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Energy, Climate Change & Environment

2016 Insights

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

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Foreword

The Paris Agreement reached at COP21 in December 2015 was a major milestone capping more than two decades of global negotiations aimed at averting dangerous climate change. The outcome was reflective of greater acceptance that a low-carbon transformation of the world's energy system is indeed possible, even inevitable, in the context of rapidly falling renewables costs and an unprecedented degree of action by nations, civil society, the business sector, cities and other non-state actors. With the Paris Agreement set to enter into force on 4 November 2016, considerably earlier than envisaged at COP21, international support for the global climate agenda adopted in Paris has only been reinforced.

The ambitious climate goal spelled out in the Paris Agreement – to limit warming to "well below 2°C" above pre-industrial levels, and to pursue efforts for 1.5°C – necessitates scaled-up, real-world implementation, particularly in the energy sector which generates around two-thirds of global greenhouse gas emissions. The Nationally Determined Contributions (NDCs) submitted by countries are an important step forward. Their full implementation will help shed light on data, policy and financing gaps. But greater ambition than is embodied in the NDCs is quickly needed to achieve the aims of Paris, and the Agreement itself provides a framework for increasingly ambitious measures. Stronger action beyond the level conveyed in the NDCs is realistic, cost-effective and essential – and is needed to achieve even a 2°C goal, let alone the well-below-2°C ambition of the Paris Agreement.

In this spirit we are releasing the *Energy, Climate Change and Environment: 2016 Insights*. As we advance further into a post-COP21 reality, the gap between the goals of the Paris Agreement and efforts on the ground looms large. Actions to both achieve and surpass the NDCs will require a sophisticated, detailed analysis of key policy areas, which can help break the overarching task down into manageable pieces. To this end, this publication presents a selected set of policy issues that we believe deserve more attention, and that have taken on heightened importance with the pressure to accelerate the pace of change following COP21. Transformation of the energy sector will play an outsized role in accomplishing this, as energy is the primary contributor to planet warming gases, but with the energy transition also holding the key to a cleaner and more secure energy future.

The IEA is working to accelerate the global energy transition, through its policy studies and recommendations, scenario analyses, statistics and implementation partnerships and will continue to pursue bilateral and multilateral cooperation in these areas. We have a renewed focus on working collaboratively not only with current IEA members but also with emerging economies that are increasingly defining the energy system of the future. Through these efforts, we can build the clean energy system that is needed to avert dangerous climate change, contribute to broader environmental sustainability and support inclusive economic growth.

Dr. Fatih Birol

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Executive summary

Efforts to respond to climate change are changing the way the energy sector is developing, and the increased ambition of the Paris Agreement on climate change, agreed at COP21 in December 2015, is accelerating that shift. The Paris Agreement represents a landmark, one in which the transition to low-carbon development paths and low-carbon energy systems is now widely seen as the "new normal". While the speed of the transition remains uncertain – with different paces altering the eventual climate implications – the direction of travel and eventual need for deep emissions reductions in the energy sector are clear. The increased climate ambition in the Paris Agreement was made possible in part by improvements in low-carbon energy technologies, notably the falling costs of renewable energy. This was most dramatic for onshore wind, for which costs fell by an estimated 30% on average, and for new utility-scale solar photovoltaic (PV) installations, for which costs declined by two-thirds, between 2010 and 2015. During the previous attempt to negotiate a new global climate agreement, in Copenhagen in 2009, a low-carbon energy system was largely seen as hypothetical. Today it is accepted as realistic, and for many, inevitable.

The challenge of implementation

Delivering on the promise of the Paris Agreement will require an unprecedented shift in global energy systems, both to implement the current Nationally Determined Contributions (NDCs)[1] and to go beyond them. The NDCs are a significant step forward in climate action, together giving an unprecedented global coverage of emissions reduction goals. International Energy Agency (IEA) analysis has found, however, that the path set by the initial round of NDCs is consistent with an average global temperature increase of around 2.7°C by 2100 and above 3°C thereafter. There is therefore a dual implementation challenge ahead for countries: to not only deliver the NDCs, but to surpass them to keep the well-below 2°C collective goal within reach.

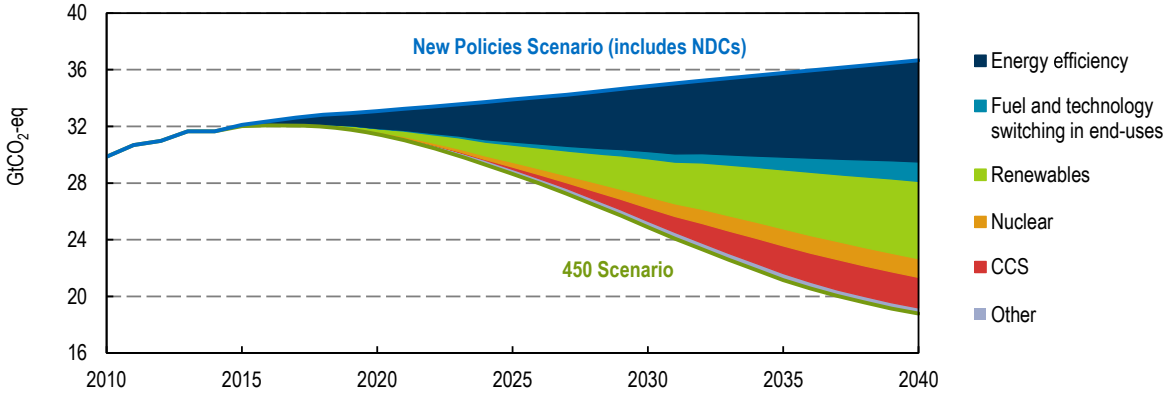
Scaled-up action in energy efficiency and renewable energy is vital to deliver the NDCs, and these measures will also be the largest contributors in moving beyond the NDCs to a pathway consistent with limiting warming to 2°C (Figure ES.1). However, a wider package of technologies and actions is also needed, including carbon capture and storage (CCS), nuclear energy and end-use fuel switching. Mitigation and resilience measures must be comprehensive, addressing technologies and policies and building capacity worldwide. While this may seem an overwhelming task, it can be made more tractable by drilling down into the specific actions needed in each sector, and each policy area; this volume explores a selected set of issues and possible solutions, briefly outlined below.

Staying well below 2°C: How the Paris Agreement has changed the energy challenge

The Paris Agreement has reset the collective global climate ambition: from the aspiration of keeping temperature rise

Figure ES.1

Measures needed to surpass current NDCs to reach 2°C trajectory (450 Scenario), through 2040



Note: The New Policies Scenario (NPS) is the central scenario of the World Energy Outlook *and includes the energy-related components of NDCs submitted by 1 October 2015.*

Source: Adapted from IEA (2015b), World Energy Outlook 2015.

1. Each Party's Intended Nationally Determined Contribution (INDC) submitted for the Paris Agreement will formally become an NDC when each Party ratifies the Agreement. This publication uses the term NDC to refer to both cases (INDC and NDC).

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below 2°C, to a new aim of limiting it to "well below 2°C" with efforts to pursue 1.5°C. Attention must therefore turn to further reducing emissions remaining within energy scenarios consistent with 2°C warming. Analysis to date has tended to focus on the sectoral contributions and actions needed to transition from current business-as-usual trends to a 2°C-consistent pathway (e.g. the IEA *World Energy Outlook* 450 Scenario and the 2°C Scenario [2DS] of *Energy Technology Perspectives*). To meet the target of keeping warming well below 2°C, some of the emissions allowed in the 2DS will need to be eliminated; accordingly, attention is turning toward identifying and addressing emissions "below the line" (Figure ES.2), as well as developing new pathways to reach lower emission levels. Limiting temperature rise to well below 2°C would entail further emissions reductions in industry, power and transport, which together represent 85% of remaining emissions in the 2DS. Power sector emissions are already reduced significantly in the 2DS, to less than 1.4 gigatonnes of carbon dioxide ($GtCO_2$) in 2050 (largely through implementation of renewables, energy efficiency and CCS), while industry and transport, which represent 76% of the remaining emissions in 2050, will become major areas of renewed focus.

