* Other energy-intensive industries include the aluminium and the pulp and paper subsectors.

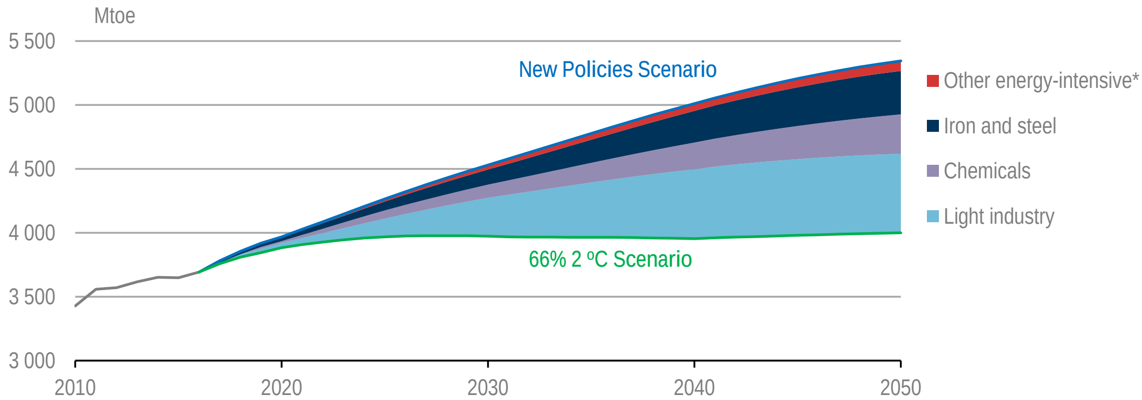
Notes: NPS = New Policies Scenario; 66% 2 °C = 66% 2 °C Scenario. Direct CO_2 emissions are from fuel combustion in the industry sector, including emissions from blast furnaces and coke ovens.

Energy efficiency is key to reducing industrial CO_2 emissions, in particular from non-energy intensive industries.

In the 66% 2 °C Scenario, the introduction of new policies and significant technology deployment would reduce CO_2 emissions from fuel combustion in industry by two-thirds in 2050 compared with the New Policies Scenario, and by more than half compared with today's levels (Figure 2.10). Cumulatively, 90 Gt of direct CO_2 emissions would be saved in the industry sector in the 66% 2 °C Scenario, representing 17% of the total effort at the global level, the third-largest contributing sector to global CO_2 emissions abatement after the power sector and transport. The share of energy-intensive industries in total industrial emissions would decrease, from two-thirds today to 50% in 2050, mainly as a result of a sharp decline in emissions from the iron and steel and the cement subsectors. CO_2 emissions abatement in 2050 in non-energy intensive industries would be on the same order of magnitude as in energy-intensive sub-sectors, relative to the New Policies Scenario. Nevertheless, as industrial output grows faster in non-energy intensive industries, CO_2 emissions from these subsectors would fall by around one-third by 2050 compared to today, one-quarter the reduction from energy-intensive subsectors in the 66% 2 °C Scenario. Compared with the New Policies Scenario, non-energy intensive industries would represent half of the energy demand savings through 2050 in the 66% 2 °C Scenario (Figure 2.11).

Key energy-intensive subsectors driving down energy demand would be iron and steel (one-quarter of the total savings by 2050) and chemicals (one-fifth), while other energy-intensive subsectors (aluminium, pulp and paper, and cement) would play a much smaller role. In the 66% 2 °C Scenario, global industrial energy demand would stabilise at a level close to 4 000 Mtoe from the mid-2020s to 2050, following a period of growth to then (the lead time necessary to trigger the required energy efficiency-related investment). This trend contrasts with the New Policies Scenario where industrial energy use continues to rise by more than 1% per year on average through to 2050.

Figure 2.11 Avoided global energy demand by industry subsector in the 66% 2 °C Scenario relative to the New Policies Scenario



*Includes cement, aluminium, and pulp and paper

Additional energy demand savings in the 66% 2 °C Scenario would be almost evenly split between energy-intensive and non-energy intensive subsectors.

At the sectoral level, and without considering the energy penalty associated with CCS deployment in some energy-intensive subsectors, energy intensity expressed per unit of industrial output would decrease by more than 40% by 2050 in the 66% 2 °C Scenario, driven by highly demanding mandatory energy efficiency standards (Table 2.2). This would be significantly more than the level reached in the New Policies Scenario in which most industry branches barely reach a 20% improvement of their energy intensity by 2050. The large-scale and rapid deployment of efficient technologies and processes allowing such improvement would be spurred by even more stringent mandatory MEPs than in the New Policies Scenario, as well as supporting measures for systematic implementation of energy management systems. Under these ambitious assumptions, the global industry sector would reach a 50% improvement in aggregate energy intensity by 2050 compared to 2016. This would be 15 percentage points more than in the New Policies Scenario.

The important contribution of light industries to overall sector energy savings in the 66% 2 °C Scenario would be supported by wider deployment of fuel and electricity efficient technologies and processes in all types of industrial activities. These include efficient boilers and furnaces, improved heat exchangers, heat recovery, improved insulation, among many others. In addition, cross-cutting efficiency measures would also provide benefits, most notably in the small industries.

Table 2.2 Global energy efficiency indicators in industry by scenario

	2016	2050 New Policies Scenario	2050 66% 2 °C Scenario
Aggregate industrial energy intensity (toe/USD 1 million)	174.4	115.1	88.2
Subsector energy intensity (index 2016 = 100)			
*Iron and steel**	100	83	60
Cement	100	88	82
*Chemicals and petrochemicals***	100	88	74
Aluminium	100	70	59
Pulp and paper	100	84	59
Light industry	100	79	59
End-use conversion efficiency (index 2016 = 100)			
Average industrial electric motor systems	100	120	148
Average industrial heat generation	100	106	128

* *Iron and steel* index includes blast furnaces and coke ovens.

** *Chemicals* and *petrochemicals* index excludes feedstock use.

Notes: Indexed energy intensity is expressed per tonne of output for each subsector except light industry, for which the sum of all other industry subsectors' value added in constant USD 2016 in market exchange rate terms is used instead of physical production. Output for chemicals and petrochemicals refers to the sum of basic chemicals production in tonnes, including ethylene, propylene, aromatics, ammonia and methanol. Subsectoral indicators exclude the energy penalty associated with the use of CCS, while the aggregate energy intensity considers all industrial energy consumption.

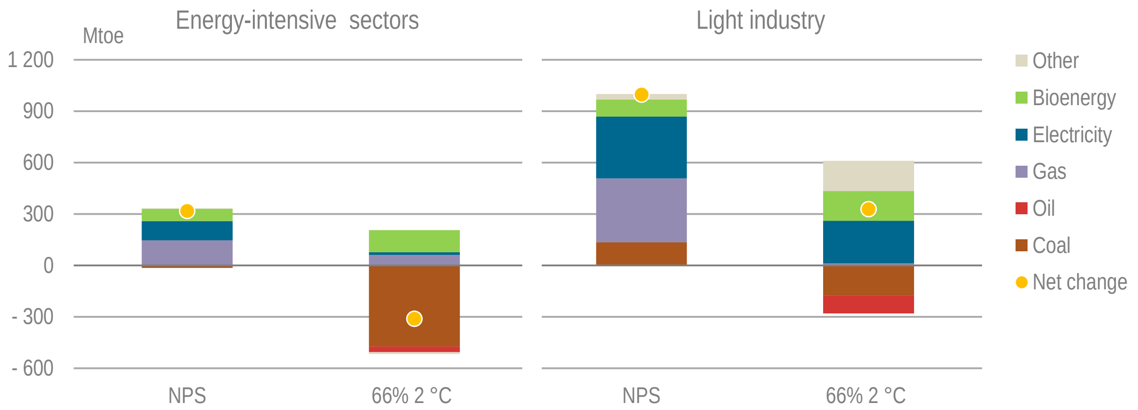
Among the electrification options, the large-scale deployment of heat pumps in the 66% 2 °C Scenario would deliver large fuel savings at the final energy demand level, but also at the primary energy demand level despite increased electricity demand.

Heat pumps would displace 500 Mtoe of fuel in light industries by 2050, while they would boost electricity demand by about 1 600 TWh, more than the total electricity generation in India today. Overall, with the additional deployment of heat pumps in the pulp and paper, chemicals and petrochemicals sub-sectors (which require significant amounts of low-temperature process heat), the global average industrial heat supply efficiency would exceed 100% in 2050, an increase of about 25% of the average heat supply efficiency above today's level. The share of industrial heat from electricity worldwide would approximately triple to 2050 from today's level.

Further deployment of efficient electric motor systems would contribute 2 700 TWh of electricity savings in 2050, compared with the New Policies Scenario. The expected growth in electricity use for motors over the outlook period would be almost halved in the 66% 2 °C Scenario relative to the New Policies Scenario, to about 1% per year on average through 2050. To reach this level of efficiency improvement, most advanced economies and China would adopt motor efficiency standards at IE4 level by 2025 and all other regions would reach that level by 2030 or 2035 at the latest.[12] Further adoption of variable speed drives and efficiency improvements of end-use devices would unlock even larger savings in electric motor systems that pay back quickly. Taking an extended system approach and adopting other system-wide efficiency measures would contribute to improving overall efficiency of industrial motor systems by almost 50% by 2050.

Electricity savings would only partially be offset by additional electrification of heat demand and further electricity use for CCS in the 66% 2 °C Scenario: net industrial electricity demand would be about 2 400 TWh below the level in the New Policies Scenario in 2050. More than half of these net savings would occur in non-energy intensive industry (Figure 2.12). The additional use of bioenergy in the 66% 2 °C Scenario would also be relatively evenly spread between the energy-intensive and the light industries. Conversely, 90% of the increase in other direct renewables would be in light industries such as food processing and textiles, where 50% of the heat demand is at low-temperature (i.e. below 100 °C) and therefore has the highest substitution potential for solar thermal or geothermal heat.[13]

Figure 2.12 Change in global industrial energy demand by subsector, fuel and scenario, 2016-50



Notes: NPS = New Policies Scenario; 66% 2 °C = 66% 2 °C Scenario.

The biggest decrease in coal use would be in energy-intensive sub-sectors and the biggest boost in gas demand would be in the light industry subsectors in comparing the 66% 2 °C and the New Policies scenarios in 2050.

Energy-intensive subsectors would also contribute a large share of energy savings in the 66% 2 °C Scenario. More than 60% of both coal and oil savings in industry in 2050 would occur in these industry subsectors, compared with less than 20% for natural gas. The low-carbon transformation of the industrial sector would be encouraged by carbon prices, alongside targeted measures to reduce the carbon footprint of industrial activities. In this context, switching from coal to gas would represent an opportunity for emissions reduction in the most energy- and carbon-intensive industrial activities, whereas this is much less relevant for light industry.

[12] IE4 refers to an International Electrotechnical Commission standard. For more information on energy implications for electric motor systems, see the WEO-2016 section on motor efficiency (IEA, 2016a).
[13] For more information about trends and opportunities for efficient supply of clean industrial heat, refer to Chapter 7 of *WEO 2017* (IEA, 2017b) and to the published commentary on the IEA website on "Clean and efficient heat for industry" (www.iea.org/newsroom/news/2018/january/commentary-clean-and-efficient-heat-for-industry.html).

The iron and steel subsector would be the largest contributor, with almost half the total savings and two-thirds of the coal savings by 2050, from energy-intensive industries in the 66% 2 °C Scenario relative to the New Policies Scenario. The improvement of energy intensity in global steel production would result from the deployment of secondary steel production routes and energy-efficient technologies and processes in all process routes. The share of global steel output produced from electric arc furnaces, based on availability of recycled scrap (through improved collection, segregation and processing) and further deployment of direct reduced iron, would rise above 50% in 2050 in the 66% 2 °C Scenario, more than doubling its current contribution. This shift alone would lead to savings of around 60 Mtoe of final energy use compared with the New Policies Scenario, with a limited increase in electricity demand in 2050.

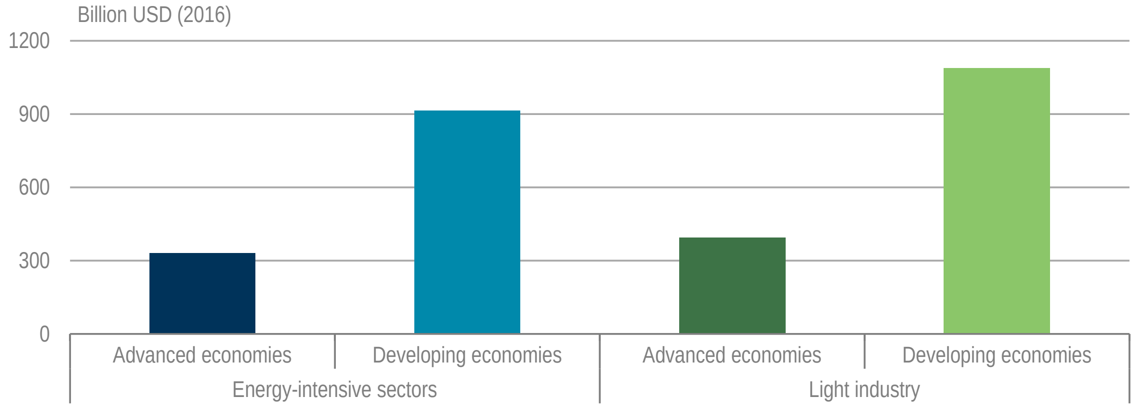
In the chemical and petrochemical industries, a portion of the energy savings in the 66% 2 °C Scenario would be the result of increased electrification of low-temperature heat demand, representing more than 10% of the sectoral heat demand today, and the increased efficiency of electric motor systems. Better process integration would also lower energy intensity in steam cracking, methanol and ammonia production, as well as in other petrochemical processes. The implementation of material efficiency strategies through increased recycling and light-weighting of final products would also lead to reduced energy use, as output of primary chemical products would decrease by about 5% to 15% by 2050.

Cumulative energy efficiency investments reach about USD 1.6 trillion in the New Policies Scenario, or around USD 50 billion annually by 2050, while investment requirements would grow to about USD 4.3 trillion dollars in the 66% 2 °C Scenario or almost USD 130 billion annually (Figure 2.13). These two scenarios follow similar patterns: investments necessary in light industries are higher than those directed to the energy-intensive sectors (in the range of 20-25% higher in both scenarios), and investments required in developing economies are almost three-times higher than in advanced economies. China would by some distance be the largest contributor to the additional investment needs in the 66% 2 °C Scenario, more than the United States and the European Union combined. However, the share of China in global energy efficiency investment in industry would be lower in the 66% 2 °C Scenario (one-quarter of the total) than in the New Policies Scenario (one-third), as other emerging and transition economies have more incremental efforts to realise.[14]

The key challenge of reaching very high levels of energy efficiency in the industry sector is maximising the diffusion of energy-efficient technologies and processes. The 66% 2 °C Scenario assumes two main channels for doing so. The first is removal of all non-economic barriers to the deployment of energy efficiency within the sector. The second is enabling industrial actors to accept longer payback periods for energy efficiency-related investments, up to the design economic lifetime of equipment (typically about 20 years), by implementing relevant policies (see Chapter 3). Under these assumptions, the vast majority of the identified energy efficiency opportunities would be adopted in the 66% 2 °C Scenario.

[14] China makes a strong push on energy efficiency in the New Policies Scenario, owing to recent policy developments. See our recent China Energy Outlook in the *WEO-2017* (IEA, 2017b).

Figure 2.13 Additional industrial energy efficiency investment in the 66% 2 °C Scenario relative to the New Policies Scenario, 2017-50



Both heavy and light industries in developing economies would require almost three times more investment in energy efficiency than advanced economies.

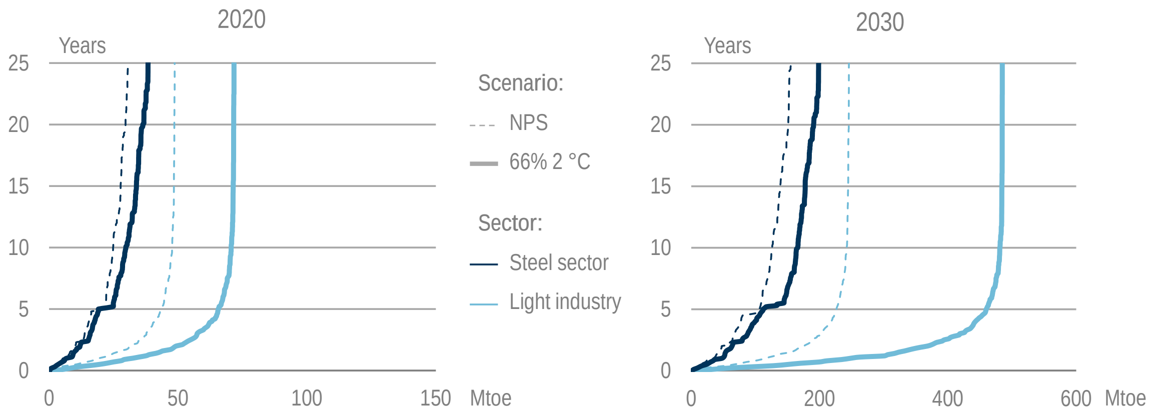
The relation between the payback periods of energy efficiency investment and the diffusion of efficient technologies is presented in Figure 2.14 for two key industrial sectors.[15] The average payback period of energy-efficient technologies and processes appears lower in less energy-intensive industries compared to the iron and steel industry: typically, more than 80% of energy-efficient technologies have a payback below three years in the less energy-intensive industries, compared with no more than 50% in the steel sub-sector. The large share of fuels and electricity in production cost structure for heavy industries, reaching typically around 40% for energy-intensive industrial products such as aluminium, and up to 80% for raw chemical products, plays an important role in triggering energy efficiency investments. Conversely, light industry generally places less focus on optimising energy use, as energy usually represents no more than 3% of the total production costs. Energy efficiency is not as crucial a factor in competitiveness in these sectors, leaving untapped large potentials that offer short payback periods (WIIW, 2015).

The comparison between the New Policies and 66% 2 °C scenarios indicates that while energy efficiency deployment in the industry sector is linked to the pace at which the required investment pays back, the broader economic context can play a significant role in unlocking energy efficiency potential. Constraints to the adoption of new energy-efficient technologies in industry include: the price and regulatory environment; existing industrial structures and their lack of flexibility to integrate new technologies and processes; awareness of potential efficiency gains; lack of skills in energy management; and strategic priorities other than energy efficiency performance. Removing those barriers, as assumed in the 66% 2 °C Scenario, would expand energy efficiency potentials in the mid and long term, including a broad array of possible investments with short payback periods. This outcome can be achieved through the implementation of obligations (e.g. MEPS, ISO 50001 certification and energy management systems), accompanied by other non-economic programmes and incentives, such as information campaigns, training initiatives, technical advice

[15] This payback analysis excludes the more structural levers to support higher energy efficiency levels, (e.g. increased recycling or the electrification of heat processes), as already discussed.

and documentation, energy efficiency networks and shared infrastructure to facilitate the adoption of new technologies, which together contribute to create the conditions for increased implementation of energy efficiency measures at a plant level (see Chapter 3). Inefficiencies can be reduced through improved process control enabled by digital technologies, allowing optimisation of energy use in factories. The organisation of supply chains for energy-efficient technologies, together with the clustering of industrial buyers would also enable the creation of better energy-efficient technology supply markets, facilitating the use and integration of energy-efficient technologies by industrial actors.