Further reducing emissions from incumbent fossil fuel facilities: A critical element of low-carbon scenarios

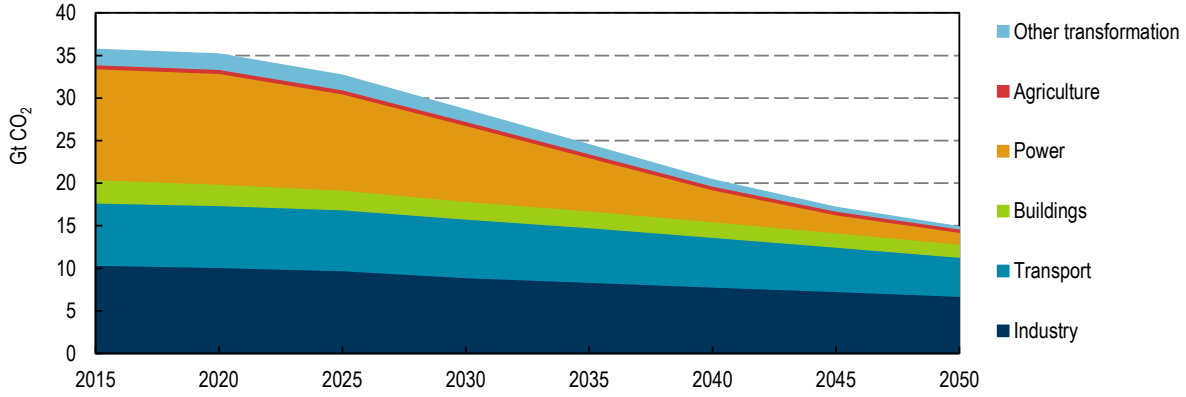
Addressing coal- and gas-fired power plant emissions – in particular emissions from coal plants that already exist or are under construction and as a result can be "locked in" – will be vital to reduce global emissions. Coal and gas power plants generate 63% of today's global electricity supply, but they are carbon-intensive and produce around 35% of global energy sector emissions. In scenarios consistent with keeping warming to 2°C, IEA modelling indicates a dramatic reduction in generation from unabated coal plants (i.e. plants without CCS) beginning in 2020 (Figure ES.3, left graph). Decommissioning regulations, dispatch rules, carbon pricing and other policies can be used to reverse the lock-in of emissions from these incumbent plants, as can retrofitting with CCS. By 2050, unabated coal generation is virtually phased out worldwide under IEA 2°C scenarios. Shifting from coal to gas helps to reduce emissions, as gas is a less carbon-intensive power source, but by 2030 even gas without CCS becomes a high-carbon alternative compared to average emission intensities consistent with the 2DS. As such, the use of unabated gas is also severely curtailed through 2050 (Figure ES.3, right graph). Delivering the deeper emissions reductions consistent with the more ambitious "well-below-2°C" goal may entail even more dramatic reductions in unabated fossil fuel generation than indicated in Figure ES.3. Technological improvements that reduce the carbon intensity of coal- and gas-fired plants, along with co-firing (with solid biofuels or biogas), can help lower their emissions and extend their use under a low-carbon scenario, particularly when combined with CCS.

Even moderate carbon prices can play a role in electricity system decarbonisation

Moderate carbon pricing, as part of a package with other policies, can provide an incentive to move toward a low-emissions electricity sector, particularly by supporting

Figure ES.2

Energy-related CO_2 emissions by sector under the 2DS



Source: Derived from 2DS modelling results in IEA (2016a), Energy Technology Perspectives 2016.

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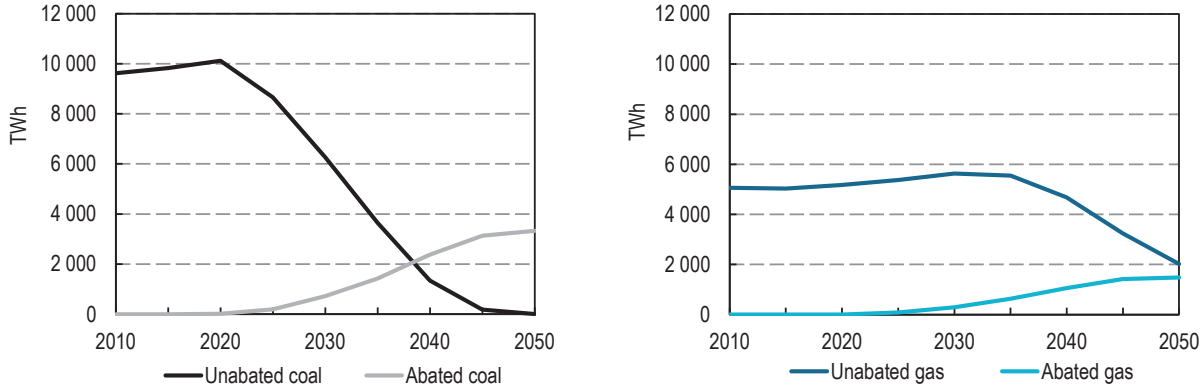
Figure ES.3

Coal- and gas-fired generation under the 2DS, with CCS ("abated") and without ("unabated")



Note: TWh = terawatt hours.

Source: Adapted from IEA (2016a), Energy Technology Perspectives 2016.

the dispatch of low-carbon generation options.[2] High carbon prices that drive deep emission reductions are a feature of modelled low-carbon scenarios, but these high prices have proven challenging to implement. More modest carbon prices can still play multiple important roles. First, for liberalised power markets, there are few alternatives to price as a driver of short-term operational decisions, so even moderate carbon pricing is an important lever in determining the mix of dispatch. The situation is more complex when it comes to guiding investment in new generation capacity: in this case, non-pricing policies such as targeted tenders for low-carbon generation can drive investment more effectively than modest carbon prices can. However, feed-in tariffs and other subsidies for clean generation can themselves be strengthened by moderate carbon prices which can be raised over time to reduce subsidy levels, making them potentially more politically sustainable. Finally, while modest carbon prices alone will not drive retirement of assets to reverse lock-in of fossil fuel generation, in an oversupplied market they can in some cases tip the balance between coal and gas operations, prompting the more carbon-intensive plants to be the first taken off-line.

COP21 has reinvigorated the push for renewables

The Paris Agreement is providing a significant push for further investment in and deployment of renewables. Announcements since COP21 have had a positive impact on the expected rate of renewable capacity additions, raising the level of expected deployment compared with levels foreseen in 2015 (Figure ES.4, dashed versus solid line). However, investments remain below levels consistent with long-term climate goals. While solar PV and onshore wind have become competitive with other electricity sources, concentrated solar power, offshore wind and various other renewable technologies require further policy support. The use of renewables also needs to be expanded for heat and transport: their importance increases in efforts to target a temperature increase well below 2°C, as industry and transport generate 57% of cumulative emissions to 2050 in the 2DS. Enhanced policy measures could accelerate renewables deployment (Figure ES.4, bars) and maintain consistency with the early emissions peak and subsequent downward trajectory required to stay below 2°C.