Figure 2.14 Global energy efficiency potential in the steel subsector and light industry as a function of payback period in the two scenarios



Note: The steel subsector energy efficiency potential excludes process change; energy efficiency potential in light industry excludes induced efficiency from electrification.

In addition to the improvement in the economic rationale for energy efficiency investments, removing market barriers is an important efficiency enabler in all industrial sectors.

In a given scenario, the rise of energy prices, as well as the progressive decline of technology costs reduces the payback period of an energy-efficient technology over time. Energy efficiency potentials thus increase over time as the integration of new technologies is eased by the renewal of industrial capacities. This positive trend is another factor leading to unlocking ever larger energy efficiency potentials in the 66% 2 °C Scenario relative to the New Policies Scenario.

Box 2.2 Challenges of modelling the effects of material efficiency and consumer preferences on energy demand

The impact of energy efficiency investments is influenced by their interactions with material efficiency initiatives as well as consumer behaviour. Both factors are essential for understanding final energy demand and greenhouse-gas (GHG) emissions, but they can be complicated to model, due to the complex relationship between production and how energy is consumed in end-uses, as well as the lack of adequate data to accurately estimate all the relevant market elasticities.

Material efficiency means reducing the amount of materials used, while still delivering the same service. This can lead to lower energy consumption and lower associated emissions. Common means to improve material efficiency include scrap diversion, increasing manufacturing yield rates, re-use and recycling, light-weighting and more intense use of products and lifetime extension. Such measures can reduce emissions both in the manufacturing process and in the use of the product. In the manufacturing process of raw materials, in particular cement, there are two sources of emissions: fossil-fuel combustion and emissions that arise from the manufacturing processes itself. Combustion emissions can be reduced by switching to cleaner fuels, but process emissions can only be tempered by reducing the volume of the material produced. Both sources need to be addressed. For example, in cement manufacturing, 65% of the CO_2 emissions arise from the chemical reaction of converting limestone into cement and 35% from fuel combustion. A instructive example of the link between production and end-use efficiency is the manufacture of a small passenger car. In this case, steel is substituted with lighter materials, which reduces the energy demand associated with steel production and, as the car weighs less, it also provides better fuel efficiency on the road. It is estimated that a 10% reduction in vehicle weight can deliver a 6-8% fuel economy improvement (US DOE, 2014).

Material efficiency initiatives are a necessary supplement to energy efficiency initiatives for realising ambitious climate goals. They are becoming more widespread in policy, addressed in the European Union's EcoDesign Directive and recent agreement on the Circular Economy Package, Japan's Fundamental Plan for Establishing a Sound Material-Cycle Society, and China's 13th Five-Year Plan. Policies mostly focus on five key materials: steel, cement, plastic, paper and aluminium, which dominate industrial emissions (Allwood, 2012).

The capacity of the IEA World Energy Model (WEM) to capture manufacturing-side benefits of material efficiency was significantly improved in 2015 with the development of a Material Efficiency Scenario (IEA, 2015). Further refinement of the model to address the systemic benefits in other end-use sectors will call for nuanced analysis, first and foremost because material efficiency is not always coupled with improved energy efficiency – sometimes there is a trade-off between the two goals. For example, with the growing prevalence of green building standards, energy efficiency is now more and more emphasised in new construction. However, these gains can be based on the use of more materials, such that embodied energy has been taking up an increasing percentage of the total energy used in the life cycle of a building. Good insulation helps to reduce energy spent on space heating or cooling, but often increases the demand for glass for double-paned windows. Extending a roof beyond the edge of a building can provide shade and reduce cooling needs, but making a structurally-sound overhang requires energy-intensive materials (Stauffer, 2016). Another trade-off between material and energy efficiency example is in the industry sector where energy is required to recycle materials. Manufacturing recycled steel uses about 40% as much energy as primary production from iron ore and recycled aluminium requires as little as 5% as much energy as primary production from bauxite (IEA, 2016b), so recycling significantly reduces the overall energy footprint of manufacturing, though a full assessment of the trade-offs, such as additional environmental impacts of collection and processing, would require a more systemic approach.

Another trade-off example is in the transport sector, where electric vehicles can reduce the transport sector's GHG and air pollutant emissions, but also require more use of cobalt, copper, and lithium in batteries (Olivetti et al, 2017; Speirs et al, 2017). This means that transport emissions might decrease with electrification, but that the embodied energy in cars will increase (Ellingsen, 2016; Hao, 2017). For the average internal combustion vehicle, around 15% of its life cycle GHG emissions originate from the production phase and 85% from the end-use phase, while for the average electric vehicle, the split is around 40% in the production phase and 60% in the use phase (UCSB, 2013; Ellingsen, 2016).

Besides policy initiatives and technology innovations for material efficiency, business models based on "sharing economies" or the provision of services on top of the manufactured goods themselves are also gaining prevalence, facilitated by better information and connectivity. For example, Rolls Royce offers "aftermarket services" for airlines that use its engines, with the manufacturer retaining responsibility for repair and maintenance. This lowers material production by extending engine lifetimes and removes the incentive for manufacturers to produce goods that will need to be replaced in a short time span. Likewise, chemical leasing, whereby producers sell the functions performed by chemicals rather than the chemicals themselves, have been found to reduce product use by around 70% and reduce energy use by around 50% (UNIDO, 2008). However, sharing economy business models are not guaranteed to yield energy savings. In fact, recent research suggests ride-sharing schemes, which use mobile applications to optimise car-pooling options, have not significantly decreased car ownership, and may even increase the number of trips that people take in the United States (IEA, 2017c; Clewlow, 2017).

The efficacy of many material and energy efficiency initiatives depends on consumer responses. This is particularly visible in the "rebound effect", which is the reduction in expected gains from new technologies that increase the efficiency of energy because of behavioural or other systemic responses. For instance, where a consumer uses a product more because of its improved energy efficiency, ultimately levelling out or increasing their energy demand. For example, when efficiency measures lower electricity bills and increase a household's disposable income, consumers could choose to spend their money on a bigger refrigerator or to increase the use of the air conditioning, which would ultimately lead to higher energy consumption and emissions.

On a related note, extending the durability of materials and lifetime of appliances can reduce manufacturing volumes, but also lead consumers to delay upgrading to more energy-efficient alternatives. This is where it becomes crucial to measure the income and substitution effects behind consumer expenditure decisions.

Consumer expenditure decisions are not always based on economic rationale, making it difficult for modelling how energy efficiency initiatives will be taken up. Consumers may hesitate to take action in the face of an upfront cost which delivers delayed benefits, which is the case for most energy efficiency investments. Energy-efficient buildings are more expensive to buy, but less expensive to operate. This has been found to be a major deterrent for investors and discount rates in energy models must reflect this factor accurately. At the same time policy makers must focus on policies to reduce and overcome barriers to energy efficiency investment. Barriers to investment can be particularly high in landlord-tenant situations where a landlord may have little incentive to invest in retrofits and upgrades. Consequently, leased space sees a larger gap in energy efficiency efforts than owner-occupied buildings (Building Efficiency Initiative, 2012), suggesting the importance of factoring trends in ownership into residential sector modelling.

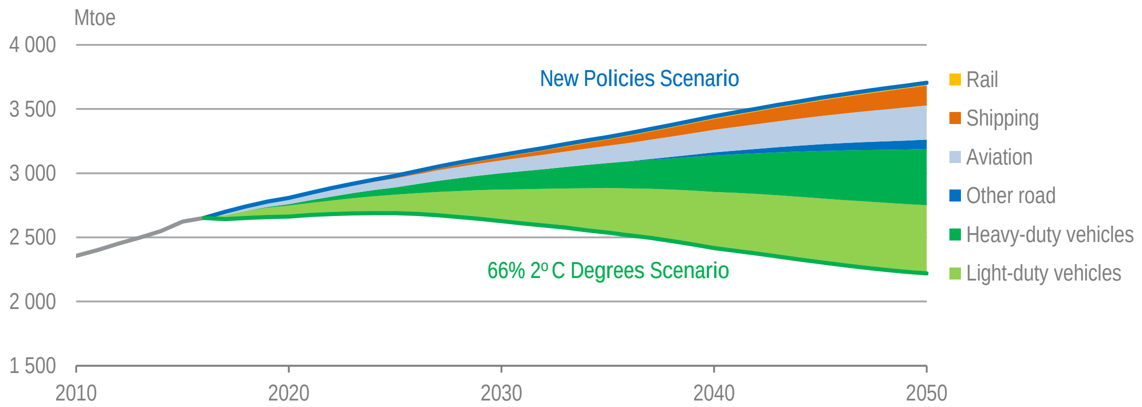
Energy efficiency in transport

The transport sector accounts for all energy consumed in the carriage of people or goods by means as diverse as cars, ships, trucks, trains and planes. The increasing number of people who can afford to buy a car, or take a plane or train trip several times a year, is driving a surge in demand for mobility. For example, the annual distance travelled by the passenger light-duty vehicles (PLDVs) fleet worldwide increased by an annual average of 3.1% over the past decade, and the quantity of goods carried by road – measured tonnes per kilometre – grew 3.4% per year. During the same period, the distance travelled by passengers in the air – expressed in revenue passenger-kilometres – grew 5.8% per year.

Today, the transport sector accounts for one-fifth of total energy demand. The key characteristic of the sector is its high reliance on oil, which supplies 92% of transport energy demand. More than 52 million barrels per day (mb/d) are used in engines for mobility purposes, equivalent to 56% of global oil consumption. Among the different transport modes, light-duty vehicles (LDVs), which include passenger and commercial cars, vans, sport-utility vehicles and light-duty trucks, account for 46% of total energy demand for transport. Heavy-duty vehicles (HDVs), which include, medium- and heavy-duty trucks, account for 23%, followed by aviation (11%) and shipping (10%). The remaining demand is from buses (4%), two- and three- wheelers (3%) and rail (2%).

Increasing population and incomes along with relatively low fuel prices and technology advances increase demand for mobility over the outlook period in all the scenarios considered in this report: by 2050, the distance travelled by PLDVs doubles from current levels and road freight activity more than doubles in the New Policies and the 66% 2 °C scenarios. Aviation energy use rises by 3.6% per year. With its current high reliance on low-efficiency internal combustion engines, the transport sector is an important reservoir of energy savings potential. It offers a portfolio of available efficiency improvement options depending on the vehicle type, its propulsion mode and the type of service it provides (Figure 2.15). Options include, but are not limited to, friction reduction (tyres, enhanced aerodynamics), light-weighting, downsizing, hybridisation and switching to electricity.[16]

Figure 2.15 Avoided energy demand by transport mode in the 66% 2 °C Scenario relative to the New Policies Scenario



More than one-third of cumulative energy savings would come from LDVs although energy savings from HDVs would catch up by 2050.

In the New Policies Scenario, even though oil demand growth in the transport sector slows down in the coming years, transport remains a cornerstone of oil demand accounting for an increase of more than 20% by 2050 compared with today. In the 66% 2 °C Scenario, it would be a radically different trend. Thanks to important energy efficiency improvements in ICEs and the switch to electric engines, energy demand in transport would peak by the mid-2020s and decline at an annual average rate of 0.8% per year thereafter to 2050. Energy efficiency improvements in conventional engines for road vehicles and ships or turbojets for aircraft are a key driver for energy demand savings in transport. Road transport accounts for 70% of end-use energy efficiency savings, followed by aviation (17%) and shipping (11%).

In road transport, LDVs would account for a majority of the cumulative energy savings, given their relative share and the comparatively low efficiency of the existing fleet. Their average on-road specific consumption in 2050 would be reduced by a factor of more than three, compared with today, and would be more than 40% lower than the 2050 level in the New Policies Scenario (Table 2.3). Reaching this level of specific fuel consumption would require a large change in the structure of the global vehicle fleet: electric LDVs, including battery and plug-in hybrids, would

[16] Intermodal shift, such as aviation to high-speed rail, as well as autonomous and connected vehicles could enable additional energy savings. However, they are outside the scope of this report.

constitute around 70% of the fleet by 2050. Conventional LDVs running on gasoline or diesel would be almost phased out, as much of the remainder would be hybrid vehicles in 2050. Energy efficiency in non-road modes, such as aviation and shipping, would contribute to around 30% of the cumulative energy savings in the transport sector. Technical improvements and the switch to electric road systems would drive down the average on-road specific fuel consumption by more than 50% in 2050 in the 66% 2 °C Scenario, compared with today and they would be complemented by systemic improvements to the road freight system. The energy footprint of carrying a tonne of goods over one kilometre would be reduced by almost two-thirds thanks to higher load factors enabled by digitalization of the entire supply chain along with increased reliance on heavy-duty trucks for long-haul carriage of goods.

Table 2.3 Global energy efficiency indicators in transport by scenario

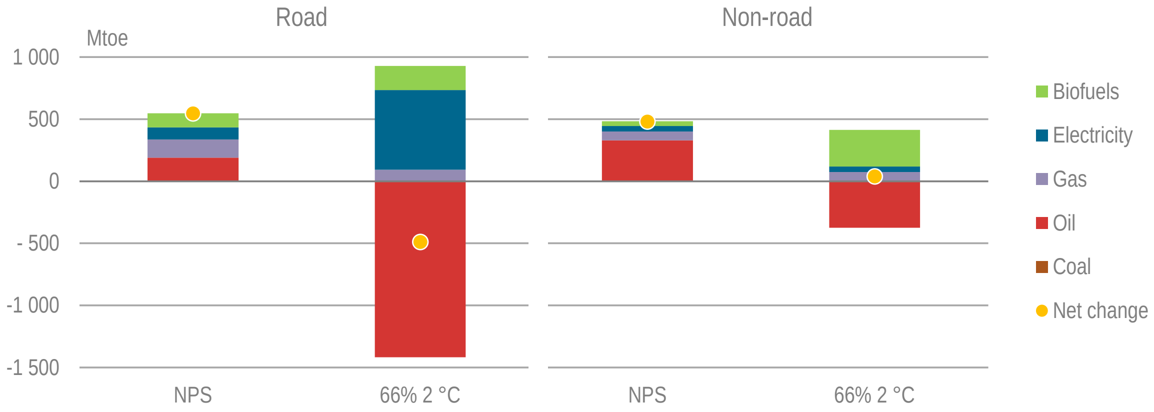
	2016	2050	
		New Policies Scenario	66% 2 °C Scenario
Average on-road specific fuel consumption PLDV (lge/100 km)	9.4	5.3	3.0
Average on-road specific fuel consumption HDV (lge/100km)	44.2	34.6	20.5
Overall road freight efficiency (MJ/tkm)	1.33	0.81	0.49
Aviation efficiency (index 2016 = 100)	100	57	30
Rail efficiency (index 2016 = 100)	100	77	59
Shipping efficiency (index 2016 = 100)	100	58	37

Notes: PLDV = passenger light-duty vehicles; Lge = litre of gasoline equivalent; HDV = heavy-duty vehicles; tkm = tonne per kilometre. Efficiency indexes are calculated on the basis of: for aviation as revenue per passenger/km; for trains and ships as kilometres travelled.

Energy efficiency enhancements in aviation would account for 18% of the cumulative energy savings in transport. Compared with today, average aviation efficiency – expressed in energy used per revenue passenger kilometres – would fall by 70% in 2050 in the 66% 2 °C Scenario. The scale of this reduction would imply large-scale deployment of technology improvements for engines (open rotor, geared turbofan and counter-rotating fan) as well as improved aviation traffic management. Shipping would contribute 8% of the cumulative energy efficiency savings in transport by way of expanding average ship size and load factors, as well as optimised vessel design and improvements of propulsion systems (IEA, 2017d).

Fuel use in transport would change considerably in the 66% 2 °C Scenario. Oil demand would peak before 2020 and decline steeply thereafter even with the projected rise in mobility demand, resulting in a cut of almost 38 mb/d in 2050, compared with today (Figure 2.16). This is equivalent to 40% of current global oil demand. Energy efficiency improvements would contribute to oil savings of more than 20 mb/d in 2050, in addition to a switch to electricity, and, to a lesser extent, a higher use of biofuels and natural gas. Electricity demand for transport would increase by almost 8 000 TWh in the 66% 2 °C Scenario in 2050, relative to today, reaching a level four-times higher than electricity demand in the New Policies Scenario. Consequently, this switch to electricity would make an important contribution to improving the overall efficiency of transport.

Figure 2.16 Change in energy demand in transport by fuel and scenario, 2016-50



Oil demand would be lower in 2050 for road and non-road modes even with robust increase in demand in the 66% 2 °C Scenario thanks to efficiency gains and shifts to electricity.

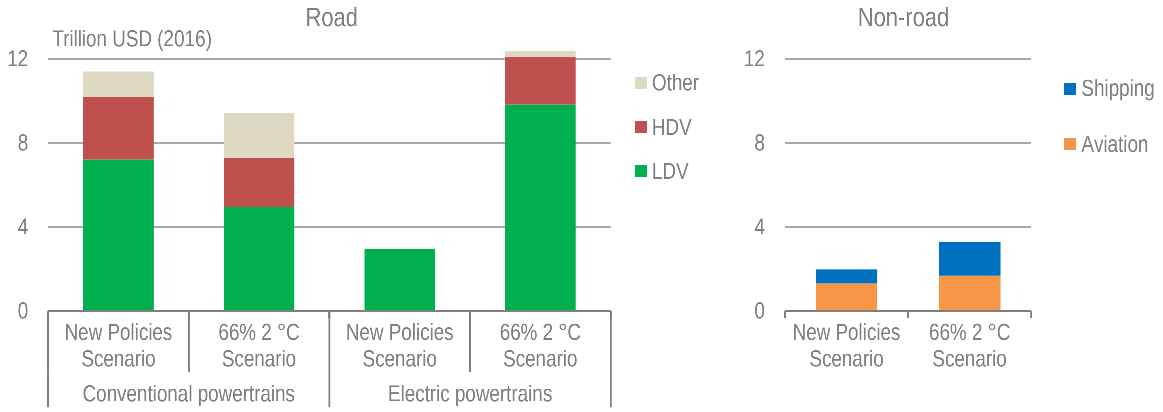
Direct CO_2 emissions from the transport sector would decline dramatically in the 66% 2 °C Scenario to 2.7 Gt in 2050, down from 7.8 Gt today, as a result of a steep decrease in oil demand and increased reliance on electricity. Energy efficiency would be the primary driver of this change and account for around 45% of the 112 Gt cumulative CO_2 emissions savings in transport between the 66% 2 °C Scenario and the New Policies Scenario.

The deep transformation of the transport sector in the 66% 2 °C Scenario, taking into account alternative powertrains, would require an average annual additional investment of almost USD 260 billion compared to the New Policies Scenario. Investment requirements would increase considerably over time from the deployment of increasingly efficient vehicles, trains, ships and planes as well as the switch to electric powertrains. The global average investment in the transport sector would increase from around USD 440 billion per year during 2017-30 to USD 1 trillion per year during 2030-50.

Three-quarters of the cumulative investment in energy efficiency would be allocated to road transport and the remainder would be evenly split between aviation and shipping. In road transport, energy efficiency investment in both ICEs and hybrid vehicles would actually be lower in the 66% 2 °C Scenario than in the New Policies Scenario, although their specific investment cost is higher, because of the significantly lower market share of conventional engine technologies. The majority of the investment would support a huge uptake of electric vehicles, which would absorb more than 50% of the cumulative investment in transport in the 66% 2 °C Scenario, up from just over a fifth in the New Policies Scenario (Figure 2.17).

Similarly to other energy end-uses, the investment numbers alone conceal the benefits of energy efficiency improvements in terms of annual fuel expenditure reductions for consumers. To consider the costs and benefits from a consumer perspective, we calculate the payback period of investing in a recent vehicle relative to a reference vehicle, i.e. the incremental investment cost divided by the difference in annual fuel expense, for each powertrain, vehicle type and model region.[17] The results show strong variations in payback periods for road vehicles, depending on the region and the powertrain type. In general, further energy efficiency investments in conventional and hybrid vehicles would tend to pay back more slowly over time as a result of the combined effect of an increase of the incremental cost of additional energy savings and a slowdown of the rise in fuel prices in the 66% 2 °C Scenario. While technological learning dampens the effects somewhat, it is not sufficient to tilt the balance. The opposite is true for electric cars, where a decrease in battery and electric engine costs leads to a fall in the payback period despite plateauing electricity prices.

Figure 2.17 Cumulative investment in energy efficiency and electrification for selected transport modes in the two scenarios, 2017-50



Notes: LDV= light-duty vehicles; HDV = heavy-duty vehicles; *Other* = motorbikes and buses. *Conventional powertrains* include both internal combustion engine and hybrid vehicles running on gasoline or diesel.

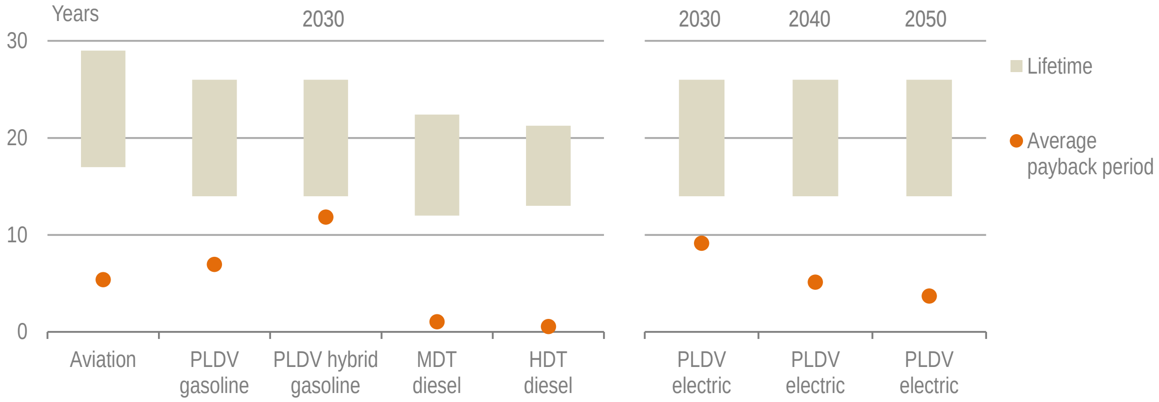
Lower cumulative investment in energy efficiency improvements in the 66% 2 °C Scenario are more than offset by the four-fold increase of investment in electric powertrains.

The impact of these opposing trends is that the economic rationale for choice between technologies would change markedly over time in the 66% 2 °C Scenario. In 2030, for example, efficiency investment for a conventional gasoline PLDV would have a payback period between five to ten years, and even longer for hybrid gasoline vehicles (Figure 2.18). At the same time, the additional investment in electric cars would pay back within six to ten years, meaning that the relative competitiveness of such investment changes in favour of electric cars. Paybacks of efficiency improvements of medium- and heavy-duty trucks would be lower than two years in 2030 in the 66% 2 °C Scenario. The main reason is that distances driven for trucks are much higher than for PLDVs, which leads to a higher differential in annual expenditures between the more efficient and the reference technology. Energy efficiency investment in aviation and shipping vary considerably across regions because of their different price environments. Similarly, payback

[17] The reference vehicle is an older vehicle (with lower efficiency) which runs on the same fuel as the assessed vehicle type. For instance, a hybrid gasoline PLDV is compared to a conventional internal combustion engine gasoline, which is five years older. For medium- and heavy-duty trucks, the lag time is three years given the higher turnover of the fleet. For aviation and shipping, the payback period corresponds to the investment for a given year divided by the difference between fuel expenditures of that year and the previous year.

periods generally increase over time because of the higher incremental efficiency gain cost associated with the stabilisation of international energy prices.

Figure 2.18 Regional sales-weighted distribution of payback periods of selected road vehicle types and aviation



Notes: PLDV = passenger light-duty vehicles; MDT = medium-duty trucks; HDT = heavy-duty trucks.

In 2030, investing in energy efficiency is economically rational since payback periods are lower than vehicle lifetime. Important opportunities remain in the freight sector.

Energy efficiency and the energy transition

Although not always as obvious as supply-side options, energy efficiency is an essential component of the transition to a clean and sustainable energy system and the impact of energy efficiency measures can go far beyond energy savings. Energy efficiency improvements can be a key contributor to economic growth and social development. The avoidance of energy demand, due to efficiency gains, can result in lower energy expenditure, higher levels of energy security and avoided investment in new energy supply assets. Reduced fossil fuel use, stemming from energy efficiency (as well as electrification and renewable energy), delivers lower GHG emissions, lower fuel import bills for importing countries, better buildings and associated health improvements.

Improving energy efficiency requires wider deployment of more efficient technologies that are usually associated with higher upfront investment cost. Conversely, practical and financial constraints on how quickly energy-related capital stock can be replaced affect the rate at which new technologies can be introduced and, consequently, the rate of improvement in energy efficiency. In many sectors, the payback periods that reward investment in energy efficiency through fuel cost savings are long given the range of product life cycles. They increase over time as more efficient technologies are deployed and the incremental cost of raising the efficiency of already very efficient technologies rises disproportionally in comparison with the additional fuel cost savings that can be accrued. In most cases, the required additional investment would still pay back within the lifetime of the more efficient technology. But the increasing time until which such investment pays back becomes an increasingly important policy consideration for the long run, especially where low-carbon alternatives exist.

There are other factors not considered in this outlook that would increase the projected energy efficiency potential: for example, this analysis does not fully take into account the impact of digitalization and other breakthrough technologies in improving energy efficiency. Other elements that fall beyond the scope of this analysis, such as the influence of changes in consumer behaviour or structural changes in the economy are excluded. For example, in the buildings sector, it excludes densification of urban areas, further decentralisation of renewable energy production and reduced per capita floor space requirements from better layout design. In the transport sector, it excludes demand management strategies (e.g. carpooling, car-sharing, teleworking), the impact of autonomous driving and intermodal shifts. In the industry sector, switching to higher value light industry, beyond what is included in the New Policies Scenario, is not covered. Non-technical and non-economic barriers also are a major obstacle in energy efficiency initiatives and the challenge for policy makers is to reduce such barriers while providing market participants with visibility of the long-term benefits from savings in energy costs. One such significant barrier is the fact that the costs and benefits of an energy efficiency investment decision can often fall on different actors (split incentives), such as in residential buildings. Another is that the payback period for investing in an energy efficiency improvement is longer than the length of time the buyer intends to own the asset. These are barriers that must be tackled.

Improvements in energy efficiency which lead to reduced fossil fuel energy consumption result in a reduction in GHG emissions. Energy efficiency measures would contribute 35% of the carbon abatement needed by 2050 for attaining the 66% 2 ˚C Scenario. These savings would be spread across all sectors with transport, buildings and industry combined accounting for almost 60% of the direct emissions savings attributable to energy efficiency. Energy efficiency also impacts energy security, both in the long as well as short term. Long-term energy security requires adequate and timely investments that take account of economic development and environmental concerns. Short-term energy security requires the energy system to react promptly to sudden disruptions in energy supply, changes in market conditions or government intervention via emergency measures to maintain system balance. Energy efficiency can play a crucial role in ensuring long- and short-term energy security in a cost-effective manner. One way in which energy efficiency can benefit a country's energy security is by reducing its reliance on imported energy. Energy efficiency also reduces the likelihood of supply interruptions. Furthermore, in the event of a disruption, efficiency measures can work with emergency conservation measures to reduce demand.

Alongside energy efficiency, renewables and electrification also have a very important role to play in the clean energy transition and many energy strategies being developed today are increasingly integrating efficiency and renewable energy along with electrification (IEA, 2017a). As renewable energy and energy efficiency technologies command higher levels of attention, and achieve higher levels of deployment, addressing these two factors independently is not effective. While a broad system-wide perspective has always been desirable, in practice, policies and strategies have generally been made separately for different fuels and sectors, and without much cross-reference between renewables and energy efficiency. Both energy efficiency and renewables bring new qualities to energy systems, particularly as they grow in importance.

Electrification does not necessarily mean higher electricity demand; under the assumptions of the 66% 2 °C Scenario, electricity demand would reach about the same level as in the New Policies

Scenario as stringent efficiency policies for appliances, lighting or electric motors and widespread adoption of efficient heat pumps would constrain electricity demand growth. But electrification means that electricity takes a higher share in final energy demand as its efficient use becomes pervasive across many more areas of energy demand while energy efficiency measures dampens the use of other fuels. Such electrification introduces new, more flexible sources of electricity demand that can be adjusted to more readily match the availability of renewables-based electricity generation, thereby enabling the indirect use of renewables in many sectors. Electrification can also improve overall energy efficiency where new technologies, such as heat pumps and electric vehicles, have better energy performance than existing technologies. Investment in energy efficiency reduces overall demand thereby enabling renewables to capture a higher proportion of supply. Energy efficiency, renewables and electrification could each contribute to a solution or simultaneously influence the realisation of more than one objective. A well-balanced portfolio of efficiency and renewable energy measures can optimise the sizing of distributed energy systems, avoiding additional investment to deal with imbalances, such as electricity storage.

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Chapter 3. A strategic approach to energy efficiency

Highlights

- More effective energy efficiency policies are needed. Without rapid expansion of policy coverage and strengthening of existing policies and programmes, the efficiency gains needed to meet established environment and development goals will not be achieved. Energy efficiency should be a cornerstone of government efforts and well integrated in policy actions in all sectors. While governments increasingly recognise the benefits of energy efficiency, more than two-thirds of global energy consumption was not covered by mandatory efficiency measures in 2016. Some technologies, such as lighting, have broad coverage of energy performance standards, though some approaches are not very stringent and significant efficiency potential remains untapped. In other areas, such as retrofits of existing buildings, more effective policies and implementation would be needed to achieve the ambitious energy savings and investment requirements called for in the 66% 2 degrees Celsius (°C) Scenario.
- A strategic mix of policies is important if energy efficiency is to fulfil its fundamental role in the transition to a clean energy system. Committing to a long-term policy strategy for improving efficiency (e.g. setting targets, establishing sectoral pathways), is an important complement to appropriate energy pricing policy, such as removing fossil fuel subsidies. An effective strategy gives clear signals to investors and consumers, and ensures that policies are properly targeted and aligned. A mix of measures is essential, including regulations to set energy performance standards, information and incentive schemes to raise awareness and accelerate uptake of the most energy-efficient technologies, and market-based instruments to encourage innovation.
- Policies need to be designed to be appropriate to national and sectoral circumstances, and properly implemented. There is a wealth of experience to learn from best practice in policy design and execution to maximise impact at least cost. These approaches range from established measures such as building codes and appliance standards to more innovative business models involving public and private sector collaboration, and new ways to overcome financing challenges. Best practice in policy design and implementation should be leveraged across all sectors and end-uses. International co-operation in designing policies and setting standards can improve effectiveness, particularly for internationally traded goods.
- Policies and programmes should focus on unlocking investment. Many sources of capital, both public and private, are available to address particular market needs for efficiency improvements. In addition to ambitious and well-designed policy measures, a range of economic measures should be used to deliver the required investment, such as fiscal measures (e.g. taxes), financial measures (e.g. loans and grants) and market-based instruments (e.g. utility obligations and auction schemes). Well-placed policy is needed to better link opportunities through public and private sector intermediaries to solve challenges such as transaction costs, investor confidence, expertise and aggregation.
- Building the capacity needed to deliver energy efficiency is critical. Governments need to make significant investment in developing adequate capacity with a focus on effective policy design, governance, compliance and market development. Significant investment in institutional capacity is also needed to deliver the broad scope and scale of results required to achieve climate and sustainable development goals. Human and capital resource requirements need to substantially increase.

Introduction

The previous chapters outlined how energy efficiency across the major end-use sectors is essential to drive the clean energy transition. Regardless of the exact trajectory, evidence from both clean energy transition pathways considered in this report – the Sustainable Development Scenario and the 66% 2 °C Scenario – is that maximising energy efficiency across all sectors is a critical enabler of achieving a cleaner and more sustainable energy future that is compatible with environment and development goals.

Energy efficiency has been improving around the world in recent years as many countries have actively supported relevant policies. But the accelerated pace and broad reach of the efficiency improvements required to achieve the clean energy transition scenarios considered in this report require a step change in ambition. The substantial energy and fuel bill savings associated with more efficient technologies mean that, in many cases, the upfront investment needed can be amortised over their lifetimes. In some cases, however, the payback periods involved may exceed those that generally would be supported by market expectations. Unlocking the necessary substantial investment of around USD 1 trillion (United States dollar) per year as required in the 66% 2 °C Scenario and ensuring that information about the benefits of these investments is available to all market participants is an important policy challenge.

This chapter outlines some of the policy implications that arise from the analytical findings presented in the previous chapters. Driving the needed strong rate of improvement over the outlook period to 2050 requires ambitious policies set within a long-term framework that gives as much certainty as possible to investors and stakeholders over the direction, strength and timing of policy development. In many respects, the types of policies needed are well-known; a mixture of regulatory measures, market-based instruments and information/awareness programmes. This chapter is structured around three central aspects of long-term energy efficiency frameworks:

- **Committing to a more energy-efficient world** and making explicit efficiency goals a cornerstone of a broad long-term clean energy transition strategy.
- **Implementing ambitious policies to transform markets** in order to drive the needed investments.
- **Strengthening institutional capacity** in order to implement, enforce and evaluate efficiency policies to ensure their effectiveness.

The emphasis is on a detailed discussion of ambitious policies to transform energy markets at the sectoral level, to serve as a practical guide for implementation. These three aspects are of equal relevance for the clean energy transition to be successful.

Committing to a more energy-efficient world

Committing to a long-term vision and strategy to improve energy efficiency is a key initial step to boost the levels of ambition. Commitments are critical in that they provide clarity and predictability for the main energy efficiency market participants, notably investors and companies that need to consider major multi-year investment plans, as well as key players across the energy sector that are affected by energy efficiency policies. At the national level, making commitments related to efficiency could include establishing broad principles that explicitly require policy makers to consider efficiency measures before pursuing expensive supply-side options to ensure that energy strategies are undertaken at the lowest cost to society. Setting an ambitious energy efficiency target is also a way of maintaining high-level focus on improving efficiency (Box 3.1 Goals and targets are also useful at levels of governments such as cities and municipalities, where they can be adapted to specific local circumstances.

For investors, important elements of an energy efficiency strategy would relate to the objectives, timelines and policy frameworks. An agreed long-term overarching target also gives confidence to businesses and consumers that the government is serious about maintaining policy measures over a timeframe long enough to influence investment strategies. Providing clarity on ambition levels and the way in which policy is likely to evolve is essential for both energy consumers and the manufacturers of energy-using products in order to plan their investment decisions. Periodic reviews of ambition levels and policy approaches are needed to ensure that the balance of effort between efficiency and other ways of achieving objectives are appropriate.

Box 3.1 Energy efficiency targets

National energy efficiency targets can drive action towards improved efficiency by providing a high-level focal point for the development of the policies required to meet them. There is not one prescription for how to set a target for energy efficiency. Various approaches have been taken across the world, which have their pros and cons (Table 3.1).

In Mexico and the European Union, additional efficiency targets have been introduced, which focus on the central role of policy in delivering efficiency goals. Mexico's National Energy Strategy and the National Programme for the Sustainable Use of Energy include a target to increase the share of final energy consumption covered by regulation from 46% in 2012 to 51% 2018. The European Union's Energy Efficiency Directive, updated in November 2016, proposed an energy efficiency target of 30% by 2030, relative to 2005. In addition, the proposed update mandates that energy distributors and retail energy sales companies must achieve 1.5% of total energy consumption as savings per year through the implementation of energy efficiency measures.

Table 3.1 Economy-wide energy efficiency targets

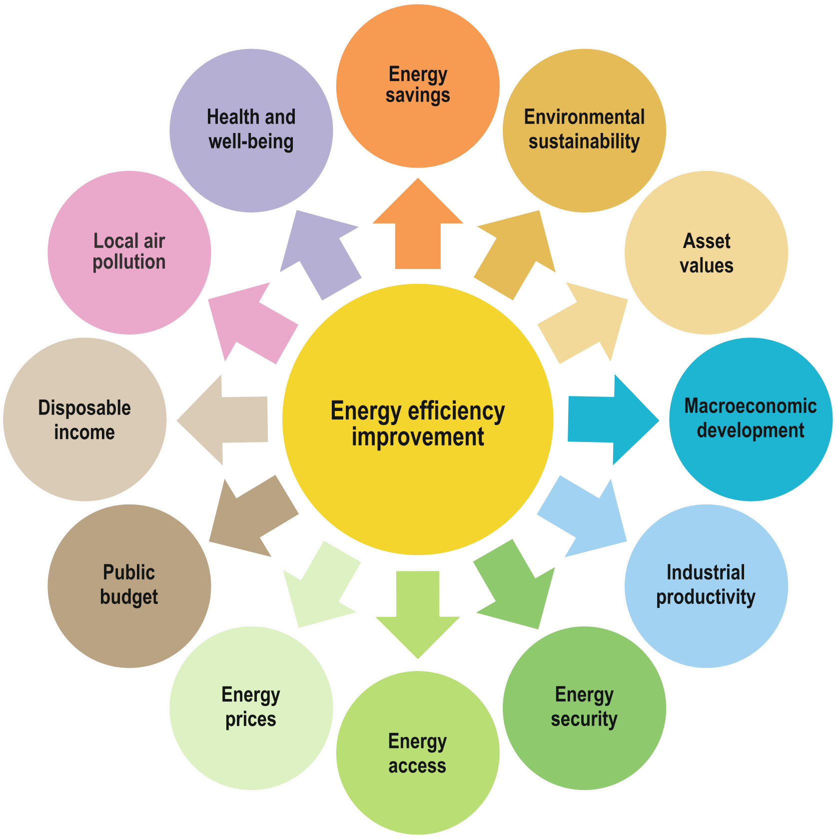
Target Type	Pros	Cons	Example
Energy Intensity Energy consumption per unit of GDP	Most commonly used benchmark.	Influenced by structural change and other factors.	China's 13th Five-Year Plan: target to reduce intensity by 15% between 2015 and 2020.
Energy Productivity GDP per unit of energy consumption	Positive economic association rises over time.	Influenced by structural change and other factors.	Australia's National Energy Productivity Plan: target to improve energy productivity by 40% between 2015 and 2030.
Energy Elasticity Ratio of energy consumption growth and GDP growth	Focus on decoupling energy and GDP growth.	More difficult to understand.	Indonesia's National Energy Plan (2014): target to reduce energy elasticity as a function of GDP to below one by 2025.
Energy Consumption Absolute limit to energy consumption	Easy to understand.	Influenced by economic growth, structural change and other factors.	Germany's Climate Action Plan 2050: target to reduce primary energy consumption by 20% by 2020 and 50% by 2050, from a base year of 2008.