Greater use of energy efficiency and other demand-side levers is needed

Managing energy demand is a vital tool to reduce emissions, notably through energy efficiency measures which improve energy productivity and thereby reduce the amount of energy needed to support continued economic growth. Lower levels of energy demand are tied to lower emissions across the IEA 2°C scenarios. In the 2DS, energy efficiency contributes the largest share of global emissions reductions (nearly 40%), helping to avoid over 3 000 exajoules (EJ) of energy demand through 2050 (equivalent to five years of current global total primary energy supply), compared with a scenario based on current trends.[3] Structural change within economies, from more to less energy-intensive sectors, is emerging as an important factor in curbing energy demand while supporting continued economic growth; for example, over two-thirds of avoided energy demand under China's 13th Five-Year

2. *In this analysis, "moderate" carbon pricing refers to levels similar to those in the World Energy Outlook NPS of USD 15 per tonne of carbon dioxide (tCO_2) to USD 40/tCO_2 in 2030, compared with the higher USD 100/tCO_2 of the 450 Scenario.*

3. *The Energy Technology Perspectives 4DS.*

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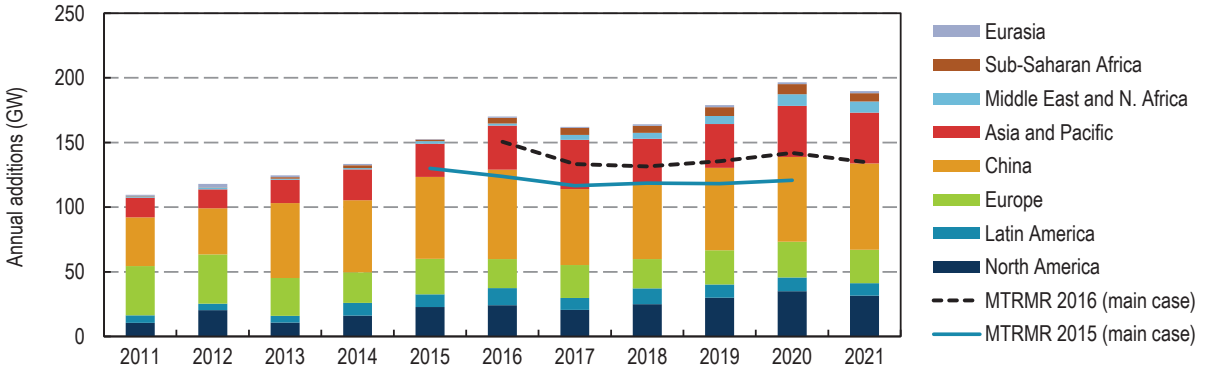
Figure ES.4

World grid-integrated renewable power capacity growth: Historical and projected (accelerated case)



Note: Bars represent historical data through 2015 and projections during 2016-2021 (accelerated case).

Sources: IEA (2016b), Medium-Term Renewable Energy Market Report 2016*; IEA (2015a),* Medium-Term Renewable Energy Market Report 2015 *(for "MTRMR 2015 [main case]" only).*

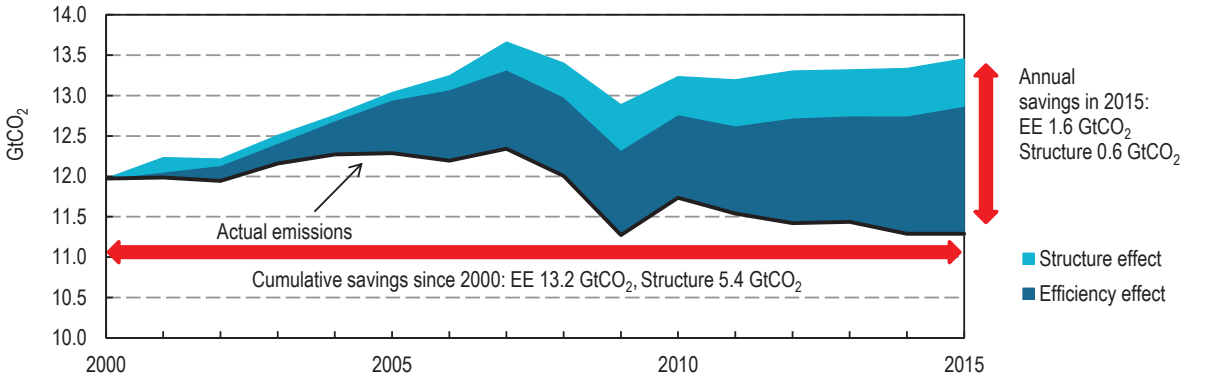
Plan is the result of structural change. In IEA member countries, energy efficiency improvements have reduced emissions by 13.2 $GtCO_2$ and structural changes have cut emissions by 5.4 $GtCO_2$ since 2000, for a cumulative total of 18.6 $GtCO_2$ (Figure ES.5) – more than the current annual energy emissions of China and the United States combined.

Looking beyond "what" and "how" to "who": Tailoring solutions to motivate state-owned enterprises

State-owned enterprises (SOEs) are an often overlooked class of actors that can play a dominant role in climate change mitigation; influencing their actions requires tools adapted to their differences from traditional private sector businesses. SOEs own over 40% of high-carbon fossil fuel power generation globally; they also own 60% of low-carbon renewable and nuclear capacity (Figure ES.6a). Taken together, a group of 50 large SOEs across power, industry and other sectors generates over 4.4 $GtCO_2$ annually in energy sector emissions – greater than any country's emissions other than those of China or the United States (Figure ES.6b). State-owned banks also provide substantial financing for other SOEs and the private sector, notably development and other public sector banks in various emerging economies such as Brazil and China. As high-carbon emitters, low-carbon suppliers, financiers and sources of innovation, SOEs are key actors in the energy transition. These companies, however, frequently respond to a different incentive framework and operate within a different corporate culture than private companies. For example, they often need to fulfil a broader set of economic and social objectives, including

Figure ES.5

IEA member country end-use emissions savings from energy efficiency improvements and structural changes since 2000



Source: Adapted from IEA (2016c), Energy Efficiency Market Report 2016*, based on the IEA* Energy Efficiency Indicators *database (2016 edition).*

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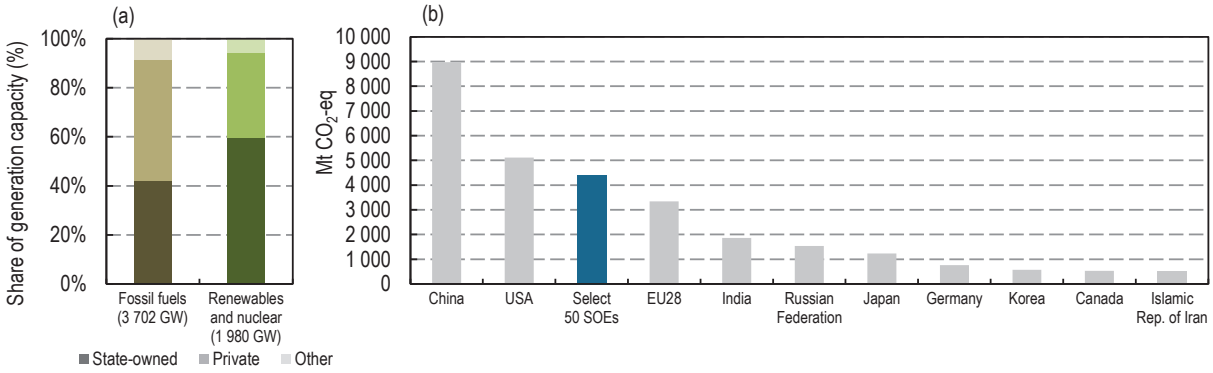
Figure ES.6

(a) Ownership of global generation capacity (2012); (b) CO_2-equivalent emissions of 50 selected SOEs compared with the top 10 emitting countries/regions



Notes: GW = gigawatts; $MtCO_2$-eq = million tonnes of carbon dioxide-equivalent; "Other" refers to auto-producers, communities and households; "Renewables" includes utility-scale renewables and distributed generation.

Source: (a) IEA (2014), World Energy Investment Outlook*; (b) IEA analysis (see Figure 6.2).*

meeting energy access and employment objectives. Effective energy transition design must therefore more fully address the specificities of SOEs.

Building resilience: Ensuring the energy sector's ability to support growth

Greater resilience to the impacts of climate change is needed to protect the delivery of energy services to businesses, communities and households. Recognising the challenges present at even low levels of temperature increase, the Paris Agreement includes objectives to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change. Governments need to develop policies to catalyse private sector action; to deliver climate information, build capacity and support emergency preparedness and response; and to strengthen resilience practices for their own energy infrastructure. Furthermore, both the public and private sectors have key roles to play in mobilising financial resources for resilience investments. Much of the energy focus among policy makers has been on decarbonisation, and much of the discussion on climate change adaptation has highlighted non-energy sectors. However, in face of a changing climate, concrete action is required for the energy sector in order for it to continue providing the energy that underpins economic activity and essential social services. Effective resilience plans will need to address not only current energy sector dynamics, but those of the future energy sector transitioning to low-carbon operations.