Box 3.2 Multiple benefits of energy efficiency

Energy efficiency is a key component of climate change mitigation policy. They go hand-in-hand. Successful energy efficiency provides numerous benefits for households, businesses and society (Figure 3.1). For example, energy efficiency measures can: improve energy security and trade balances by reducing reliance on fuel imports or freeing up fuel for export; support economic growth, such as by boosting household disposable income through lower energy bills; and improve industrial productivity. In the power sector, energy efficiency improvements can reduce the costs of providing energy system adequacy by limiting the infrastructure required to transmit and distribute energy. Efficiency gains are beneficial to address energy poverty by enabling limited energy resources to provide more energy services and they can lead to better health conditions, through improvements in outdoor and indoor air quality. A detailed analysis of the multiple benefits of energy efficiency has been documented by the IEA (IEA, 2014a).

Improvements in energy efficiency can also contribute to reaching UN Sustainable Development Goal targets. For example, reduced energy consumption from improved energy efficiency would allow a higher number of people in developing economies access to electricity and energy services (contributing to the delivery of SDG7 target 7.1 – to ensure universal access to affordable, reliable and modern energy services by 2030).

Figure 3.1 Multiple benefits of energy efficiency



Source: IEA (2014a), *Capturing the Multiple Benefits of Energy Efficiency*,.

Improving energy efficiency can be a powerful means to achieve multiple benefits thereby making investment attractive to a broad range of stakeholders.

Making a strong, credible commitment to improving energy efficiency can be explicitly linked to tackling climate change and other policy objectives. For example, energy efficiency targets are already the cornerstone of many economies' climate policy and feature in many countries' Nationally Determined Contributions (NDCs) (see Chapter 1). The UN Sustainable Development Goals (SDGs) recognise the importance of energy efficiency; SDG7 includes a target to double the rate of energy efficiency progress by 2030 (Target 7.3).

Energy efficiency brings multiple benefits. It is characterised by its cost-effectiveness relative both to other actions needed to achieve climate objectives and, in many cases, to taking no action at all. This means that well-designed policies can boost economic growth by improving productivity in the commercial sector, increasing disposable income by cutting energy bills in households and providing employment in regions with slack labour markets, for instance for retrofitting buildings. Linking the co-benefits of energy efficiency with the large levels of investment required should provide greater political capital to support the implementation of the wide range of the policy measures that will be needed to achieve a clean energy transition scenario (Box 3.2).

Implementing ambitious policies to transform markets

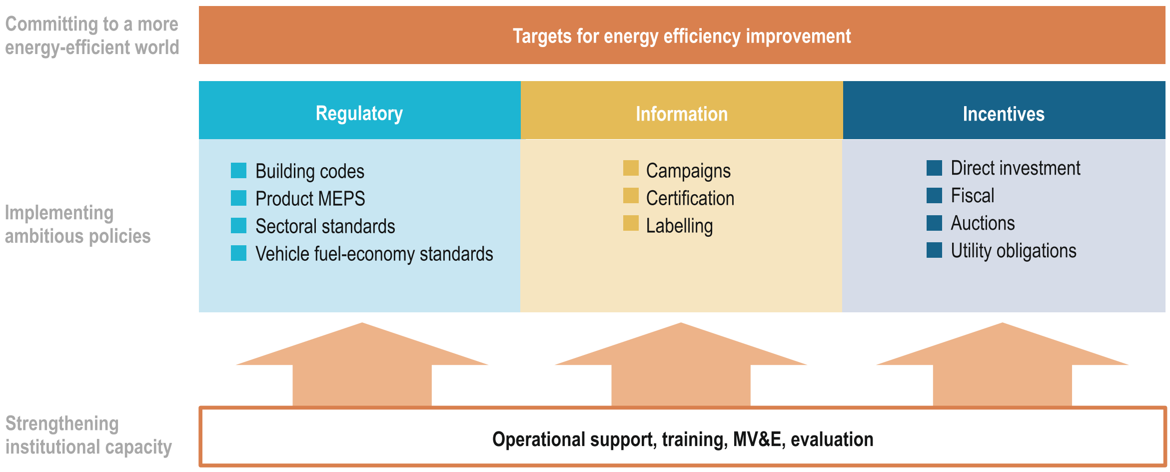
Successfully harvesting the efficiency potential of the energy sector requires policies that align with long-term vision and targets, and signal ambitious and concrete actions to be taken at the sector and subsector levels. A range of policy measures can be used to increase the amount of investment for improved energy efficiency of goods and services. Many of these individual measures are well-known. A simple taxonomy of policy measures to increase investment in energy efficiency is shown in Figure 3.2. For energy efficiency to play its essential role in an ambitious energy transition, understanding the saliency of various policy measures in different sectors, how they interact and how they can provide synergies is crucial.

Decisive and well directed policy can affect the amount of investment required to deliver energy efficiency, the speed and scale of its uptake and even who bears the cost. A mixture of regulations, market-based incentives and information-based policies, supported by cost-reflective energy pricing is needed to create the right conditions for investment, innovation and the development of new business models. The relative importance of each of these policy elements varies by end-use.

Regulatory approaches are key policy tools in many sectors. For buildings, appliances, equipment, and lighting building codes and minimum energy performance standards (MEPS) are the most important measures in efficiency policies, mostly as regulations, but sometimes as voluntary agreements with product manufacturers. Regulations for passenger vehicles, often in the form of corporate average fuel-economy standards, are a core approach for efficiency improvements, and they are increasingly being applied in road freight. In industry, standards for the efficiency of electric motors have been adopted in most major markets, while in a small number of jurisdictions, most notably People's Republic of China (China), whole industry sectors are subject to meeting mandatory energy intensity improvement targets (e.g. energy use per unit of output).

In all cases in which codes and standards play a dominant role in the policy framework, the investment decisions associated with making products more efficient are upstream with the manufacturers. If they have a clear view of the policy landscape and its longevity, they plan effectively to minimise the costs associated with improving efficiency levels. In many product markets, the prices paid by consumers have not risen along with the introduction or tightening of efficiency standards, because manufacturers have found ways to implement improved efficiency more effectively (at a lower cost), reduced other costs (offsetting the efficiency costs) or because investment has been shifted from other features to efficiency.

Figure 3.2 Measures contributing to a policy strategy to increase energy efficiency



Note: MEPS = minimum energy performance standards; MV&E = monitoring, verification and enforcement.

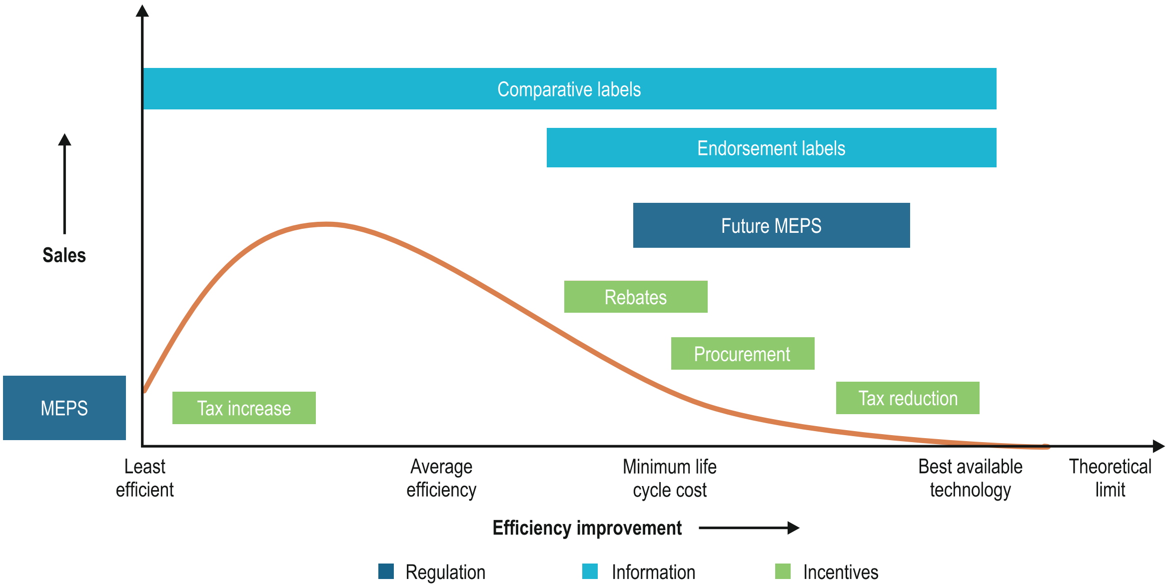
Regulations, information and incentives to improve energy efficiency need to be signalled in advance and underpinned by robust institutional capacity.

Information and incentive-based policies also play an important role in the transformation of markets where regulations are in place. Labels raise awareness among consumers and provide the infrastructure for incentives and procurement campaigns aimed at increasing the average efficiency of new products and expanding the market for the most efficient products, making it easier to strengthen MEPS in future. An example is in the passenger vehicle market, where both market-based incentives, such as tax credits at the point of purchase, and other incentives such as priority access to special lanes and parking facilities, support the uptake of electric vehicles (EVs). Some of these measures do not significantly affect the overall efficiency of the new vehicle fleet at the time, but do move markets closer to the large-scale uptake of EVs, enabling a faster transition in future rounds of standard setting.

Incentives include *fiscal measures*, which have been successfully used to penalise inefficient goods and services and to provide advantages such as lower taxes on favoured goods and services. For example in the transport sector, fiscal measures have been used to incentivise the purchase of efficient vehicles (through vehicle registration taxes and differentiated taxes on vehicle use) and fuels (through fuel taxes). In the buildings sector, taxes levied at the point-of-sale or annual property taxes can be linked to improving energy efficiency in commercial and residential buildings. In industry, companies that adopt efficient equipment or energy management systems can be rewarded through reduced energy or environmental taxes (as in Germany) or through enhanced capital allowances (as in the United Kingdom) that reduce a profitable company's tax bill. Such measures can be intricate, for example as in for the transport example, where the levels of purchase and ownership tax for passenger cars vary depending on the efficiency or emissions profile of the vehicle.

A combination of regulatory, information and incentive-based policies can lead to transformative impacts on markets. In the appliances sector, for example, regulation (e.g. MEPS act to remove the least efficient products from the market, information (e.g. appliance labels) help to differentiate product quality to consumers as well as within the supply chain, and incentives can help target and accelerate the uptake of the most efficient products. Higher performance levels in measures can be phased in over time to allow technology advances and manufacturing capabilities to provide for efficient goods and services (Figure 3.3).

Figure 3.3 Market transformation for appliances



MEPS remove the least efficient products from the market, labels help differentiate product quality, and incentives accelerate the uptake of the most efficient appliances.

Where appliance standards have become more stringent over time, manufacturers have usually been able to produce models to meet the enhanced standards. There appears to be a continuing "supply" of energy efficiency for appliances, even if some of the energy savings may be shifted to increased size or additional features. After the various iterations of MEPS in Australia, the European Union and the United States, further cost-effective efficiency opportunities were identified, often leading to tighter MEPS levels being implemented. There is evidence that with a co-ordinated market transformation strategy, multiple iterations of increasingly rigorous MEPS can deliver significant and cost-effective efficiency gains.

Energy prices have a significant influence on investment and behaviour related to energy consumption. Energy efficiency measures are best supported by energy prices that reflect the true costs of production, including the external costs associated with the greenhouse gas (GHG) emissions and removing fossil fuel subsidies (Box 3.3). Energy efficiency can play a significant role in easing the burden of subsidy reform on consumers.

Ambitious policy measures require support from a range of other *economic measures* to underpin energy efficiency investment. Generally these are of two types:

- Financial measures such as loans and grants from public and private sources to support acquisition of efficient products, processes and services.
- Market-based instruments that set outcomes (e.g. energy savings, cost-effectiveness) to be delivered by market actors without prescribing the delivery mechanisms or specific measures. Common types of market-based instruments include energy efficiency obligations and auction schemes (IEA, 2017a).

Box 3.3 Fossil fuel subsidy reforms can prepare the ground for saving energy

Fossil-fuel subsidies are prevalent around the world. The rationale for the subsidies often has been to achieve particular political, economic and social objectives; for example, to reduce energy poverty, ensure energy access and redistribute wealth stemming from the exploitation of indigenous resources. In practice, however, untargeted fossil-fuel subsidies rarely have been an efficient or effective tool to meet policy objectives, and in many cases disproportionally benefit wealthier people that consume more of the subsidised product. Fossil-fuel subsidies also encourage inefficient use of energy and discourage investment in energy-efficient equipment.

The global value of fossil-fuel subsidies in 2016 was estimated at USD 260 billion, of which oil and electricity each account for around 40% of the total (IEA, 2017b). The value has been declining since 2012, due in part to lower international fuel prices, but also to continued efforts to reform subsidies. Many economies have taken advantage of lower fuel prices, as they allow governments to reduce subsidies without raising end-user prices too steeply, thereby reducing the political sensitivity. Fossil-fuel subsidy reform can be accompanied by supporting policies and measures, notably by efficiency policies, which can in fact enhance the impact of the efficiency policy. By raising end-user prices, subsidy reform increases public awareness about energy efficiency, reduces payback times and encourages investment in efficiency improvements. For example, in Indonesia, by removing all of the subsidies for gasoline, the average payback period for more efficient gasoline-fuelled vehicles with better fuel economy could be reduced by up to 30% to around two years (IEA, 2017c). Strengthening efficiency measures can also help countries improve energy security by creating a safeguard against the impact of potential rise in demand or prices in the future.

Buildings sector policy insights

Today around two-thirds of energy consumed by equipment in residential buildings is not covered by mandatory energy efficiency standards. Similarly, about half of the floor area additions projected for the period to 2050 – around 100 billion square metres (m^2) – are in countries that currently have no mandatory energy-related building codes. There are clear opportunities to introduce standards for equipment and building codes for these countries. Moreover, a significant share of the global residential buildings stock in 2050 will have been built within the next 10-15 years, indicating the need for early action to avoid lock-in of inefficient buildings and energy demand from these long-lived assets.

Chapter 2 highlighted that the 66% 2 °C scenario would require USD 11 trillion of investment for the additional energy efficiency in buildings relative to the New Policies Scenario, with a further USD 2.5 trillion for local renewable energy sources that are used directly in the buildings sector such as solar thermal.[18] Chapter 2 also highlighted that in the buildings sector, with the exception of lighting (where LEDs are cost-competitive), investments in improving energy efficiency generally have a payback period of more than five years. To deliver the required levels of investment for the clean energy system transition, carefully designed policy packages are needed to address the sometimes lengthy payback periods and other market failures and barriers that affect the buildings sector.

Table 3.2 highlights key policy measures for two main categories of energy end-use in the buildings sector:

- *Heating and cooling* of space in buildings and water heating, which are often installed during building construction or renovation and are long-lived types of equipment that typically remain with the building through a change of ownership.
- *Lighting and appliances* including cooking and office equipment, which are often installed by owners and tenants and are usually short-lived technologies that can be readily upgraded.

Table 3.2 Key policy measures and energy intensity improvements in the buildings sector in the 66% 2 °C Scenario relative to the New Policies Scenario

<table>
<tr><th>End-use</th><th>Energy intensity improvement in 2050 (%)</th><th>Key Policy Measures</th></tr>
<tr><td>Space heating</td><td>31%</td><td rowspan="6">Regulation (MEPS, compliance and enforcement, point-of-sale/lease/rental requirements, “Top Runner” standards, government procurement).
Incentives (utility obligation schemes, auctions, tax incentives at point-of-sale, lower taxes on energy efficiency, grants, loans, rebates, procurement/bulk purchase).
Information (labels, energy performance certificates, energy audits for existing buildings).
Skills (professional training programmes and accreditation schemes).</td></tr>
<tr><td>Space cooling</td><td>54%</td></tr>
<tr><td>Water heating</td><td>12%</td></tr>
<tr><td>Lighting</td><td>26%</td></tr>
<tr><td>Cooking</td><td>12%</td></tr>
<tr><td>Appliances</td><td>24%</td></tr>
</table>

Notes: MEPS = minimum energy performance standards. Energy intensity refers to the amount of energy linked to the specific end-use divided by global population. The intensity improvements in the 66% 2 °C Scenario are percentage improvements relative to the New Policies Scenario.

Heating and cooling measures

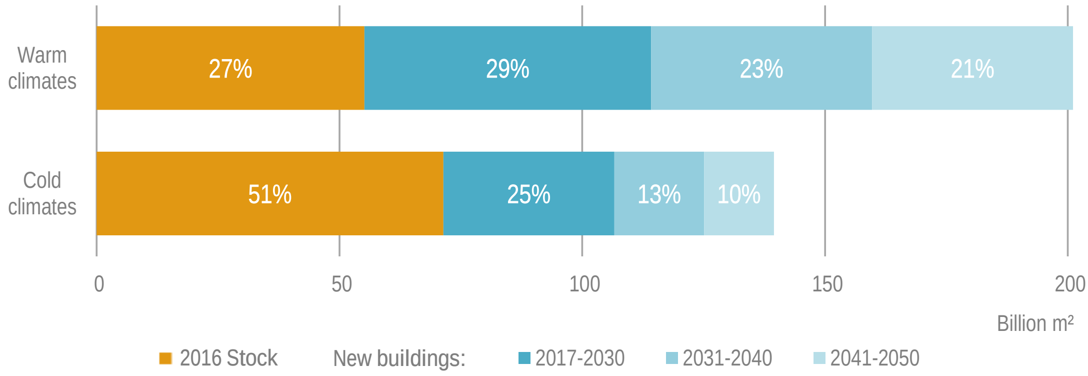
Building codes and standards are the most important measures for the construction of new buildings. Improving the efficiency of new buildings is easier and more cost-effective than renovating existing buildings. Given the long-lived nature of most heating and cooling measures, failure to tackle the thermal properties (the building envelope) at the time of construction risks the loss of a significant proportion of the most cost-effective energy efficiency potential. For example, there is the risk of locking in inefficient heating and cooling systems in new buildings that have relatively poor insulation.

[18] This investment figure excludes photovoltaics in buildings which are treated as part of power generation, requiring an additional USD 450 billion.

This means that policy makers need to urgently prioritise the coverage of codes and standards and progressively strengthen them towards near-zero emissions levels. Technology neutral standards that specify energy- or climate-related performance levels allow developers to be innovative and choose least-cost solutions. Ensuring compliance with new building codes and monitoring performance once completed is particularly important in buildings, and policy design should explicitly include these elements. Third-party accreditation of building professionals and service installers can improve compliance. Demonstration buildings and temporary financial incentives for best available technologies can also give a boost to the market and can help raise the bar on efficiency in subsequent building code revisions.