Tracking tools and better, more comprehensive data can promote energy sector transition

Stronger tracking frameworks and better energy data and metrics can support sound domestic policy development and implementation, and help countries understand whether current actions are consistent with short- and long-term goals for the low-carbon energy transition. Meeting the goals of the Paris Agreement will be facilitated by improved tracking of energy sector investments and operations. Developing and monitoring pertinent energy metrics can help focus attention on energy transformation: emission levels alone are not enough to understand underlying energy infrastructure change, so tracking a wider range of energy metrics can provide policy makers with the tools they need. Tracking appropriate metrics, supported by robust data, will enhance the credibility of the tracking framework and promote action that supports a sound low-carbon energy sector transition. The goal of reducing emissions to a level consistent with limiting temperature increase to well below 2°C could thus be made more achievable.

Next steps: Accelerating Paris Agreement implementation

With the Paris Agreement set to enter into force, it is time to speed up and scale up implementation action across all parts of the energy sector. The IEA stands ready to support member and partner countries and other stakeholders, in analysing and

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implementing efficient, cost-effective climate policies for the energy sector that support IEA objectives of energy security, economic growth and environmental sustainability. Significant challenges accompany the enhanced ambition of the Paris Agreement, but they are challenges that must be confronted directly to provide a better and safer future for all. Energy has played a central role in supporting economic and social development worldwide, and the IEA will work to ensure that it continues to do so during the transition to a low-emissions world.

References

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IEA (2016b), *Renewable Energy Medium Term Market Report 2016*, OECD/IEA, Paris.

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1.1 A wealth of opportunities, but also immense challenges

The year 2016 opened on an auspicious note for the international climate change agenda, with an historic global climate deal adopted at COP21 in Paris in December 2015 by 196 nations. The Paris Agreement capped two decades of at times fractious international negotiations meant to avert dangerous climate change. It contains some surprisingly ambitious elements, chief among them a long-term global goal to limit warming to "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C". The Agreement was the culmination of several work streams established under the United Nations Framework Convention on Climate Change (UNFCCC) process after COP15 in Copenhagen in 2009, and involved an unprecedented level of engagement by civil society, businesses and other non-state actors in the run-up to COP21. The details of many of the Agreement's decisions are yet to be worked out.

There were also other important developments, such as the launch of Mission Innovation, a global initiative announced by 20 countries to double funding for clean energy innovation, central to tackling climate change.[1] The mainstreaming of renewable energies has happened in recent years, with historically low costs of renewables contributing to the confidence that enabled agreement in Paris: costs for utility-scale solar photovoltaic (PV) are down by two-thirds, and for onshore wind by 30% compared with five years ago. And there is reason to believe that coal use in China, the world's largest greenhouse gas (GHG) emitter, peaked as of 2014, ahead of expectations and potentially signalling the decoupling of Chinese economic growth from rising coal consumption (Qi et al., 2016).

However, serious challenges have also presented themselves. First off, countries will need to actually implement what they have pledged under the Agreement – their Nationally Determined Contributions (NDCs) – ensuring that their paper commitments are translated into real-world policies and actions. While this would be a significant achievement, an ambition gap would still remain: according to the *World Energy Outlook Special Briefing for COP21* (IEA, 2015a), the level of collective ambition to mitigate climate change pledged by individual countries in the run-up to COP21 would not be sufficient to keep temperature rise below 2°C – nor, by implication, to keep it "well below 2°C" (discussed in Section 1.3 below). Another challenge is that fossil fuel prices across the board continue to be low, and support for renewables and clean energy technologies has waned in some parts of the world. Low fossil fuel prices can complicate the transition to clean energy fuels, as they can lure policy makers into short-term perspectives and curb support for clean energy technologies and energy efficiency.

Another challenging reality is that the carbon intensity of the global energy supply has remained stubbornly unchanged over the last two decades. This is captured by the Energy Sector Carbon Intensity Index (ESCII), which tracks the amount of carbon emissions from fuel combustion (in tonnes of carbon dioxide [tCO_2]) per unit of total primary energy supply (TPES), indexed to a base year (Box 1.1).[2] The ESCII shows the net impact of policy changes, shifts in investment and technology developments on CO_2 emissions in the energy sector, with declines in the index indicating a cleaner energy supply. In the IEA *Energy Technology Perspectives* (*ETP*) 2°C Scenario (2DS), in which global temperature rise is limited to 2°C above pre-industrial levels, the ESCII falls 13% by 2025 and over two-thirds by 2050, compared to 2014 (Figure 1.1a). While COP21 may well prove to be a turning point in the world's collective willingness to confront the climate change challenge, this simple metric indicates the magnitude of the task ahead. A separate challenge will be slowing the increase in the amount of energy consumed (discussed in Chapter 5).

1.2 Paris Agreement: A suite of robust outcomes

The Paris Agreement fulfils the long-standing need for an overarching accord that would send the strong political signal to governments, businesses and investors that the global energy sector – which accounts for more than two-thirds of global GHG emissions – is headed for a fundamental transformation over the next several decades. At the core of the Agreement is an ambitious long-term global goal defined in terms of both temperature and emissions. The rise in global average temperature is to be limited to "well below 2°C" from pre-industrial levels, and efforts are to be pursued to limit the increase to 1.5°C. The means of achieving this is by peaking global emissions "as soon as possible", and undertaking rapid reductions thereafter to "achieve a balance between anthropogenic emissions by sources and removals by sinks" of GHGs in

1. In addition, 28 high-profile investors have pledged through the Breakthrough Energy Coalition to invest in early-stage technology development that emerges from Mission Innovation initiatives.

2. Chapter 9 presents ESCII computations at the regional level for ten world regions.

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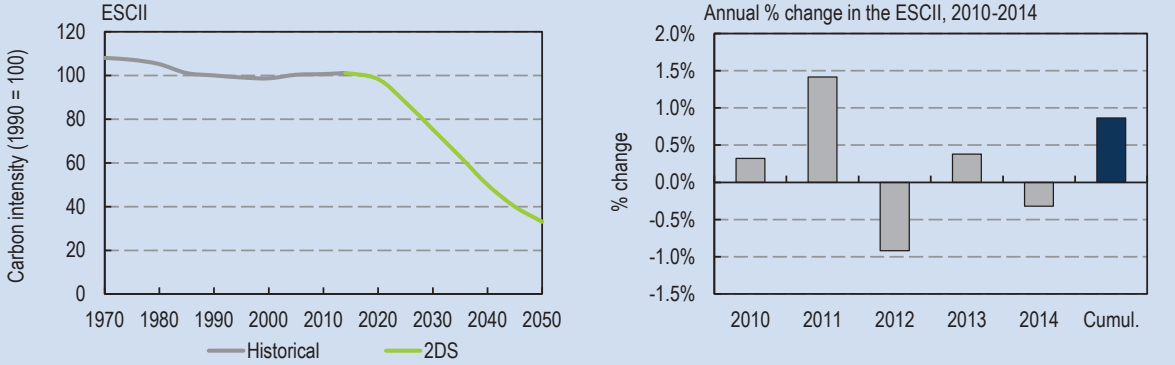
Box 1.1

Reducing the carbon intensity of our energy system: The ESCII measurement

For nearly five decades, the ESCII has changed little, fluctuating over the last 25 years within a band of +/-2% of its 1990 level (Figure 1.1a). As of 2014, the world's energy supply was 1.2% more carbon intensive than it was in 1990. While the growth rate of global emissions has varied over this period, with emissions at times declining during periods of economic recession, the ESCII has remained essentially flat. Even developments during the last five years have been unable to move the index onto a decidedly downward trajectory (Figure 1.1b). These include continued increases in net capacity additions of renewables, with dramatic growth in solar PV, and declines in the growth of global coal consumption and even an absolute decline in 2014 (the first ever this century). While there was a slight decline of 0.3% in the ESCII in 2014 relative to the previous year, it is difficult to determine whether this is the beginning of a trend reflecting increasing climate action. IEA scenarios demonstrate that absent a concerted effort to significantly lower the ESCII by mid-century, global average temperature is likely to rise 4-6 °C, far above the well-below-2 °C target of the Paris Agreement, or even a 2 °C target.