Unlocking the investment required to renovate the existing building stock would be key to achieving the 66% 2 °C Scenario. Over half of the residential buildings that will exist in cold climates in 2050 have already been built and in warm climates 27% of the 2050 stock already exists (Figure 3.4). In the 66% 2 °C Scenario, most of these buildings would need to have some form of deep renovation over the period to 2050. This is a tremendous challenge for policy makers, investors and energy efficiency market players.

Figure 3.4 Floor area in residential buildings in 2050 by construction date



A rapid increase in new residential buildings in warm climates will require early adoption of building codes to limit the energy required for mechanical cooling.

In contrast to new buildings, codes and standards generally have a more limited role in improving the efficiency of the existing building stock. There are examples however, such as in England and Wales, where MEPS have been introduced recently for rental properties (UK Government, 2017).[19] The efficiency levels of buildings can also be linked to incentive measures, such as variations in annual property and point-of-sale taxes. Even though the impact of such measures may be low initially, it is important to send signals to the market, setting expectations of increased future performance requirements. Mandatory regular energy audits play a key part in ensuring compliance and accuracy of these kinds of policy measures.

[19] Under these regulations, it is unlawful to rent a property with an Energy Performance Certificate lower than level E, which is on the lower end of the energy performance rating spectrum that ranges from A (best performer) to G (worst performer). To avoid excessive costs and other issues, there are some exceptions to the requirements. This A-G rating scheme applies across the European Union.

For renovating existing buildings, non-regulatory measures will need to be employed. For example, in Italy, fiscal measures have been used to successfully drive energy-efficient building renovations in residential and non-residential buildings. Under the scheme, building owners can reduce up to 75% of the taxes paid on a diverse range of eligible technologies, up to a maximum spend of EUR 100 000 (Euro). The reward for building owners has been two-fold: improvement in energy efficiency and reduction in personal or corporate income taxes. While the state receives less tax revenue related to sales of efficient building equipment, the scheme was designed to be budget positive, resulting in a net increase in tax revenue of around EUR 8.8 billion over the lifetime of the measure (discounted figure for 2017), thanks to projected increases in value-added tax and income tax stimulated by the scheme (ENEA, 2017).

The nature of energy efficiency investments for renovating buildings – upfront investments to deliver long-term financial savings and other benefits – means that there is significant scope for innovative business models to increase the flow of investment and finance. Financial innovation has been underway for some time and some financial products already are considered mature, such as dedicated credit lines, energy performance contracting, covered bonds and leasing. Additionally, in the residential sector, unsecured finance and secured finance (e.g. re-mortgage) have long been used for financing energy-efficient homes. Increasing requirements on existing homes may help to drive the mortgage market. For example, if non-renovated homes become a resale risk as a result of not meeting resale requirements, banks may be enticed to provide greater access to preferential rates to reach new performance requirements.

There are other emerging financial products and business models that may provide additional funds and investment for energy efficiency, such as:

- Energy service agreements (e.g. with ESCOs) – pay-for-performance service contracts between a third-party investor and an asset owner to deliver energy savings as a service.
- On-bill financing and repayment (e.g. California utilities that pay the upfront efficiency investment which are then repaid via utility bills).
- On-tax finance (where upfront financing by private capital is repaid via long-term tax bills).
- Community energy finance (usually a local community using a co-operative structure).

Both on-bill repayment and on-tax finance (utility and tax bills) have the potential to significantly grow the energy efficiency investment markets in commercial and residential buildings. The improvement and additional certainty around the default risks together with their resolution of the split incentives (between owner and occupant, and over time) and their successful initial use in the United States make them key emerging financial instruments to improve finance flows to energy efficiency investments to private sector buildings.

Incentives and financial support can be used to encourage the kind of deep renovations or retrofits that would be required for the 66% 2 °C Scenario.[20] For example, under the French Energy Transition Law for Green Growth (LTECV), there are incentives and interest-free loans for the bundling of renovation works. Similarly, the German framework of incentives and finance provided

[20] While definitions of deep renovations and retrofits vary, this report considers building envelope energy efficiency improvements of between 50% to 75% or more.

by the German development bank (KfW) and the national government, provides progressively higher levels of incentives as the efficiency improvement increases. Ultimately, the challenge is to stimulate a renovation market that leads to broad-scale, deep interventions across the existing building stock. Energy audits can play an important part in helping to build an accurate picture of the performance of existing buildings, which can in turn inform roadmaps for achieving deep renovations. Innovative financing and incentives, accompanied by training and accreditation measures to ensure consistency and quality of interventions, are further key policy ingredients for policy makers to consider.

Lighting and appliance measures: Implications and best practice

The main policy approach for delivering more efficient equipment under the 66% 2 °C Scenario would be to set stringent MEPS supported by energy labels, which would be ratcheted up over time. Currently, more than 80 countries have implemented mandatory MEPS and labels for major energy-using equipment (EES and Maia Consulting, 2014). Under these programmes, 75% of global lighting energy consumption, 50% of electric motors and 30% of the global energy consumption by appliances currently are covered by these minimum performance regulations (IEA, 2017d). Even though mandatory MEPS are in place for these products, their stringency levels vary considerably across the globe.

MEPS can be very effective policy instruments (Box 3.4), and increasing the coverage of MEPS to other countries is a relatively straightforward policy opportunity. The two main challenges lie in setting standards at a sufficiently stringent level and ensuring compliance. Aligning with neighbouring countries should make regulations easier to implement and enforce. Initially, for some emerging economies the requirement levels may not be as stringent, but over time they should converge with global best practice. International support may be needed for large-scale transition.

MEPS also require strong institutions if they are to be implemented and enforced effectively. Institutional capacity building can be important, especially for economies new to these programmes (discussed in the Strengthening Institutional Capacity section.)

Improvements in efficiency can be obtained without significant increases in consumer purchase prices (Box 3.5). There are many well-known market barriers which hamper the accelerated uptake of energy efficiency lighting and appliances. A common barrier is that consumers do not have adequate information on the product's energy elements to make an informed choice. Another barrier is the "principal agent issue" in which those buying the equipment do not pay the energy bills. In some cases, the energy efficiency benefits are bundled with other features such as size that can make the purchase price for high efficiency products more expensive than their less feature-laden counterparts.

Given these challenges, a market transformation approach – beginning with policy intervening early in the supply chain (e.g. at the point of manufacture and/or sale) – is more cost-effective than forcing early replacement or removing equipment after it has been purchased (see Figure 3.3).

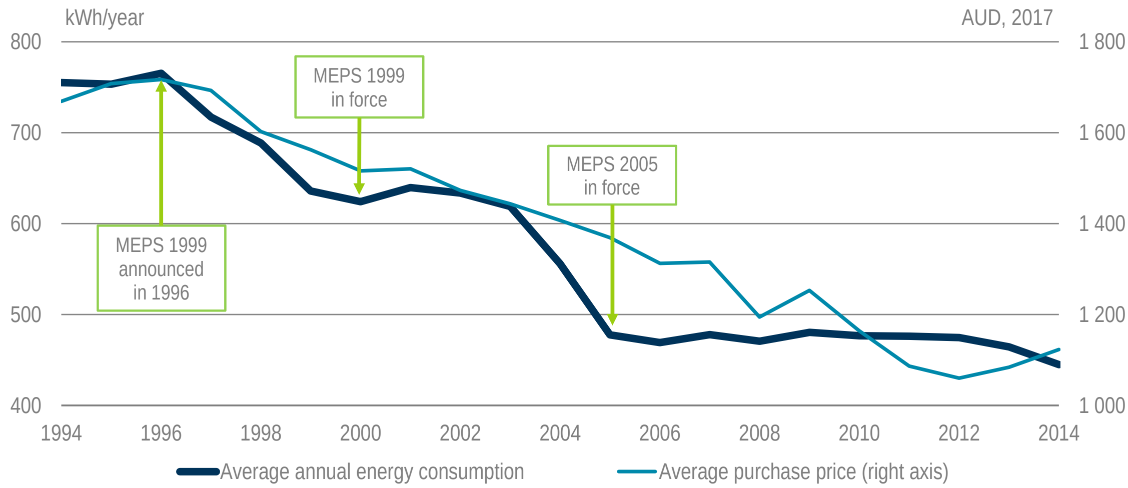
Box 3.4 Effective minimum energy performance standards can deliver significant energy savings

Minimum energy performance standards (MEPS), reinforced by energy labelling, is a strategic policy combination that has proven to be highly effective at improving efficiency of new appliances. These policies have provided multiple other benefits such as improved comfort levels, reduced water consumption and lower emissions (IEA-4E, 2016).

In Australia, a significant reduction in the average energy consumption of new refrigerators has been driven largely by MEPS (Figure 3.5). In two successive rounds of MEPS, the average consumption of new refrigerators declined by around 40%. In 2001 at the time of announcing the MEPS to become effective in 2005, no products on the market could meet the standards. Over the same period the average consumer purchase price fell. In the absence of MEPS, the efficiency of the products on the market would not have improved (E3, 2017; Harrington, 2017).

Similar findings are evidenced in other markets. In the United States, for example, four rounds of MEPS for refrigerators (1990, 1993, 2001 and 2014) drove average efficiency improvements of 4% per year and average purchase price reductions of 2.5% per year from 1989 to 2010 (Van Buskirk et al., 2014).

Figure 3.5 Relative energy consumption of new refrigerators in Australia, 1994-2014



Notes: kWh = kilowatt-hour; AUD = Australian dollars.
Source: Based on E3 (2017) and Harrington, L. (2017).

Two rounds of MEPS have cut the average energy consumption of refrigerators by 40% since 1993 while purchase prices declined.

Other approaches can be used to support MEPS by helping to "pull" the market, i.e. voluntary measures to encourage the more efficient offering on the market. They include information and targeted incentives to promote the best available equipment and practices. Measures that support very high efficiency also bring forward innovation and lower future costs of increased efficiency. Measures to help spur innovation and market penetration include research and development (R&D) support and aggregated technology procurements to underpin market entry for new high efficiency equipment.

Augmenting the use of MEPS and labels, additional measures can help to rapidly transform markets. In emerging economies, using fiscal measures and funding widespread installation of new equipment may be appropriate. Their objective should be to cost-effectively transform markets while supporting efficient and innovative technologies. For example, in 2010, Bangladesh's government, with support from the World Bank, procured and distributed more than 10 million energy-efficient compact fluorescent lamps. In this case, the government used bulk purchasing power to alter the market towards more efficient lamps without new standards or labels, and avoided the need for 300 megawatts (MW) of generating capacity. United for Efficiency (U4E) – a public-private partnership led by the United Nations Environment Programme (UNEP) and others – provides extensive guides and tools to inform policy makers as they develop their approaches to MEPS (U4E, 2018). Similarly, CLASP, a non-profit organisation, provides extensive guidance on how to effectively use MEPS and supporting policy for lighting and appliances (CLASP, 2005). In general, support measures should not be used to subsidise technologies that only offer average efficiency levels.

There are other regulatory approaches to setting mandatory MEPS. For example, Japan uses an approach known as "Top Runner" where the current best practice performance levels become the future minimum standards (Siderius and Nakagami, 2013). The target levels are discussed in detail with the relevant industry to ensure the appropriateness of the targets. This approach in Japan has delivered outcomes similar to MEPS in other countries (IEA-4E, 2014; Siderius and Nakagami, 2013). In the Top Runner case, it is more difficult to independently verify the outcomes, but there is a culture to ensure compliance.

Box 3.5 What is the cost of increased efficiency?

In the United States, Europe and other economies, the MEPS thresholds are usually set at a level to minimise the life cycle costs (i.e. the purchase costs plus running costs) to consumers. Additional efficiency may cost more, and potentially mean higher purchase prices, but these costs are offset by lower consumer energy bills.

The cost of the additional efficiency in these life cycle assessments is based on detailed engineering examinations of the equipment cost rather than the purchase price. Though the impact of the design cost on purchase price is inferred, so as to undertake consumer life cycle analysis. Recent research suggests that these ex-ante engineering cost estimates are overestimating the actual cost of incremental efficiency gains following the regulation (ACEEE, 2015; Desroches et al, 2013).

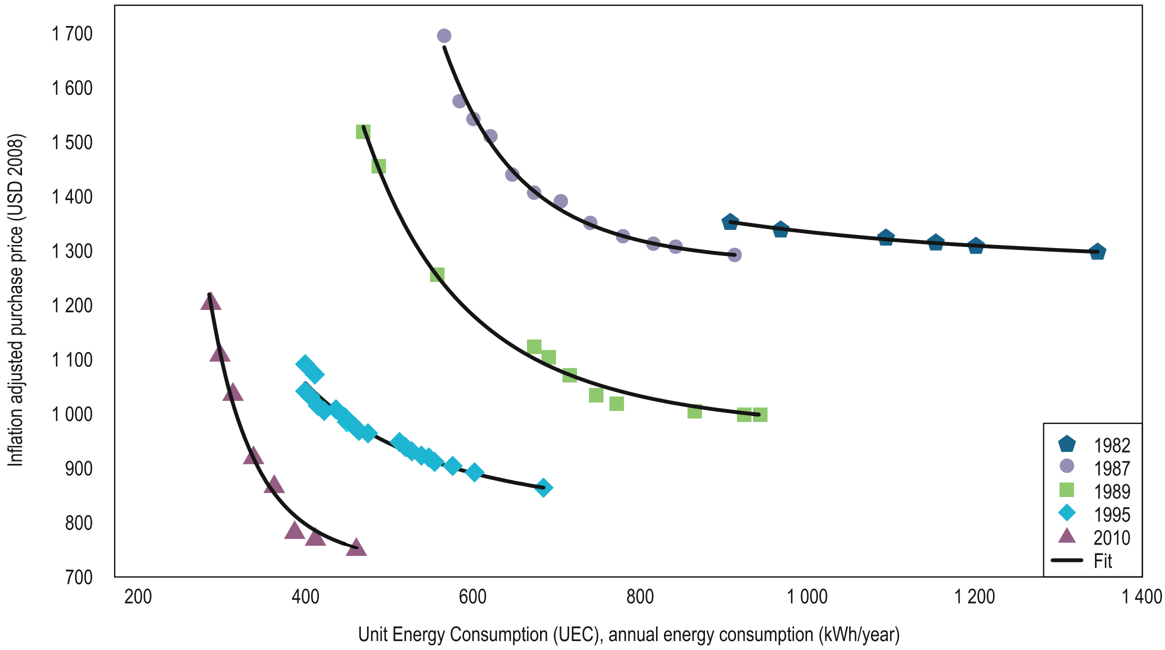
For example, the United States first introduced national MEPS for refrigerators in 1987, with three subsequent updates. They delivered significant reductions in energy consumption and corresponding falling purchase prices. An engineering analysis was based on industry costs of efficiency improvements, which were also translated to consumer prices. Figure 3.6 shows the historic sequence of price efficiency engineering estimates for a 17-18 cubic foot refrigerator with top-mount freezer and automatic defrost, for each of the MEPS revisions (Van Buskirk et al., 2014). Over the period considered, the efficiency of the least efficient refrigerator on the market improved at an average rate of 4% per year while its price dropped 2.5% per year.

This analysis also suggests that the expected price increases from better efficiency have not led to higher purchase prices because of innovation and learning-by-doing in appliance design and production. The United States now incorporates the learning effect in setting mandatory MEPS (Desroches et al., 2013).

Such analysis is not new: other researchers have observed a robust long-term decline in both specific price and specific energy consumption of large appliances, e.g. IEA 4E mapping and benchmarking studies.[21] One analysis found that the specific price of wet appliances decline at learning rates[22] of 29±8% and cold appliances at 9±4% (Weiss et al., 2010). Their results demonstrate that technological learning leads to substantial price decline, thus indicating that the introduction of novel and initially expensive energy efficiency technologies does not necessarily imply adverse price effects in the long term. Their analysis suggests that effective energy policy might be able to bend down energy experience curves, which would mean investment costs are lower than projected.

The energy savings and investment analyses undertaken in this report are also based on engineering costs, with costs declining over time. How such costs will eventually materialise in prices critically will be determined by policy considerations.

Figure 3.6 Price efficiency engineering estimates for ex-ante assessments of MEPS rounds in the United States



Source: Van Buskirk et al. (2014). A retrospective investigation of energy efficiency standards: policies may have accelerated long-term declines in appliance costs, http://iopscience.iop.org/article/10.1088/1748-9326/9/11/114010/meta

Engineering cost/price efficiency analysis over time shows that the starting base case, on average, used less energy while the purchase price was lower.

[21] The IEA Technology Collaboration Programme on Energy-Efficient End-Use Equipment (4E) undertakes mapping and benchmarking of lights and appliances to understand product performance and energy consumption (IEA-4E, 2016). More information at: www.iea-4e.org/.

[22] Learning rates in this report show the estimated average fall in price for each doubling of production.

Industry sector policy insights

Chapter 2 highlighted that under the 66% 2 °C Scenario, aggregate industrial energy intensity would decline from USD 174 million per tonne of oil equivalent (toe) in 2016 to USD 88 million/toe in 2050. To achieve this reduction in energy intensity, cumulative additional investment to 2050 would be just under USD 2.7 trillion, relative to the New Policies Scenario.

Much of the additional investment in industry required to meet the 66% 2 °C Scenario would pay back within three to five years in the energy-intensive sectors and in less than three years in the light industry sector, as shown in Chapter 2. The combination of carbon pricing and reductions in technology costs with deployment are significant factors in bringing down payback periods and imply that most policy effort should be focused on removing traditional market barriers for energy efficiency in the industry sector in order to:

- Increase the adoption of energy management systems.
- Shift activity towards less energy-intensive production routes.
- Support innovation to improve the efficiency of industrial equipment and reduce capital costs.
- Encourage the adoption of new business models, especially for projects with long payback periods.

Table 3.3 Key policy measures and energy intensity improvements in the industry sector in the 66% 2 °C Scenario relative to the New Policies Scenario

<table>
<tr><th>Industrial energy efficiency</th><th>Intensity index (2016 = 100)</th><th>Efficiency index (2016 = 100)</th><th>Investment to 2050 beyond NPS (billion USD)</th><th>Key policy measures</th></tr>
<tr><td>Total industrial energy efficiency</td><td></td><td></td><td>2 725</td><td></td></tr>
<tr><td>of which heat pumps</td><td></td><td>128*</td><td>259</td><td>Strengthened performance standards.
Support for third-party financing and ESCOs.</td></tr>
<tr><td>of which VSD, electric motors and driven equipment</td><td></td><td>148**</td><td>265</td><td>Strengthened performance standards.
Incentives for replacement of existing less efficient motor units.
Support for third-party financing and ESCOs.
Policies to support adoption of EMS.</td></tr>
<tr><td>Subsector energy efficiency</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Iron and steel</td><td>60</td><td></td><td>406</td><td rowspan="6">Sector-wide targets and agreements.
Support for the increased adoption of EMS.
Innovation and R&D through public-private partnerships.
Availability of finance to support implementation of measures with payback periods more than four years.
Incentives for use of products from secondary processing routes.</td></tr>
<tr><td>Cement</td><td>82</td><td></td><td>94</td></tr>
<tr><td>Chemicals and petrochemicals</td><td>74</td><td></td><td>384</td></tr>
<tr><td>Aluminium</td><td>59</td><td></td><td>94</td></tr>
<tr><td>Pulp and paper</td><td>59</td><td></td><td>266</td></tr>
<tr><td>Other industry</td><td>59</td><td></td><td>1 481</td></tr>
</table>

*Global average industrial heat supply efficiency. **Global average industrial electric motor systems efficiency.

Notes: VSD = variable speed drives; ESCOs = energy service companies; EMS = energy management systems.

The importance of electric motor-driven systems in light industry

Electric motor-driven systems are responsible for over 50% of global electricity consumption, with even higher levels of electricity consumption in the industry sector – over 70% in some countries and regions. China is responsible for the majority of global electricity demand in industrial motor-driven systems – 42% in 2014 – and will continue to be responsible for the majority of future electricity demand, though there is strong growth in India and other emerging economies.

MEPS for electric motors have been established and strengthened in many economies for an extended period. By the end of 2016, over 50% of industrial motor energy use was covered by a minimum performance standard. However, if all industrial electric motors currently in operation were replaced, coverage would increase to more than 90%. This "coverage gap" is due to the long operational life of electric motors – 15 years or more – meaning that inefficient motors can remain in operation for a long period, despite the presence of MEPS for new motors. Policy measures to ensure that inefficient motors are replaced at the end of their operational life or to encourage early replacement can unlock efficiency benefits. Such measures may include third-party finance to support the cost of upgrading motor units and support for energy service companies (ESCOs)

Continued adoption and strengthening of MEPS for motor units is an important policy measure. However, efficiency gains become more marginal due to the already high efficiency levels of existing motors. Therefore further gains must be obtained through improvements to the entire motor-driven system. Such improvements include the increased installation of variable speed drives (VSDs), which allow motor power demand to be varied depending on the service being provided, improved design and efficiency of end-use devices, such as pumps, fans and compressors and improvements across the wider motor-driven system which include improved maintenance practices and reduction in unnecessary motor use. The introduction and strengthening of standards can drive an uptake of VSDs and more efficient end-use devices. However, given that a VSD can be installed into an existing motor system with relative ease, wider deployment could potentially be achieved through the expanded use of ESCOs.

Despite technological improvements, the majority of energy efficiency improvements associated with electric motor-driven systems in the 66% 2 °C Scenario would need to come from system improvements. Measures include reducing leaks and unnecessary use, and improving operation and maintenance practices. The key to unlocking the efficiency gains from these system-wide measures is the increased adoption of energy management systems.

Use of electric heat pumps is a good example of how an electric motor-driven system in light industry can contribute to efficiency improvements. Increased adoption of electric heat pumps as an alternative to gas- or oil-fired boilers presents an opportunity for industrial firms to improve energy efficiency and reduce direct GHG emissions. Today, electric heat pumps are best suited to low-temperature applications (less than 100 °C), which are most prevalent in light industries such as food processing and textiles. Low-temperature industrial applications are estimated to account for over two-thirds of projected growth in industrial heat demand. The increased adoption of electric heat pumps will be an important driver of future efficiency gains.

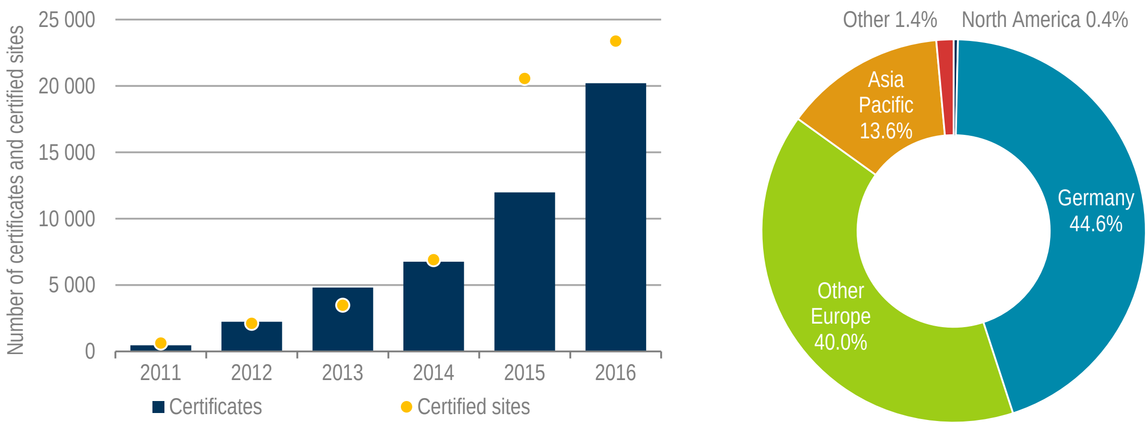
The adoption of particular energy-efficient technologies can be boosted with special tax treatment such as accelerated depreciation. This provision allows a company to write-off the value of certain assets more rapidly than the lifetime of the asset, or in their entirety, reducing the total cost of the equipment over its operating life. Such schemes are often based on product lists, which outline what energy-efficient technologies are eligible. Making equipment such as VSDs for electric motors or electric heat pumps eligible on the product would provide stimulus for their adoption.

Installing VSDs for electric motors and electric heat pumps are opportunities for industrial energy efficiency that can be replicated at scale and as part of smart energy management systems. It is an example of where ESCOs, operating with a supportive policy and financing environment, could facilitate more widespread adoption. (This is explored further in the finance section.)

Energy management systems

Energy management systems (EMS) provide the procedures and practices for an industrial firm to ensure the systematic planning, analysis, control and monitoring of energy use in order to continuously improve efficiency. An EMS can take many forms, but, since its launch in 2011, the global standard is ISO 50001. By the end of 2016, there were around 20 000 ISO 50001 certifications worldwide, covering nearly 24 000 sites. Nearly 85% of these certificates were obtained by companies in Europe, with Germany having the world's largest number of certificates (Figure 3.7).

Figure 3.7 ISO 50001 certificates and certified sites, 2011-16 (left) and regional allocation of certificates, 2016 (right)



More than 20 000 ISO 50001 certificates for industries were in place in 2016, 40% of which were in Germany.

ISO 50001 has become a central focus of energy management programmes in industry in many countries, including Germany, Indonesia, Korea and the United States. So far in China, the adoption of ISO 50001 has been limited as the major industrial energy efficiency policy, where the Top 10 000 Programme, incorporates an equivalent Chinese energy management standard (GB/T 23331).

Energy management programmes are intended to drive an increased adoption of EMS, such as ISO 50001 through direct regulation, incentives or information. An example of an incentive-based policy is in Germany, where companies are eligible for sizeable reductions in environmental and energy taxes following the implementation of an ISO 50001 certified EMS. This scheme has been successful in Germany where it is projected that nearly half of the global total ISO 50001 certifications by the end of 2020 will be held. In the United States, the Superior Energy Performance (SEP) Program provides companies with information and assistance to implement ISO 50001, with third-party verification of implementation and performance leading to SEP certification and public recognition. Regulatory measures can mandate the implementation of an EMS, such as in Indonesia, where industrial firms that use more than 6 000 tonnes of oil equivalent (toe) per year are required to implement an EMS in accordance with ISO 50001.

All energy management programmes have challenging aspects. As implementation of an EMS does not guarantee efficiency improvements, some incentive schemes have coupled their implementation with agreed targets for improvement of energy efficiency (e.g. the Long-term Agreements in the Netherlands). Regulations provide the most likely degree of certainty that an EMS will be implemented. However, without incentives to go beyond the legal requirements, regulatory measures can see focus switch to minimum compliance, rather than the needed step change in energy efficiency improvements.

Several countries including Canada, China, Germany and Mexico are seeking to increase the adoption of EMS by establishing energy efficiency learning networks. These networks bring together industrial companies from the same sector, region or supply chain to collectively set objectives to improve efficiency, share experiences and receive training, with a key topic being how to implement an energy management system. Germany has set an ambitious target to establish 500 energy efficiency learning networks by 2020. Mexico is looking to leverage its experience to assist with the establishment of networks in other Latin American countries, including Argentina.

Increased adoption of EMS would be essential to unlocking the energy efficiency improvements in the 66% 2 °C Scenario. This is not just for motor-driven systems, but across all industrial subsectors. Recent analysis suggests that companies that implement ISO 50001 or similar EMS can realise substantial efficiency improvements, resulting annual energy and financial savings of over 10% (IEA, 2017d). Policy makers could also consider whether to mandate or incentivise the realisation of certain measures (such as those with a two- or three-year payback period) identified by energy management systems and/or energy managers.[23]

Other industry sector measures

Improvements in resource efficiency will be important drivers of future efficiency gains. *Secondary production routes*, such as the production of steel, aluminium, paper and plastics from collected scrap or waste products, are significantly less energy intensive than primary production routes. As an example, the global average energy intensity of producing secondary steel using collected scrap is more than 60% lower than the production of primary steel through the coke oven-blast furnace-basic oxygen furnace route, which today is the most common form of production (IEA, 2017e).

[23] Policy makers need to exercise caution with such an approach to ensure that the realisation of projects with short payback periods do not undermine the business case for more extensive projects (with a longer payback times) that can deliver significant energy savings.

Box 3.6 Australia's Co-operative Research Centres

Australia's Co-operative Research Centre (CRC) Programme commenced in 1991 with the aim of fostering high quality research to solve industry-identified problems, through collaborations between industry, researchers and the community. The programme contains funding streams for medium to long-term research (CRCs) and short-term research projects (CRC-Ps).

CRC grants provide successful applicants with access to funding for up to ten years. To be eligible the CRC must include at least one Australian industry association and one Australian research organisation. CRC-P's provide successful applicants with grant funds for up to three years and must include two Australian industry associations, including one small or medium-size enterprise (SME), and one Australian research organisation.

Several CRCs have included a focus on improving the energy efficiency of industrial activity, with a notable example being the CRC for Optimising Resource Extraction (CRC ORE), which commenced in mid-2010. CRC ORE has the explicit aim of improving the productivity of mining operations, including energy and water efficiency. Key innovations developed by CRC ORE include an integrated extraction simulator, which models the impact of an entire mining process and maps its impact onto a virtual mineral deposit to allow mining companies to determine the impact of extraction in certain locations. The work of CRC ORE is supported by seven mining companies, seven technology providers and ten research organisations. To date the CRC ORE has gathered support of more than AUD 110 million in investment, with AUD 34.4 million from the Australian government and the remainder from other participants.

Sources: www.business.gov.au/assistance/cooperative-research-centres-programme; www.crcore.org.au/.

The ability to improve the energy efficiency of energy-intensive industry subsectors by increasing the use of secondary process routes is limited by the availability of scrap or waste material. Therefore, policy measures aimed at increasing scrap collection and recycling rates can assist in shifting production towards less energy-intensive secondary production routes. Measures aimed at incentivising or encouraging the consumption of recycled products, such as labelling or standards requiring the inclusion of a percentage of recycled materials in standard product mixes, can also increase market demand for recycled products and drive higher output through more efficient secondary production routes.

Improvements in materials efficiency – delivering the same material service with less overall production of materials – also contribute to better resource efficiency. Efficiency gains are possible through the use of improved product designs, which reduce raw material input. Incorporation of these better product designs into appliance and equipment standards will push the market to enhance material efficiency and limit consumption of appliances and equipment produced through more energy-intensive routes.

Policy action on resource efficiency has included the launch of the G7 Alliance on Resource Efficiency, which is a forum for sharing knowledge and promoting best practice established by G7 leaders. Strategies and targets have also been developed in China, Europe and Japan. The IEA is also increasing its efforts to highlight the benefits of improved resource efficiency. An, example is the Future of Chemicals project, which is part of a series of reports exploring the implications for energy and the environment of critical energy demand areas. The forthcoming analysis will cover key aspects of chemicals production such as upstream impacts on oil and natural gas demand, knock-on effects of consumer product demand and waste management strategies on different production routes, as well as strategies to support a sustainable transition such as energy and material efficiency, and technology innovation.

Continued support for *innovation and R&D* is particularly important for the industry sector. Innovation is necessary to improve the design and operation of industrial equipment and production processes, and to reduce the capital cost of energy-efficient equipment, making investment more attractive. At present, support for industrial R&D and innovation includes government funding for universities and research centres, and internal research conducted by industrial firms. Partnerships between government, industry and universities have also been effective at driving innovation within industry, an example being Australia's Co-operative Research Centres (Box 3.6).

Energy efficiency targets for industry subsectors and companies

Some governments have implemented subsectoral and company level targets to drive improvements in industry energy efficiency. These targets are implemented using either regulation, in which companies and sectors are required by law to achieve specified efficiency targets; or voluntary agreements, where companies agree to an energy efficiency target, in return for a reduced tax burden or other financial incentive.

Regulation has been used to implement energy efficiency targets in China, India and Japan. The Chinese Top 10 000 Programme, which built on the previous Top 1 000 Programme, is mandatory for the largest 10 000 energy-using enterprises in China. National industry energy intensity improvement targets are set, which are transposed into subsector targets and then passed down to regional and local level targets and ultimately to company level targets. Individual plants must meet targets or face potential closure, although rewards are also available to the most efficient plants in terms of preferential energy prices.

In India, the Perform, Achieve, Trade Scheme sets mandatory energy performance improvement targets for designated consumers in select energy-intensive sectors. Companies that exceed their targets generate energy savings certificates, which can be sold to companies that are not able to meet their specified targets. In Japan, a mandatory energy efficiency benchmarking policy was implemented in 2010, which requires large energy users to set efficiency targets by subsector, with an obligation to improve efficiency by 1% per year.

Voluntary agreements have been a component of industrial energy efficiency policies in Europe for many years. In the United Kingdom, companies can voluntarily agree to Climate Change Agreements (CCAs), which involve either energy or GHG emissions reduction targets. To incentivise involvement, companies entering CCA agreement receive a reduction in the tax burden associated with the UK's Climate Change Levy. In the Netherlands, long-term agreements with industry have been in place since 1992. Through these agreements companies voluntarily agree to develop energy efficiency plans every four years and develop roadmaps to reduce GHG emissions by 50% by 2030. To incentivise involvement, companies that have a long-term agreement with the government pay a lower energy tax.

Energy efficiency targets for industrial sectors and companies provide policy makers with greater certainty that efficiency improvements will be achieved. Mandatory targets provide the greatest certainty, but are not politically feasible in all jurisdictions and can lead to a minimal compliance approach, where companies only achieve what is required, unless incentivised to seek further improvements. Voluntary schemes can lead to companies pursuing ambitious improvement objectives, but policy makers need to consider what type of incentives are most effective at encouraging participation. The ability to set strong company or subsector level targets is also complicated by the fact that many industrial firms operate in multiple countries and outputs are traded across national borders. Concerted action on industry energy efficiency across different countries would make it easier for individual countries to set targets consistent with meeting the 66% 2 °C Scenario.

Transport sector policy insights

Over 90% of transport energy use is dependent on oil products, with transport accounting for 28% of global final energy consumption in 2016. Less than 30% of global transport energy use in 2015 is covered by mandatory energy performance standards (IEA, 2017d).

Chapter 2 showed that in the absence of modal shifts in transportation,[24] the increased energy efficiency needed in the 66% 2 °C Scenario would require just above USD 9.1 trillion more investment (cumulative to 2050) than the New Policies Scenario. Of these funds, USD 3.6 trillion would be required to stimulate the switch from internal combustion engines to more efficient electric vehicles (EVs). The higher uptake of EVs in the 66% 2 °C Scenario would mean investment in conventional fossil fuel vehicles is likely to decline relative to the New Policies Scenario (by around USD 2.0 trillion).

The formulation of long-term transport efficiency targets is essential to provide certainty to the market on the direction of policy. A series of specific policy measures will be needed to bring forward the efficiency gains across the various transport modes (Table 3.4). The general approach will be similar to other sectors, including:

- *Regulation* - Ratcheting up fuel efficiency standards (such as corporate average fuel efficiency, and zero-emission mandates). This will be the most important policy tool to encourage future efficiency improvements beyond the initial market introduction of fuel saving technologies and to ensure that efficiency targets are being met.
- *Information* - Provision of running costs and efficiency information to consumers as well as fleet managers that purchase or lease vehicles.
- *Incentives* - Creation of incentives and disincentives, at the points of purchase/lease and operation, to switch to higher efficiency options including EVs.

[24] The 66% 2 °C Scenario does not explicitly examine reductions in demand for mobility or the consequences of modal switching or shifting. (See Box 3.8)

Table 3.4 Key policy measures and energy intensity improvements in the transport sector in the 66% 2 °C Scenario relative to the New Policies Scenario

End-use	Energy intensity improvement (2050)	Investment to 2050 beyond NPS	Key policy measures
All modes		USD 9.1 trillion	Establishing a long-term vision for efficiency improvements and emissions reductions, including clear targets for each transport mode. Include externalities in cost-benefit assessments. Fuel pricing/taxes.
Passenger cars	68%		Vehicle efficiency and emissions standards. Purchase rebate or purchase tax exemption. Differentiated vehicle tax based on efficiency performance. Zero-emission vehicle mandates. Incentives for R&D and infrastructure deployment (e.g. EV charging stations.) EV access to priority lanes, waivers on road tolls, ferries, etc. Labelling of operating costs and emissions profiles.
Buses, coaches	47%		Vehicle efficiency and emissions standards. Public procurement promoting low-carbon vehicles. Correct sizing and integrating bus and emerging mobility services to high-capacity public transport.
Trucks	63%		Vehicle efficiency and emissions standards harmonised across countries. Differentiated vehicle taxation based on efficiency and GHG emission performance. Purchase tax rebate or exemption. Low interest loans for energy-efficient trucks. Targeted scrappage of very old inefficient vehicles. Standards and labels on components (e.g. tyres, engines). Standardise use of technologies e.g. that reduce the influence of driver behaviour. Mandatory CO_2 reporting.
Rail	41%		Support for the use of zero-emission technologies (battery, electric, hydrogen) on tracks that are not economical to electrify with overhead lines.
Aviation	70%		Tightening of energy efficiency regulations at the international level.
Shipping	63%		Tightening of maritime fuel efficiency and emissions standards at international level. Enabling proper monitoring of energy efficiency of ships. Electrification of ships operated on short distance routes.

Light-duty vehicle measures: policy implications and best practice

The decline in average fuel consumption of new light-duty vehicles (LDVs), which include passenger cars, light trucks and sport utility vehicles (SUVs), has slowed in recent years, reflecting increasing sales of bigger passenger cars and SUVs. The decline may be influenced by relatively low gasoline prices in recent years. In the same period, the sales of EVs, which are generally more energy-efficient and can have lower emissions than equivalent internal combustion engine vehicles) expanded worldwide by 40% in 2016, though the global market share of EVs is only around 1% (IEA, 2017f).