Figure 1.1

a) The ESCII since 1970, compared to 2DS targets; b) Annual percentage change in the ESCII, 2010-14, and cumulative 5-year change



Source: IEA (2016a) Energy Technology Perspectives 2016*; IEA (2016b),* CO_2 Emissions from Fuel Combustion 2016*; IEA (2016c),* World Energy Statistics and Balances.

the second half of this century. The global goal builds on a previous UNFCCC decision at COP16 in Cancun in 2010 (following the non-binding Copenhagen Accord in 2009) which signalled the goal to hold global temperature rise to below 2°C above pre-industrial levels, and to consider lowering that maximum to 1.5°C.

Architecturally different from previous approaches in some important respects, the Agreement contains both bottom-up and top-down elements. Importantly, developed and developing countries are no longer separated into distinct groups as in the Kyoto Protocol. All Parties are expected to undertake ambitious climate action, with the recognition that peaking emissions will take longer for developing countries and that they will require support for ambitious implementation. The accord is built around countries' NDCs, which cover a medium-term period extending through to 2025 or 2030, and a five-year review-and-revise approach designed to promote progression of Parties' efforts over time. Following periodic global stocktakes of collective ambition, NDCs are to be communicated every five years and are to reflect each Party's "highest possible ambition", in light of different national circumstances. The first such stocktake is scheduled for 2023, though under the supporting COP21 decision a facilitative dialogue is to take place in 2018 as a precursor to that process. Submission of NDCs is legally binding, as are reporting and review requirements under a new, common (but flexible) transparency framework (see discussion in Chapter 8). However, the elements of these contributions, including attainment of emission targets, are not binding under international law.

The ultimate success of the Paris Agreement will depend on the underlying ambition of the individual country contributions and the actions taken to realise them. To date, 163 NDCs have been officially submitted to the UNFCCC, representing 190 countries and corresponding to almost 99% of global GHG emissions (including land use and forestry).[3] Around two-thirds of these submissions contain GHG emission targets expressed in a variety of ways, such as absolute emission targets, deviations from "business-as-usual" GHG trajectories, emission intensity targets

3. According to the World Resource Institute's CAIT Climate Data Explorer: http://cait.wri.org/indc/.

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(i.e. GHG emissions per unit of gross domestic product [GDP]), or decreases in per-capita emissions. Thirty-five NDCs set quantified energy targets in the form of renewable energy or low-carbon energy supply and, of these, 15 also include energy efficiency or energy demand targets (see Chapter 8). Still other countries mention domestic renewables targets as supporting information, rather than as a commitment, in their NDCs. A number of pledges contain unconditional and conditional elements, pegged to the level of external financial support or other factors.

Carbon markets are another area that received an unexpected boost. A new market mechanism has been established as successor to the Clean Development Mechanism, and the Agreement allows for use of international carbon market transfers toward NDCs. The Agreement also puts renewed focus on the importance of support for innovation, by calling for strengthening of the Technology Mechanism to promote technology development and transfer, establishing a technology framework to guide its work, and reinforcing the relation between technology and financial bodies. Significant recognition was also given to the role that forests play in offsetting emissions from human activities. The Agreement is somewhat vague on the issue of climate finance, declining to name a specific sum, though the supporting COP21 decision determines that a new collective goal shall be set before 2025, with the current USD 100 billion per annum as a floor. For developing countries, institutional and technical capacity building, including for transparency and technology development, are to be scaled up. Countries are also encouraged to develop and communicate national long-term, low-carbon development strategies, mindful of the collective goal of the Paris Agreement.

The Paris Agreement will come into force on 4 November 2016, significantly earlier than was expected when the Agreement was adopted at COP21. As of late October, 191 Parties had signed the Agreement and 85 Parties had formally joined – including China, the United States and India, the world's top three country emitters, and the European Union – together representing 61% of global emissions.[4] This exceeds the threshold criterion for the Paris Agreement to enter into force – that at least 55 Parties representing at least 55% of global emissions must join (i.e. ratify, accept, approve or accede to it). With entry of the Agreement into force, COP22 in Marrakech will be the first official meeting of Parties to the Paris Agreement. In the pre-2020 period, the working group established under the Agreement will focus on the development of implementation rules, while countries turn their attention to developing their own plans for implementation of NDCs and longer-term strategies.

4. Only emissions of EU countries that have completed their domestic ratification processes count towards this total.

1.3 Four targets on the path to increased ambition

GHG emissions mitigation efforts coming out of COP21 can be divided into four distinct levels of ambition: (i) implementation of the NDCs, which cover the period through to 2025 or 2030[5] and have a 50% probability of limiting warming to about 2.7°C by 2100, with higher temperature increases thereafter if stronger action is not taken after 2030 (IEA, 2015a); (ii) deeper emissions cuts that involve a near-term peaking of global energy-related emissions and are consistent with a 50% probability of limiting warming to 2°C by 2100, which has been extensively analysed by the IEA in the *ETP* 2DS and the *World Energy Outlook* (*WEO*) 450 Scenario;[6] (iii) the increased ambition, newly established in Article 2 of the 2015 Paris Agreement, which resets the global goal to "well below 2°C"; and (iv) the Agreement's call to "pursue efforts to limit the temperature increase to 1.5°C", which existing analyses, though scant, indicate will likely move forward by one to two decades the date by which carbon neutrality will have to be achieved, compared with 2°C scenarios, requiring further modelling and analysis.[7]

1.3.1 Implementing the NDCs

In the *WEO Special Briefing for COP21*, the IEA estimated that if NDCs are implemented fully (the INDC Scenario), annual growth in energy sector GHG emissions slows dramatically by 2030 to around 0.5%, but does not yet come to a halt, which is a prerequisite for limiting temperature rise to 2°C or less.[8] In this analysis, global emissions under the NDCs are one-third higher in 2030 than they are today, reaching almost 42 gigatonnes of carbon dioxide-equivalent ($GtCO_2$-eq)[9] (Table 1.1), while emissions from CO_2 alone

5. The actual time frames vary (e.g. many contain targets through 2030, while others contain targets to 2025), but in general they provide a basis for projecting the evolution of the energy system over the medium term.

6. The IEA has two compatible 2°C scenarios calculated under different models, the ETP 2DS to 2050 and the WEO 450 Scenario to 2040.

7. Including as part of a 2018 Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of warming of 1.5°C and related global GHG emission pathways, as called for in the supporting COP21 decision.

8. This assumes that NDCs are implemented through 2030, and that stronger climate actions are not implemented beyond this point in time. Other mitigation scenarios exist in which countries could undertake enhanced action post-2030 and still limit long-term temperature rise to below 2°C (UNFCCC, 2015). However, the estimated rate of decline of global annual emissions during 2030-50 would need to double in comparison with least-cost mitigation scenarios that assume enhanced mitigation action by 2010 or 2020, increasing by an average annual reduction of 1.6 (0.7-2.0) to 3.3 (2.7-3.9) per cent.

9. Energy-related GHG emissions include CO_2, methane (CH_4) and nitrous oxide (N_2O). All gases are quantified in terms of their global warming potential relative to CO_2.

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Table 1.1

Global energy- and process-related GHG emissions in the INDC Scenario ($GtCO_2$-eq)

	2014	2020	2025	2030
Energy-related GHG emissions	35.5	36.9	37.5	38.4
Process-related CO_2 emissions	2.8	3.2	3.4	3.5
Total	38.2	40.1	40.9	41.9

Notes: The INDC Scenario depicted in this table covers NDCs submitted up to mid-October 2015. Energy-related GHG emissions include CO_2, CH_4 and N_2O emissions from combustion of fossil fuels. Process-related emissions are non-combustion emissions related to industrial processes such as cement.

Source: IEA (2015a), Energy and Climate Change: World Energy Outlook Special Briefing for COP21.

plateau at less than 35 Gt (Figure 1.2). On a regional basis, under the INDC Scenario the energy-related emissions of countries representing at least half of world GDP will already be in decline by 2030 or will have plateaued (such as in the European Union, the United States and China). By sector, the NDCs achieve a decoupling of power generation emissions, which remain broadly flat to 2030, and electricity demand, which grows by 40%. Low-carbon sources fuel 70% of additional power generation by 2030.

Achieving the goals and targets of the NDCs is a significant challenge: in the INDC Scenario full implementation of these pledges will require a USD 13.5 trillion investment in energy efficiency and low-carbon technologies – 40% of total energy sector investment to 2030. It will be important to help ensure robust and timely implementation, and to track progress and quickly identify areas in which implementation may be falling short, as underperformance in the INDC Scenario is a possibility, particularly prior to 2020. One key will be to mobilise sufficient public and private financing, as reflected in the conditional targets of many of the NDCs for emerging countries. While full implementation of the NDCs would put global emissions on a lower trajectory, the NDCs alone are not sufficient to limit temperature increase to 2°C; they must therefore be viewed as a starting point for more stringent mitigation measures over time.

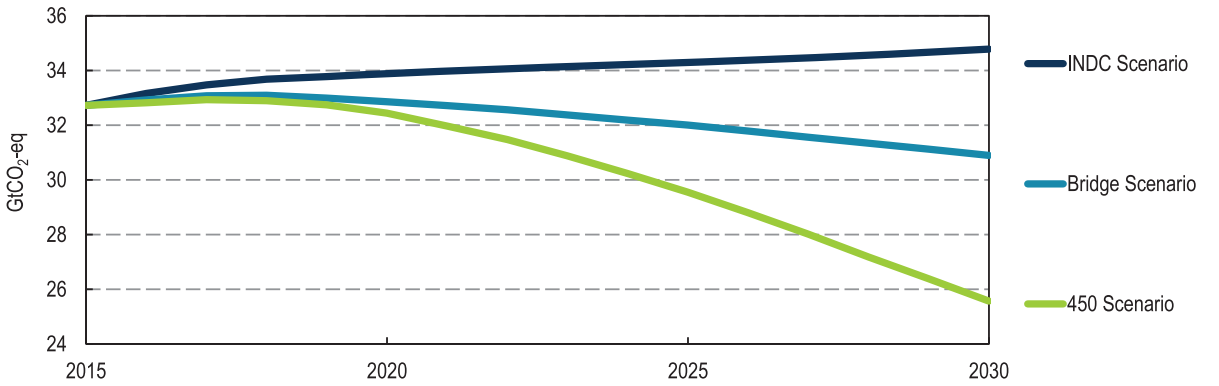
1.3.2 Getting to 2°C from the NDCs: The Bridge Scenario and beyond

IEA analysis (notably in both the *WEO* and *ETP* series) has stressed that limiting temperature rise to 2°C will require a peaking of near-term global energy-related emissions and a marked decline thereafter (e.g. the 450 Scenario through 2030 in Figure 1.2), which is in line with the aims of the Paris Agreement. The IEA has proposed a Bridge Scenario using existing technologies that could deliver a peak in global energy-related emissions by 2020 at no cost to global economic activity compared with the INDC Scenario – in essence, a GDP-neutral pathway to greater emissions reductions (IEA, 2015c) (Figure 1.2).

Globally, about half of the emissions savings in the Bridge Scenario are achieved through energy efficiency measures in the industry, buildings, and transport sectors. Another quarter of the emissions savings come from targeting power generation: 9% through a gradual reduction in the use of subcritical coal plants and a ban on construction of new plants, and another 17% through the use of appropriate policy signals to increase investment in renewable energy to USD 400 billion by 2030, up from USD 270 billion today. Policies to reduce methane releases from upstream oil and gas production can achieve 15% of emissions savings, and the final 10% is realised through an almost complete phase-out

Figure 1.2

Global energy-related CO_2 emissions under the INDC, Bridge and 450 Scenarios through 2030



Note: The INDC Scenario depicted in this graph covers NDCs submitted up to 14 May 2015.

Source: IEA (2015c), Energy and Climate Change: World Energy Outlook Special Report.

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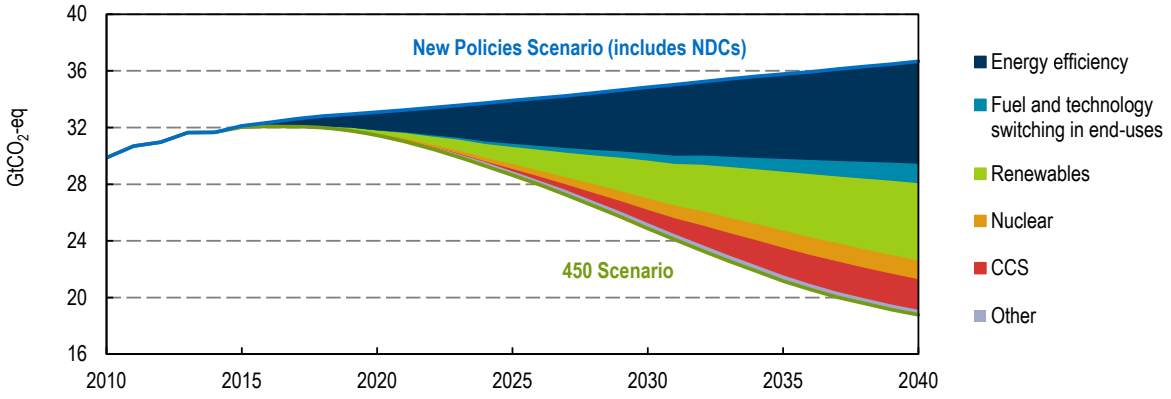
Figure 1.3

Measures needed to surpass current NDCs to reach 2°C trajectory (450 Scenario), through 2040



Note: The New Policies Scenario (NPS) is the central scenario of the World Energy Outlook *and includes the energy-related components of NDCs submitted by 1 October 2015.*

Source: Adapted from IEA (2015b), World Energy Outlook 2015.

of fossil fuel subsidies by 2030. As underscored in the 2015 IEA Ministerial Statement on Energy and Climate Change, countries could strengthen their immediate ambitions beyond the current NDCs by implementing actions in the Bridge Scenario. The supporting COP21 decision encourages countries to communicate updated contributions by 2020; elements of the Bridge Scenario could be incorporated into these, or countries could seek to outperform their current NDCs by pursuing elements of the Bridge Scenario.

However, as Figure 1.2 illustrates, deeper emissions reductions than those provided through the Bridge Scenario are required to achieve a 2°C cap on global temperature increase. CO_2 emissions under the 450 Scenario are 5.1 Gt lower in 2030 than in the Bridge Scenario, which itself is 3.9 Gt lower than the INDC Scenario. Greater action across the spectrum of clean energy technologies is required to generate both deeper decarbonisation of the energy mix and greater decoupling of energy demand from GDP (Figure 1.3) (see Chapter 2 on coal and gas; Chapter 3 on electricity markets; Chapter 4 on renewables; and Chapter 5 on energy efficiency). While energy efficiency and increased renewables are foreseen as the dominant sources of emissions reductions, carbon capture and storage (CCS) and nuclear also play important roles. Additional action in all of these areas could be part of subsequent NDCs, as contemplated by the Paris Agreement.

1.3.3 The greater challenge of the well-below-2°C goal

The Paris Agreement has formalised the greater ambition of limiting temperature increase to well below 2°C. Although the precise temperature threshold implied in this wording is currently uncertain, it is clear that limiting temperature rise to well below 2°C in a cost-effective manner will be a complex effort, requiring a strong foundation of robust long-term scenario modelling as well as expanded and refined modelling tools, which the IEA is currently working on.[10] The emissions pathways consistent with a 50% probability of limiting global temperature increase to 2°C, reflected in the modelling results of the 2DS and the 450 Scenario, provide a solid benchmark for analysing strategies to achieve the deeper emissions reductions that will be needed for consistency with the Paris Agreement.