Efficiency improvements for passenger cars in the 66% 2 °C Scenario would require both increasing the efficiency of conventional engine vehicles (such as through material substitution to reduce vehicle weight and low rolling resistance tyres, as well as power train improvements) and shifting to efficient EVs. Economic considerations are likely to support such a transition; as discussed in Chapter 2, the payback period for efficiency technologies on conventional vehicles is expected to increase over time as further efficiency improvements become increasingly expensive. Conversely for EVs, payback periods are likely to fall as battery costs decline with increased production volumes.

The required upfront investment for vehicle efficiency measures pays back during the lifetime of all vehicles, as shown in Chapter 2. However, such a payback may still be beyond what most consumers would deem acceptable, and thus represents a barrier to efficiency uptake. Well-designed policy interventions therefore are essential. The primary policy tools will be fuel efficiency (or carbon emission) standards, along with zero-emission vehicles (ZEVs) mandates which have shown to work well (e.g. California ZEV mandates). Around 55% of the light-duty vehicle stock was covered by mandatory efficiency standards in 2016 (IEA, 2017d). These standards are well developed, understood by policy makers and can be extended to economies which do not yet employ these instruments, where the standards would need to be ratcheted up over time to support delivery of the 66% 2 °C Scenario. These are consistent with the long-term levels laid out by the Global Fuel Economy Initiative (Box 3.7).

To support such standards, information on the running costs of cars, for example by energy labels, can facilitate a fairer comparison across a range of vehicles. Such information, while useful to consumers, also allows policy makers to track progress and guide future incentives and finance models linked to efficiency.

As EVs are currently more expensive to purchase than conventional cars, in the short term, additional incentives may be necessary to develop the market. Public procurement is important to support early market development. Beyond this initial phase, incentives making plug-in electric vehicles (PEVs) competitive with their conventional alternatives have been shown to effectively stimulate market uptake. These incentives can be designed in a way that is revenue-neutral across all vehicle sales; taxes raised from the sale of inefficient cars can provide subsidies for more efficient alternatives and for EVs (such as the "feebate" schemes in California and the bonus/penalty system in France), or be channelled towards supporting public transport. Vehicle registration taxes can be complemented by differentiated taxes on vehicle usage and policies aiming to facilitate the expansion of charging infrastructure. All these instruments can be reinforced by local incentives for EVs, for example, preferential parking rates, free charging and priority access to parts of the road network. Norway, which currently has the highest market share of EVs (39% of vehicle sales in 2017), provides an excellent case study on how such measures can be combined to generate rapid uptake of EVs (IEA 2017f; IEA 2018a).

Although the sales of EVs are rising rapidly, further development in battery life and performance is still needed to ensure this transition continues, spreading from the early adopters to the rest of the market. This requires a focus on innovation and R&D investment, which is also important to support the development of competitive industrial clusters in a field that requires significant changes with respect to incumbent technologies. Such developments can be aided by public procurement and R&D to help create new market demand, and also bring down future costs.

Scrappage schemes are another measure that has been used in recent years to incentivise the replacement of old vehicles with more efficient new ones. While past schemes have been challenged due to their high cost (Foster and Langer, 2011) and potentially negative life cycle assessments (Brand, Anable and Tran, 2013), their main role for increasing energy efficiency can be where a rapid change and early replacement of an inefficient stock is required. For example, if other policy actions to shift towards a clean energy pathway are delayed, this improves the case for this type of (potentially expensive) measure.

A move towards electrification of the vehicle stock may also be expedited through other societal and technological developments which aid the capitalisation of these new technologies. Examples include the increased use of shared vehicles or autonomous vehicles. Such developments may be a result of new business models around mobility, which could increase the earlier adoption of EVs (and their "capitalisation"), to allow them to be more cost-effective, with shorter payback periods, enabling a faster uptake, with consequential benefits for energy efficiency and carbon dioxide (CO_2) emissions.

Box 3.7 Global Fuel Economy Initiative

The IEA is part of the Global Fuel Economy Initiative (GFEI), together with five other organisations: International Transport Forum; United Nations Environment Programme; International Council on Clean Transportation; University of California Davis and the International Automobile Federation (FIA) Foundation. At COP21 in Paris in 2015, the GFEI committed to extending practical support to 100 countries to implement policies to promote cleaner, more efficient vehicles. The GFEI has increased in-country support to over 70 developing and emerging economies, and engage many more through the G20 (Transport Task Group) and the Organisation of Economic Co-operation and Development (OECD).

GFEI is accelerating policy change and expanding its focus to support efforts to improve the fuel consumption of heavy-duty vehicles and to integrate EVs into vehicle fuel-economy policy frameworks. The GFEI provides governments with capacity building support and guidance that is tailored to the vehicle fleet and patterns of sales in each country, and in the context of wider sustainable transport initiatives. This includes capacity building across countries in Latin America, Africa and Asia and expert input into formal policy consultations in China, the European Union and Australia, among others.

Source: www.globalfueleconomy.org/media/460944/cop23-update-report.pdf.

Heavy-duty vehicles: policy implications and best practice

Heavy-duty vehicles, i.e. trucks and freight, account for around 40% of total oil consumption for road transport, with significant opportunities to improve efficiency. There are two main approaches to realising this potential: first, through improving the efficiency of the trucks themselves (e.g. fuel-economy standards, information and incentives), and, second, through systemic (logistical) efficiency improvements.

Improving truck efficiency

Mandatory energy efficiency policies only covered 16% of worldwide energy for trucks in 2016 (IEA, 2017d). While the main policy options for trucks are similar to those for passenger cars, there are some key differences that need to be respected to ensure effective implementation.

As with passenger cars, the key policy for improving efficiency of heavy-duty vehicles is fuel-efficiency standards coupled with energy labelling to provide information to market actors. As of early 2018, fuel-economy standards for trucks were only in place in five countries – Canada, China, India, Japan and United States.[25] The European Commission has proposed a regulation on the monitoring of CO_2 emissions and fuel consumption for new heavy-duty vehicles, and plans to propose standards by the end of 2018 (European Commission, 2018). A number of other major truck markets such as the Association of Southeast Asian Nations (ASEAN), Brazil, Korea, Mexico and South Africa are planning vehicle efficiency and/or GHG standards on new sales and their early adoption should be priority.

As an alternative, or a complement, to fuel efficiency standards, there is a role for ZEV mandates. Pioneered in California for the light-duty vehicle market and now used for medium-duty vehicles, their use has spread to several other US states, along with some parts of Canada and China. The original scheme was based on a system of tradable credits, which provides manufacturers with increased flexibility in meeting the targets (IEA, 2017g).

Care needs to be taken on the design of fuel-economy or GHG regulation as trucks tend to be more diverse than cars; there are different types, operations and sizes. As trucks are more heterogeneous than cars, computer simulation models are needed to estimate energy consumption and carbon emissions. These simulation models (such as the GEM in the United States and VECTO in the European Union) need to be adapted if they are to be used as the basis of fuel efficiency regulations beyond their original scope of application. Where there is a challenge to implement these types of standards, requirements on energy efficiency of components (such as tyre labelling standards) can be helpful to improve the overall efficiency (IEA, 2017g).

The provision of robust and reliable information on energy efficiency of trucks is important. Not only will this allow operators to make judgements on the benefits of energy efficiency, it will also allow policy makers to develop incentive schemes based on efficiency ratings.

As with passenger vehicles, differentiated vehicle taxation can have a role in improving efficiency of heavy-duty vehicles. Although unlike cars, the purchases of heavy-duty freight vehicles are not typically taxed, so there will be more challenges to apply a revenue neutral feebate to the truck market. Other measures, such as low interest loans may be more suitable to stimulate the purchase of more efficient trucks.

Innovation will be required to support a rapid transition to more efficient trucks. Research, development and demonstration support will be required to narrow the performance and cost gaps between incumbent and alternative technologies. Key examples that have implications for

[25] In the case of India, the standard relies on a testing procedure at constant vehicle speed meaning tested fuel consumption values may not accurately reflect real world driving conditions.

energy efficiency include electricity storage in vehicles using batteries, given the demands of long-distance freight transport and the lower energy use per kilometre (km) of electric powertrains compared with combustion technologies.

Improving systemic efficiency

Beyond energy efficiency of vehicles themselves, wider systemic measures, will be needed to deliver more sustainable freight and trucks, such as:

- Using complementary measures to develop an appropriate infrastructure, such as for electric charging.
- The demonstration of electric road systems, such as overhead power lines, to enable the use of electricity for long-haul freight transport on roads (IEA, 2017g).
- Restricting access to certain urban areas based upon vehicle GHG emissions.
- Using modal alternatives such as rail and shipping (while taking into account the non-road emissions considerations described below).

Further, improving the logistics of freight is a major opportunity to improve the overall efficiency of freight transport. There are several considerations to enable this to happen. First, collecting better data on truck operations will allow operators to exploit such opportunities to improve systems and logistics efficiencies. One clear efficiency opportunity is to increase modularisation as in the shipping industry; for example, harmonising truck sizes globally, would support modular and seamless integration. Similarly, platooning – where several trucks are in a single file, to minimise air friction – could provide further efficiency opportunities.

Non-road transport

Non-road transport encompasses aviation, shipping and rail. To increase the efficiency of these transport modes as in the 66% 2 °C Scenario would require an additional USD 1.3 trillion investment, cumulative to 2050, beyond the investment in the New Policies Scenario. Increasing the efficiency of these sectors represents a significant challenge for policy makers. This is partly due to the transboundary nature of these modes and their participation in international agreements, which may limit the scope for action of individual national governments. In the aviation sector, the main policy measures to date have been market-based carbon offsetting schemes such as the EU Emissions Trading System. Global CO_2 emissions policies are currently being developed by the International Civil Aviation Organization (ICAO), with initial voluntary measures agreed in 2016 capping future CO_2 emissions to 2020 levels, through carbon offsetting measures and some technological improvements to engines, airframes, traffic management and alternative fuels. The expected second phase of ICAO measures from 2027 to 2035 will be a mandatory phase. However, the Carbon Offset and Reduction Scheme for International Aviation is likely to fall short of achieving its goal of carbon neutral growth to 2020, since the first phase is voluntary and not all international civil aviation countries have joined. To go further and meet the 66% 2 °C Scenario, standards would need to be further tightened over time, include economies not currently participating and reduce the dependency on biofuel and offsetting mechanisms.

As in aviation, efficiency measures for shipping are undertaken by an international organisation, in this case, the International Maritime Organization (IMO). The IMO's Energy Efficiency Design Index (EEDI) – the equivalent of MEPS for shipping – is likely to result in ships with a fleet average efficiency improvement of 1% per year to 2025 (OECD, 2017). In the 66% 2 °C Scenario, annual efficiency improvement would need to increase further to over 2% through 2030. Robust and transparent information on the energy use of ships offers an opportunity to stimulate investment from ship owners to improve vessel efficiency, as it would improve the competitiveness of vessels with good GHG ratings to earn higher time charter rates than those with poor GHG ratings (Prakash et al., 2016). Such information would also be useful as a first step for addressing the principal agent issue where ship owners pay for efficiency improvements, while ship operators reap the benefits of the lower running costs. Separately, a mechanism to enable a CO_2 price for fuel used in shipping would provide an additional incentive to move towards a low-carbon pathway, such as incentives to develop wind assistance for ships.

Box 3.8 Alternative sustainable transport futures: The role of modal shift and urbanisation

The 66% 2 °C Scenario rests on direct energy efficiency improvements at a vehicle level and switching to alternative fuels, especially electricity. Yet, there are other possible pathways towards a very low-carbon future for the transport sector, potentially at lower cost and with wider societal benefits. Such futures would target travel behaviour and modal shifts, aiming to avoid unnecessary travel and reduce the demand for total motorised transport activity. Examples include incentivising low-carbon transport by investing in bicycling infrastructure and public transport as well as promoting ride-sharing schemes. For example, the City of Orlando, Florida began a project in 2013 to: 1) increase the percentage of trips made by carpool, public transit, bicycling or walking from 20% to at least 50%; 2) double the amount of streets that are accessible to pedestrians; and 3) eliminate pedestrian and bike fatalities by 2040 (City of Orlando, 2017). The project involves investments for sidewalks, bike racks, electric vehicle charging stations and other infrastructure. Other systemic strategies seek to reduce congestion through land-use and teleworking options, and implement pricing mechanisms to support automated, electrified and smaller vehicles (Meyer and Shaheen, 2017). Public transport schemes need to be affordable and more convenient than private transportation for significant modal shifts to occur.

The United Nations estimates that an additional 2.5 billion people will live in urban areas by 2050, 6.4 billion in total. As such, there is a significant role for policy makers at the municipal and regional levels to deliver liveable and sustainable infrastructure within cities and urban spaces. The UN Sustainable Development Goals highlight the importance of making towns and cities more resilient (especially SDG Goal 11) with targets to provide accessible and sustainable transport systems, notably through public transport. Recognising the increasing levels of urbanisation, proactive rather than reactive measures to shape the future of mobility are needed to avoid locking in inefficient transport infrastructure and practices. Measures include implementing congestion charges, pedestrian zones, increasing urban density and managing the availability of parking to balance supply and demand while levying revenues for investment into modal shifts. At the inter-city and national scale, high-speed rail can reduce the dependence upon airline travel for short-haul flights and cut emissions per passenger-kilometre.

Transportation planning policies can also support innovative business models that accelerate the capitalisation of EVs, thus shortening payback periods and enabling a faster uptake by consumers. But amid the revolution of automation, electrification and ride-sharing, it is important to be discerning about which business models are effective at achieving decarbonisation. Studies have found that car-sharing reduces the number of vehicles on the road, vehicle miles travelled and GHG emissions (Shaheen et al, 2015), whereas ride-hailing services tend to increase the number of trips (IEA, 2017h).

Cross-cutting economic measures to drive energy-efficient investment

In addition to the ambitious policy measures discussed, a range of economic measures could be used to drive increased investment to improve the energy efficiency of goods and services in all sectors of an economy. Such measures can be classified into two main types: financial and market-based instruments.

Financial measures to increase efficiency usually encompass private institutions and government-run financial institutions providing loans and grants to consumers and businesses, specifically aimed at increasing efficiency of equipment purchases, buildings or plants. Growing numbers of institutions are providing an increasing range of financial products, but the use of such measures would need to be expanded significantly if the objectives of the 66% 2 °C Scenario are to be achieved.

For the period 2014-20, almost 60% of all energy efficiency investment is estimated to be through self-financing from savings, revenues or tax revenues (IEA, 2014b). For households, much of this investment is undertaken without external financing, though consumer loans (unsecured debt) are regularly used for purchasing vehicles, appliances and heating, ventilation and cooling (HVAC) systems, including more efficient models. With energy prices being a large business cost, the industrial sector currently finances many of its energy efficiency improvements without using third-party financing. However, to increase energy efficiency investment significantly will require additional financial products to be made available, including to less energy-intensive industries where energy costs make up a lower proportion of operating costs.

An increasing number of institutions are providing finance for energy efficiency and related projects. These include multilateral banks, national development banks, foundations and investment funds. These institutions make use of a variety of financing instruments, depending on their respective markets, conditions, clients and types of project. The types of financing instruments vary widely, such as grants, bonds, green loans, carbon financing and market-rate loans. A challenge in this context has been overcoming asymmetric information (e.g. where investors do not sufficiently understand what is meant by "green", compared to potential clients and efficiency practitioners who have a better understanding (Box 3.9).

Box 3.9 Green tagging to overcome asymmetric information

In terms of financial innovation, banks are designing a new range of green financial products in terms of lending and also in debt capital markets and securitisation. A challenge for the success of these products is that there is not yet a clear, universally accepted definition or standard of "green". Banks, however, see energy efficiency and GHG emissions intensities as useful indicators of green projects. For banks to develop these new products, they need further evidence on the link between green performance and financial performance. There is a range of current barriers to understanding this link, such as energy performance certificate data quality, data privacy and definitions. One proposed solution to providing financial market actors with insights into the financial performance of green measures is the development of a common European Union database of energy performance. Such a database is being developed by the Energy Efficiency Financial Institutions Group (Box 3.11).

Source: Sweatman and Robins (2017).

Most of the institutions predominantly finance projects that are not climate or efficiency specific. However, energy efficiency is increasingly seen as providing worthwhile opportunities for investment as the risk perception surrounding energy efficiency investment begins to change, thanks to the growing (yet still small) evidence base supporting energy efficiency returns. Some are more explicit about their intention. For example, in the European Union, from 2014-20, the European Structural and Investment Funds allocated EUR 18 billion to energy efficiency, EUR 6 billion to renewable energy – notably in buildings and district heating and cooling – and around EUR 1 billion to smart distribution grids (European Commission, 2018).

Despite recent progress and an increase in efficiency-related funding, if the 66% 2 °C Scenario is to be realised, the amount of activity and funding from these institutions and their instruments will need to ramp up significantly. Even if the cost-effectiveness of energy efficiency projects is present, barriers remain to adopting such projects and rapidly expanding their energy efficiency portfolios (Box 3.10).

Box 3.10 Energy efficiency investment barriers

The barriers to investing in increasing energy efficiency include:

- Internalising externalities. For many efficiency projects the benefits accrue to others who have not invested in the project (e.g. reduced GHG emissions, or energy security), while polluting investments may inflict harm on others who do not benefit from the investment (e.g. reduced air quality). These externalities need to be appropriately captured in project assessments.
- Maturity mismatch. Many efficiency projects have longer return periods than non-climate projects, coupled with larger upfront costs. This is expected to be an opportunity for green bonds.
- Scale. The small-scale nature of some energy efficiency projects makes investment returns potentially less attractive and increases transaction costs for financing multiple smaller projects.
- Energy subsidies. These mask the real costs and benefits from energy efficiency improvements making channelling investment more difficult.
- Lack of clarity on finance for efficiency projects. Definitions are needed to allocate funding to align the energy efficiency community expertise with financial sector needs.
- Asymmetric information. Investors tend not to have knowledge of the market, and more will be needed on disclosure and consistent reporting/labelling.
- Lack of standardisation. More consistency is needed, for example, in due diligence processes, to ensure that efficiency investments are evaluated in a consistent manner.
- Lack of technical understanding and assistance. There is a relatively low understanding of energy efficiency risks. Risks surrounding “brown” investments may be underestimated while the risks of “green” investments may be overestimated.

Source: Based on G20-GFSG (2017).

While public funding is made available to finance energy efficiency, it is often oriented towards vulnerable consumers or specific market failures. Public financing will not be sufficient to address the energy efficiency needs in the private sector, nor will it provide the majority of support needed for a mature and fully investible market. That said public money can be used to reduce the cost of capital, provide loans with longer maturities, or lower collateral requirements. In this respect, more could be done to deliver innovative business and financial instruments to leverage private finance with public funding.

Globally, efforts are underway to develop tools and networks that better address the barriers faced by the private sector investment community to energy efficiency project development. Typically, banks often make loan agreements based on the credit status of their clients or the property value; however, the benefits of energy efficiency improvements are often not taken into account. Benchmarking information is important to allow financial institutions to better understand the risks and rewards around projects. The Energy Efficiency Financial Institutions Group, supported by the European Commission, is developing an initiative that aims to change these practices and inform financial institutions, investors and project promoters about the real benefits of energy efficiency investments (Box 3.11).