While more robust modelling is being developed for a well-below-2°C scenario, the profile of CO_2 emissions that are still emitted under the 2DS provides a sense of the challenge and the areas to be addressed (Figure 1.4). Both the cumulative emissions during the 2DS period (2015-50) and the emissions that will be generated at the end of the modelling horizon in 2050 are revealing in this respect. While discussions of the 2DS, the 450 Scenario and other mitigation scenarios usually focus on the emissions eliminated under more ambitious climate policies (e.g. the emissions reduction wedges in Figure 1.3), the following analysis examines the remaining emissions – those "below the line" – for possible further actions to move towards a well-below-2°C emissions pathway.

Cumulatively, industry and transport account for nearly 60%[11] of energy sector emissions in the 2DS over the 2015-50 period (Figure 1.5, which translates the sectoral emissions trajectories in Figure 1.4 into cumulative amounts and shares). Tackling these sectoral emissions through a combination of actions, including increased use of renewables and improved energy efficiency (see Chapters 4 and 5), as well as greater deployment of CCS in industry,[12] can help reduce overall emissions to a

10. For example, WEO 2016 *examines related emissions reduction options through 2040, and* ETP 2017 *will deepen this analysis.*

11. Includes process emissions. If process emissions are excluded, this joint share is 54%.

12. See discussion in IEA (2016d), 20 Years of Carbon Capture and Storage, *Chapter 2.*

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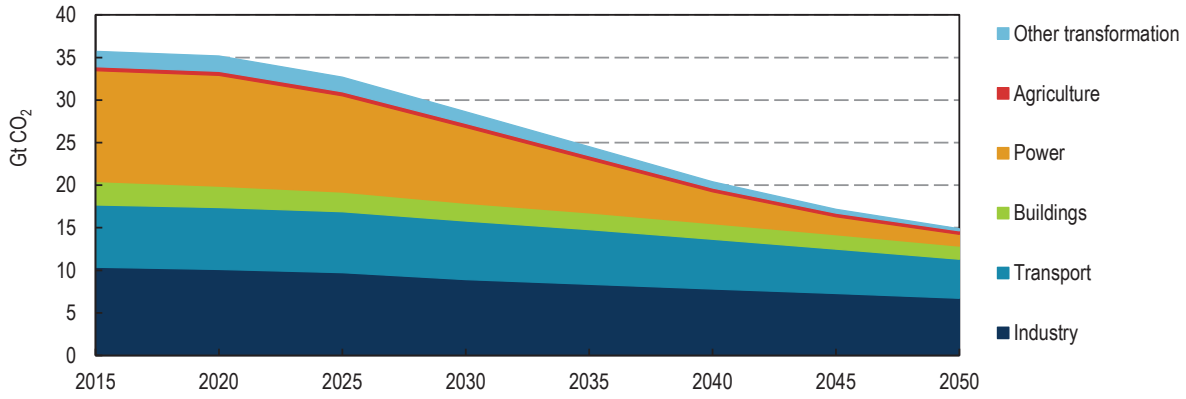
Figure 1.4

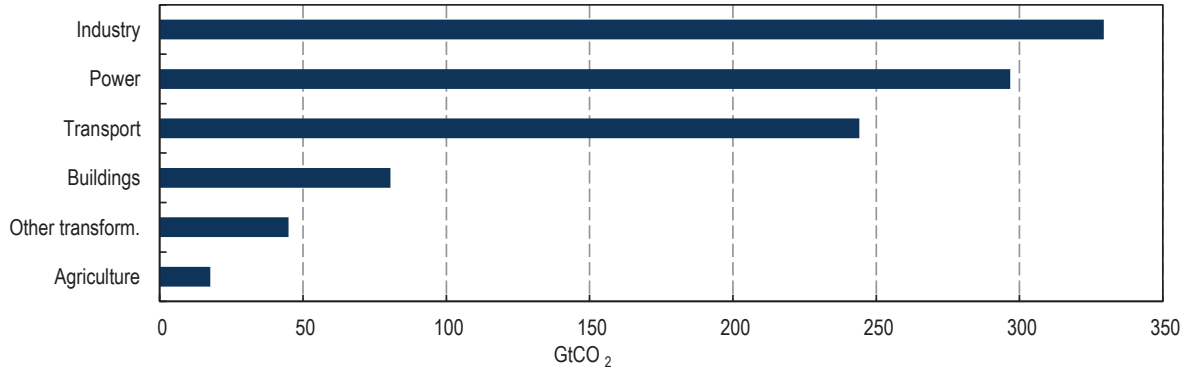
Energy-related CO_2 emissions by sector under the 2DS



Source: Derived from 2DS modelling results in IEA (2016a), Energy Technology Perspectives 2016.

Figure 1.5

Cumulative energy-related CO_2 emissions in the 2DS, 2015-50: Industry, power and transport dominate



Note: Includes process emissions.

Source: Derived from 2DS modelling results in IEA (2016a), Energy Technology Perspectives 2016.

level consistent with a well-below-2°C target. The electric power sector, which undertakes the largest share (40%) of emissions mitigation in getting to the 2DS from business-as-usual,[13] is significantly decarbonised by 2050 (producing just 1.4 $GtCO_2$ in 2050 compared with over 13 $GtCO_2$ in 2015). However, cumulative emissions from the power sector through 2050 still total almost 300 $GtCO_2$, or 29% of total cumulative emissions over the period. Given the magnitude of these remaining power sector emissions in the 2DS, moving to a well-below-2°C emissions pathway will likely require significant additional reductions in this area; the expanded deployment of low-carbon alternatives (such as renewables, discussed in Chapter 4) and accelerated reduction in fossil fuel electricity generation, or alternatively greater deployment of CCS, can help reduce these remaining emissions (see Chapter 2, which examines the role of managing coal and gas power generation in achieving global climate goals).

Cost-effective emissions pathways consistent with a well-below-2°C target will most likely require that zero or near-zero emissions be reached around 2050. It is therefore useful to examine the emissions that remain in 2050 under a 2°C target to determine in which areas future emissions reductions will be needed. In the 2DS, 14.9 Gt of total CO_2 emissions are emitted in 2050. However, as noted above, power sector emissions will have dropped to 1.4 Gt, accounting for only 9% of 2050 emissions (in contrast with

13. For comparison, the other sectors' emissions reductions account for 20% or less of the mitigation; see Figure 1.4 in ETP 2016 *for a sectoral breakdown of emissions reductions in getting from the 6°C Scenario (6DS) to the 2DS.*

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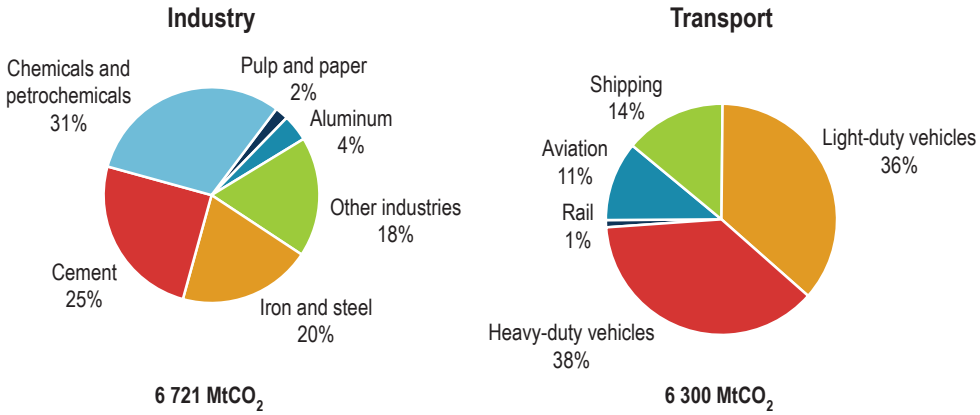
Figure 1.6

Sub-sector breakdown of industry and transport CO_2 emissions, 2050



Source: Derived from 2DS modelling results in IEA (2016a), Energy Technology Perspectives 2016.

the current 40% share);[14] accordingly, emphasis needs to shift to other sectors for 2050 and beyond.