Box 3.11 EEFIG and "de-risking energy efficiency platform"

The Energy Efficiency Financial Institutions Group (EEFIG) was established in 2013 by the European Commission Directorate-General for Energy (DG Energy) and the United Nations Environment Programme Finance Initiative (UNEP FI). It created an open dialogue and work platform for public and private financial institutions, industry representatives and sector experts to identify the barriers to the long-term financing for energy efficiency and to propose policy and market solutions.

Their de-risking energy efficiency platform (DEEP) is an open source database for energy efficiency investment performance monitoring and benchmarking, which supports the assessment of related benefits and financial risks. It allows comparison of implemented energy efficiency investments, for example by country, measure and building type.

DEEP provides market evidence from around the world, though most data are currently from Europe. The data platform provides an operational risk management benchmark, which should help project developers, financiers, and investors to better assess the risks and benefits of energy efficiency investments.

Source: EEFIG (2015).

Market-based instruments for energy efficiency set a policy framework specifying the outcome (e.g. energy savings, cost-effectiveness) to be delivered by market actors, without prescribing the delivery mechanisms or the measures to be used. The main types are:

- Energy efficiency obligations, where energy market actors such as utilities and distributors, are required to deliver energy efficiency outcomes. These obligations can be transferred to other actors through tradable (white) certificates which provide further flexibility. In 2016, 18% of the global final energy use was covered by obligation programmes (IEA, 2017a).
- Auctions (including tendering programmes) to deliver efficiency, where bids are invited for funds to deliver energy efficiency outcomes. Forward capacity auctions are often included in this category if they allow energy efficiency to compete against other supply- and demand-side resources to meet energy system adequacy requirements. The most mature example of an auction scheme is Switzerland's ProKilowatt scheme (Box 3.11).

Box 3.12 Switzerland's ProKilowatt Scheme

The Swiss transmission operator, Swissgrid AG, collects a levy on the electricity transmission grid of up to Swiss Franc (CHF) 0.015 (about EUR 1.3 cents) per kilowatt-hour (kWh) of electricity transported. The levy is paid by final electricity consumers.

In 2010, the Swiss parliament introduced the ProKilowatt scheme consisting of competitive tenders for energy efficiency projects. The auctions are administered by the Swiss Federal Office of Energy, as the buyer, and corporations and public entities bid as the sellers of electricity efficiency measures. Winners are determined based on the price (CHF/kWh) posed by the competing entities. The goal of the scheme is to promote electricity efficiency at the lowest cost.

Overall, more than CHF 100 million (approximately EUR 93 million) have been awarded to projects and programmes so far, leading to 5.5 terawatt-hours (TWh) of electricity savings in Switzerland (as of 2016). Since the start of the energy efficiency auctions, the overall budget available for projects and programmes has been significantly increased, from CHF 6 million (EUR 5.5 million) in 2010 to CHF 45 million (EUR 41 million) in 2016 and a further increase to CHF 50 million (EUR 45.5 million) per year is expected (Rategan, Bisang and Koenig, 2016).

Table 3.5 Results from the ProKilowatt Scheme, 2010-15

Year	Projects		Programmes		Total electricity saved (GWh)
	Number	Electricity saved (GWh)	Number	Electricity saved (GWh)	
2010	18	113	8	457	570
2011	32	99	13	548	647
2012	67	242	9	276	518
2013	35	167	23	421	588
2014	61	191	21	509	700
2015	50/25	150/68	30	1 270	1 488

Notes: GWh = gigawatt-hours. The increase in the electricity saved, from 700 GWh in 2014 to 1 488 GWh in 2015, is the result of the significant number of projects/programmes focusing on hot water heat pumps and LED indoor and outdoor street lighting.
Source: Rategan, Bisang and Koenig (2016).

The worldwide use of market-based instruments has increased significantly in recent years from no auctions schemes and 13 obligation schemes in 2006 to more than 50 of each type by 2016. These instruments resulted in USD 26 billion being invested in energy efficiency, accounting for 12% of the USD 221 billion invested in energy efficiency worldwide. Market-based instruments are also proving to be highly cost-effective: recent IEA analysis of programme expenditure and savings data for 37 market-based instruments around the world has demonstrated that, in comparison with the average cost of new energy supply infrastructure, market-based instruments can deliver savings well below the typical costs of energy supplied in most sectors and locations, without factoring in all of the multiple benefits or higher energy efficiency (IEA, 2017a).

When designed and implemented well, these market-based instruments have achieved significant benefits. For example, in the most ambitious jurisdictions, cost-effective savings of 3% of annual electricity consumption are being generated each year, reducing consumer energy bills and the need for supply-side investment. As a result of a decade of investment through these instruments, world energy consumption was 1.5 exajoules (EJ) lower in 2015 than it otherwise would have been. If the current programmes maintain their level of ambition over the next decade, by 2025 this impact will double to 3 EJ, more than the current final energy consumption of Poland (IEA, 2017a).

Owing to a lack of evaluation evidence, there is no conclusive proof that, in practice, obligation and auction schemes deliver efficiency outcomes more cost-effectively than equivalent options, such as grants allied with information programmes. However, experience has shown that opening delivery channels to market discipline, supported by strong monitoring and verification has enabled efficiency gains to be made at a cost well below the typical cost of supplying energy (IEA, 2017a).

Like all policy measures, market-based instruments put a premium on good design and implementation. Allowing private sector actors the freedom to innovate and discover technologies and delivery routes that work best in the market is a principal advantage of these types of instruments. The risk for policy makers is that, if designed or implemented poorly, the market will find ways to "game" the system or to focus delivery of the specified outcome in ways that policy makers would prefer to avoid. Sensible limits can be applied for special groups (e.g. vulnerable customers) and special policy goals (e.g. deep renovation), and other design elements can be imposed to mitigate risks of overpayment and high administrative costs (e.g. set maximum price caps, establish project size criteria, allow aggregation across smaller projects). However, imposing too many restrictions on the choices available to market participants weakens the ability of these instruments to take advantage of the power of market forces.

In addition, market-based instruments are not sufficient on their own to drive the uptake of cost-effective energy efficiency potential. They must be designed to work within existing policy frameworks, such as rewarding savings above MEPS levels or addressing behavioural measures where sufficient standards already exist. They must also be designed to complement or extend the benefits from other schemes (e.g. system adequacy, environmental goals) while at the same time avoid double-counting.

Business models to deliver additional investment

The nature of energy efficiency investments – often upfront investments to deliver future financial savings and other benefits – means that there is significant scope for innovative business models to increase the flow of investment and finance for efficiency. Financial innovation has been occurring for some time, and there are financial products that are already considered mature, such as dedicated credit lines, energy performance contracting, green bonds and leasing. Additionally, in the residential sector, unsecured finance and secured finance (e.g. re-mortgage) have long been used for financing energy-efficient homes.

New financial products and business models are emerging that may provide additional funds and investment for energy efficiency. These could play an important role in overcoming barriers related to long payback periods, such as in industry where the majority of energy efficiency investment is made through on-balance payments using a company's own funds. As a result, energy efficiency investments are subject to a company's internal criteria, meaning that efficiency opportunities with longer payback times (over four years) may be deemed too risky and therefore not implemented. An important challenge to overcome in the 66% 2 °C Scenario would be to increase the amount of efficiency opportunities with longer payback times that are implemented within industry. Emerging models that could help with this include:

- Bulk procurement (to drive down prices). For example, a bulk procurement and distribution scheme in India is now being expanded from LED lighting to cover other products, such as room air conditioners, smart meters and electric vehicles.
- Energy services contracting, in particular in industry using ESCOs (Box 3.13).
- Energy service agreements – pay-for-performance service contracts between a third-party investor and an asset owner to deliver energy savings.
- On-bill financing and repayment.
- On-tax finance (where upfront financing is repaid via tax assessments).
- Public ESCOs for deep renovation (public buildings and housing).
- Citizens financing – community energy finance (usually a local community using a co-operative structure) and crowd-funding (using the internet to aggregate small investors).

Further details of many of these emerging mechanisms are discussed more fully in EEFIG (2015).

Box 3.13 ESCOs in industry

Energy service companies (ESCOs) enable industrial firms to use off-balance sheet financing for energy efficiency projects, increasing the likelihood of uptake. For example, through an energy performance contract (EPC) an ESCO can provide an industrial energy user with the technology solution, such as a VSD, and guarantee the performance and energy savings. The value of the global ESCO market grew to nearly USD 27 billion in 2016, with the most activity in China, where government incentives have spurred market growth, and in the United States, where ESCOs are often part of utilities. In other markets, ESCO activity is often limited due to a reluctance of industry to engage in EPCs and lack of finance to support ESCO activity.

ESCO financing can be attractive for industrial firms, as it means that some capital expenditures can be kept off a company's balance sheet, reducing overall levels of debt and liability. The ability of a company to use off-balance sheet finance is determined by accounting principles of the country in which the company operates. For example, in the United States, under the Generally Accepted Accounting Principles, efficiency projects delivered by ESCOs through EPCs can be structured as operating leases. This means that the project does not have to be accounted for on a company's balance sheet, as it will appear on the ESCOs balance sheet. Increasing the ability of industrial firms to use off-balance sheet finance for efficiency projects may contribute to increased ESCO activity in the 66% 2 °C Scenario, as investments would become more attractive aiding the rollout of technologies such as VSDs and electric heat pumps.

The ability of a company to use off-balance sheet financing for energy efficiency projects delivered through ESCOs will also depend on whether an ESCO has the financial resources to account for the efficiency project on its balance sheet. As many ESCOs are small companies without substantial balance sheets, the ability of an ESCO to access finance at favourable rates may significantly enhance their ability to implement efficiency projects through off-balance finance. Again, improving the knowledge of investors as to the opportunities and risks associated with industrial energy efficiency projects may increase the flow of investment.

Governments have a role to play in providing a framework and support for existing business models while also helping emerging funding mechanisms flourish, for example by:

- Ensuring regulations (such as building codes) are implemented and enforced consistently to ensure a level playing field.
- Verifying that energy efficiency improvements are truly additional and not the "accidental" result of other measures.
- Providing clarity and visibility for market actors and investors on future regulatory pathways.
- Providing access to high quality and consistent open source data on energy performance contracting (e.g. as an online database) especially for investors.
- Benchmarking energy efficiency investment programmes to allow actors, including end-users, to better judge risks of proposed projects.
- Accrediting professionals and installations, along with the appropriate oversight and enforcement, to enhance confidence and the likelihood of successful project delivery.

Strengthening institutional capacity

Energy efficiency needs to be supported by strengthening capacity to design and implement policy frameworks, particularly in emerging economies. The nature of energy efficiency policy – with the mixture of standards, regulations and incentives – means that without careful design, implementation and adequate enforcement, policies will not deliver cost-effective results. Important areas of institutional capacity building include:

- Training for good policy design.
- Support for effective policy and programme implementation.
- Techniques and programmes for effective monitoring, verification and enforcement (MV&E) procedures.[26]
- Incorporating the emerging role for digitalization in policy design, implementation and MV&E.
- Training for policy evaluation.

Training for good policy design

For countries with little experience of designing and setting up energy efficiency programmes, it can be useful to learn from what has and has not worked in other countries, as part of institutional capacity building. In this respect the IEA is committed to helping countries develop institutional capacity for excellence in energy efficiency policy design. For example, since 2015, the IEA has held a number of week-long training events dedicated to sharing experience with planning, implementing and evaluating energy efficiency policies in emerging economies. These training weeks have brought together more than 600 "next generation" energy efficiency professionals, primarily from government institutions and supporting organisations in emerging economies (IEA, 2018b). The training events aim to equip junior energy efficiency policy makers with knowledge and skills to be more effective. Participants become part of the international energy efficiency

[26] Not to be confused with similar abbreviations such as M&V, which usually refers to monitoring and verification of energy savings (most commonly in building efficiency upgrades) or MRV, which refers to monitoring, reporting and verification, for example, of emissions under the EU Emissions Trading System.

community with a large support network to call upon as they progress through their careers. These have now been developed further as online courses (e.g. for energy efficiency indicators and statistics), which will mean a much wider audience for such material and more effective learning opportunities for policy professionals.

Support for effective policy and programme implementation

Even the best policy will need considerable implementation and enablement support programmes to achieve impacts at scale in a cost-effective and sustainable manner. There are many good examples of best practice experience with energy efficiency policy support, including selected European initiatives:

- Sharing networks for designing and implementing national building renovation strategies (BUILD UPON).
- Technical support for SMEs (Sustainable Energy Finance Facility).
- Tools for overcoming split incentive barriers in apartment blocks LEAF).
- Skills development for construction workforce (BUILD UP).
- Market surveillance activities (ECOPLIANT).
- Capacity development in laboratory testing (ComplianTV).
- Consumer awareness (Top Ten).

Some economies may be at the early stage of developing and implementing energy efficiency programmes. Some may be able to make use of climate finance or development monies (e.g. through development banks), coupled with international support, to initialise their energy efficiency programmes.

Techniques and programmes for monitoring, verification and enforcement

Increased focus on monitoring, verification and enforcement (MV&E) of energy efficiency policy is needed as is the accompanying capacity building required. Investment in MV&E is highly effective in ensuring energy savings in the short term and essential for success of policy measures in the medium to long term.

The IEA recommends the following good practice for MV&E policy (IEA, 2017i):

- When designing regulations, policy makers should integrate key elements of MV&E processes into the legal and administrative framework from the outset.
- Communication with stakeholders is important to educate actors on their obligations and the option of sanctions will increase voluntary levels of compliance.
- Enforcement procedures should be fair and transparent, and include a range of sanctions proportional to the level of transgression. Early communication of the results of monitoring and verification allows suppliers to take timely corrective action.
- Public disclosure of compliance activities and enforcement action strengthens the perceived risks to all stakeholders of non-compliance.

Incorporating the emerging role for digitalization in policy design, implementation and MV&E

Digitalization is a powerful tool to achieve a myriad of energy efficiency policy objectives and it can help improve the policy-making process. A key benefit includes the availability of more timely and sophisticated collection and publication of energy data. In addition, emerging low-cost digital tools, such as online registries, data from internet sources and quick response codes, can lead to more targeted and responsive programmes.

- *Improved energy statistics*. Collecting and analysing digital data has the potential to revolutionise understanding of energy consumption patterns. With access to digital data and new methods for collecting and combining data, the quality, timeliness and availability of energy data can be transformed. This, in turn, can improve the decision-making processes of policy makers, utilities, companies and other actors. However, these benefits will only be realised if policy makers and industry work co-operatively to enable access to these sources of information.
- *Data on energy efficiency standards for appliances*. MEPS for appliances, buildings and vehicles have proven to be among the most cost-effective measures used by governments around the world to improve energy efficiency. Yet these standards are sometimes less effective than they might be because of information asymmetries between manufacturers and regulators, as well as a lack of effective compliance regimes. Three low-cost digital technologies and techniques are being used to significantly improve data collection and analysis about appliance energy performance, providing better information to consumers and significantly improving the policy-making process:
    - Online registration systems are internet-based facilities where the manufacturers or importers of equipment and appliances register eligible products with a regulatory authority before they can be sold in a market. These registries help ensure product compliance with programme requirements, facilitate programme development and provide more streamlined and transparent systems that can also be useful to both manufacturers and consumers.
    - "Web crawling" (also known as web harvesting or web scraping) is a technique using search algorithms to automatically collect information from websites. Crawling can be used to collect online data on sales, prices, efficiency levels and types of products. Easy and cheap access to this data can be helpful to policy makers as they develop standards or evaluate the impact of energy labelling programmes.
    - Quick response (QR) codes are a type of machine-readable optical label, resembling a two-dimensional barcode. With the use of QR codes, imported appliances and equipment can be easily checked by customs officials by simply scanning labels, so that non-compliant manufacturers are easily detected when cross-checked with the registration database.

Training for policy evaluation

Policy evaluation is a critical part of good governance. Evaluation is particularly crucial to energy efficiency policies and programmes because their impacts are difficult to measure. In effect, one must find ways to measure the amount of energy that was not used. Evaluation is needed to test planning assumptions, monitor overall results, compare programme performance, fine-tune implementation processes and incorporate lessons learned into future policies and programmes. Unlike other types of investment, energy efficiency cannot be directly measured in terms of incremental physical output; rather, it must be evaluated as a decrement (or reduction) against a baseline of consumption or expense. Energy efficiency evaluators thus face a complex task in confirming the benefits of energy efficiency policies and programmes, making energy efficiency evaluation methodologically difficult and costly. In addition, good policy evaluation is further hindered by a lack of evaluation protocols, available data, databases and data collection frameworks.

The IEA recommends these elements for developing policy evaluation guidelines for energy efficiency organisations:

- **Integrate evaluation into good energy efficiency governance.** Information and insights gained from good evaluation are vital for improving energy efficiency policies and programme activities, and for communicating the results of energy efficiency efforts to policy makers and stakeholders. Evaluation results increase credibility, foster innovation and help build consensus on future energy efficiency efforts.
- **Tailor evaluation approaches to policy and programme design and objectives**. Care must be taken when formulating evaluation objectives and needs should be considered early on in the policy and programme development process. An effective and efficient ex-post evaluation should be specified well in advance of implementation. The evaluation plan should be a collaborative effort between policy makers, programme designers and implementers, and the evaluation community.
- **Build ancillary capacity for evaluation.** A strong evaluation framework relies on access to transparent, well-documented, accurate databases that are periodically reviewed for quality and consistency. These databases, depending on the type of energy efficiency scheme, can include energy and peak savings data, persistence data, product and market data, and consumer information.
- **Establish evaluation protocols.** Governments must invest in developing evaluation protocols that reflect specific country, local and sector contexts and establish broad guidance and standards. Such protocols are an invaluable tool for evaluators and energy efficiency practitioners; they also form the basis for training new programme evaluators and provide an as-needed resource for implementers, administrators, regulators and policy makers.
- **Adopt good governance rules.** There are three main points to remember when establishing good governance rules for the evaluation process: data credibility, independence and objectivity of analysis, and transparency of results. Addressing these issues can help to embed evaluation in the policy process. In turn, this can lead to more effective energy efficiency policies.

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IEA Publications
International Energy Agency
Website: www.iea.org
Contact information: www.iea.org/about/contact
Typeset in France by IEA - April 2018
Cover design: IEA; Photo credits: © GraphicObsession

In support of its presidency of the G20 in 2017, the German government requested the International Energy Agency (IEA) and the International Renewable Energy Agency to explore how an energy transition to address climate change might look. In this follow-up study, the IEA takes stock of progress towards a low-carbon energy sector and provides further insights into the fundamentally important role of energy efficiency to achieve a clean energy transition. This report:

- Reviews recent progress with regards to the clean energy transition and the role of energy efficiency.
- Explores two clean energy transition scenarios to assess the contribution required from energy efficiency to achieve the goals of the Paris Agreement and the energy-related objectives that the international community has set with the United Nations 2030 Agenda for Sustainable Development.
- Assesses sector-by-sector the economic case for energy efficiency investment and the payback period over the lifetime of individual technologies.
- Develops insights as to what policy makers can do to overcome economic and non-economic barriers to accelerate energy efficiency investment, ranging from high-level strategic approaches to detailed concrete end-use sector policies.

Perspectives for the Energy Transition

The Role of Energy Efficiency