Industry and transport generate over 75% of emissions in 2050 in the 2DS, with 6.7 $GtCO_2$ from industry and 4.6 $GtCO_2$ from transport. Industry is not only the largest source of cumulative emissions in the 2DS from 2015 to 2050, it is also the largest source at the end of the period in 2050. A breakdown of the sub-sectoral composition of these emissions can help to identify potential opportunities for further emissions reductions (Figure 1.6). Within industry, the three individual sub-sectors of chemicals, cement, and iron and steel account for over three-quarters of remaining industry emissions in 2050. Within transport, almost three-quarters of remaining emissions in 2050 are from heavy- and light-duty vehicles, although emissions from shipping and aviation are not inconsequential as they account for almost all of the remainder (1.2 Gt), close to the 1.4 Gt emitted by the power sector.

Actions to reduce emissions in industry and transport will therefore be critical to limit temperature rise to well below 2°C. Efforts are needed to decarbonise these sectors, such as through more extensive fuel switching to renewables and potentially increasing CCS in industry,[15] and increasing the use of fossil fuel alternatives in aviation. Efforts are also needed to address demand; for example, in transport, by finding alternatives to using personal light-duty vehicles as well as improving the dispatch of heavy-duty freight vehicles to reduce low-capacity trips.[16]

What is perhaps less apparent in the preceding figures is the impact on energy emissions of avoiding demand. Reducing emissions is not simply a case of switching from high-carbon to low-carbon energy generation systems, such as renewables and nuclear, but also managing the demand for energy. Energy efficiency is key in this regard; additional structural and even behavioural changes can also help obviate the need for energy while still meeting growth, poverty alleviation and consumer objectives (discussed in Chapter 5). For example, although total final energy consumption increases in all IEA scenarios through 2050 relative to the current level, the 2DS provides for 136 exajoules (EJ) less than the 4DS in 2050 (455 EJ compared with 591 EJ). This reduction in energy demand is greater than the current consumption of energy from coal and natural gas combined, and close to that of oil.[17]

Of course, an actual modelling exercise for an emissions pathway designed to limit global temperature increase to well below 2°C would likely involve a different set of choices among different technologies than for a 2°C pathway. The foregoing section is therefore not a prescription for how to limit temperature rise to well below 2°C, but merely illustrates some potential areas to address. Revised models and modelling scenarios in the forthcoming *WEO 2016* and *ETP 2017* will provide additional insights into energy and technology pathways needed to achieve well-below-2°C outcomes.

14. Electricity has largely decarbonised by mid-century in the 2DS: the CO_2 intensity of generation falls from 550 grammes of carbon dioxide per kilowatt hour (gCO_2/kWh) in 2015 to 40 gCO_2/kWh in 2050. Coal-fired generation without CCS is nearly completely phased out, and the share of gas-fired generation without CCS falls to under 60% of total gas-fired generation (see Chapter 2). This decarbonisation of the electricity supply provides a basis for end-use sectors to reduce emissions by switching to electricity as their energy source.

15. See discussion of how CCS can help reduce remaining emissions in industry in 20 Years of Carbon Capture and Storage, *Chapter 2 (IEA, 2016d).*

16. See, for example, discussions of efforts to manage the demand for cars in urban areas in A Tale of Renewed Cities *(IEA, 2014) and* ETP 2016.

17. Oil represented 39% of final energy demand in 2013, or 156 EJ of a total 401 EJ. Coal represented 15% or 60 EJ, and natural gas represented 14% or 56 EJ.

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1.3.4 Pursuing efforts to limit temperature rise to 1.5°C

The Paris Agreement includes the even stronger ambition to "pursue efforts to limit the temperature increase to 1.5°C." The means of achieving this 1.5°C target lie in even less-charted territory than discussions about well below 2°C, as very few studies have produced modelling scenarios consistent with 1.5°C. In the most recent IPCC assessment report (IPCC, 2014a), some of the most stringent scenarios (i.e. those that achieve emissions concentrations of 430 parts per million carbon dioxide-equivalent [ppm CO_2-eq] to 480 ppm CO_2-eq in 2100) were able to limit temperature increase to 1.5°C in 2100, but all were more likely than not to exceed ("overshoot") 1.5°C during the course of 21st century.[18] No modelling scenarios exist in which it is "likely," according to the IPCC's definition (i.e. with a probability of at least 66%), that temperature will remain at or below 1.5°C during the entire 21st century (Rogelj et al., 2015).[19] Partly in response to the limited analysis of requirements of a 1.5°C target, the countries at COP21 agreed the IPCC should submit a report in 2018 "on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways".[20]

Several points emerge from these preliminary exercises. One is that achieving a 1.5°C goal will significantly curtail the remaining global carbon budget, which for 1.5°C has been estimated to be a mere 40% of the budget needed to attain 2°C (i.e. in 2011 the budget was 400 $GtCO_2$ for 1.5°C, compared with 1 000 $GtCO_2$ for 2°C).[21] In scenarios examined by Rogelj et al., the 1.5°C limit was achieved mainly through additional reductions of CO_2, with carbon neutrality achieved around mid-century, one to two decades earlier than in scenarios that are consistent with 2°C. In all 1.5°C scenarios, cumulative emissions during 2010-2100 are lower than emissions during 2010-50. This highlights the importance of negative emissions technologies such as bioenergy with CCS (BECCS) that enable large net removals of CO_2 in the second half of this century, to compensate for higher emissions in the first half.[22] It also points to a faster pace for decarbonisation of the energy system, which could be achieved by an accelerated decarbonisation of the power sector coupled with a more rapid move toward electrification of all end-uses, and demand-side management actions that potentially go beyond technological solutions and consider policy-induced behavioural and structural changes. Innovation to accelerate technology development and deployment will be needed to support this process, as well as more effective regulations and market structures to drive deep and accelerated emissions reductions.

1.4 Conclusion

Whether the target is implementing the NDCs or limiting global temperature rise to 2°C, well below 2°C, or eventually 1.5°C, the challenge of reducing energy emissions is enormous. This effort must also be considered in the context of other overarching objectives, such as globally inclusive economic growth and social development. While significant progress was made in the lead-up to and during COP21, translating the aspirations of the Paris Agreement into reality is a daunting task – one for which failure would have dramatic consequences. Moreover, as events over the last several years have shown (including the significant changes in oil prices), the changing dynamics of the global energy system will have implications for attainment of global climate goals. Various IEA publications such as the *WEO* and *ETP* series, as well as market reports (especially those on energy efficiency and renewables), will continue to explore these circumstances; this publication is intended to complement these other IEA analyses.

The increased ambition of the Paris Agreement requires deeper examination of possible policies and mechanisms across the entire energy system to tackle the challenges of climate change. A practical starting point is to drill down into the specific actions that are needed in each sector and policy area. This publication contributes to this effort by exploring selected implementation topics – some of which have received relatively little attention so far, and others that can be looked at differently post-COP21. It is only through this type of deep examination of the details of policy implementation that workable solutions to meet the imperative goal of averting dangerous climate change can be found.

18. Rogelj et al. (2015) examined modelling scenarios that achieve the 1.5°C limit in 2100 with greater than 50% probability (with concentrations between 420 ppm CO_2-eq and 440 ppm CO_2-eq), though they generally overshoot 1.5°C as well (with the maximum increase below 1.75°C).

19. This is in contrast to the 430 ppm CO_2-eq to 480 ppm CO_2-eq scenarios in the IPCC assessment, which were "likely" to stay below 2°C over the 21st century.

20. Paris Decision, paragraph 21.

21. See Table 2.2 in IPCC (2014b), with a threshold of 66% of the simulations meeting the 1.5°C goal.

22. Biomass absorbs CO_2 as it grows, and when combusted for energy production the CO_2 is released back into the atmosphere, creating a full cycle that can have a neutral or near-neutral impact on atmospheric volumes of CO_2. BECCS permanently removes from the atmosphere the CO_2 absorbed by the biomass, giving rise to "negative emissions". Growing conditions are central to determining whether biomass is carbon-neutral, the pre-condition for BECCS to create negative emissions. See discussion in Chapters 2 and 3 of 20 Years of Carbon Capture and Storage *(IEA, 2016d).*

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Chapter 2 • Coal and gas power in the 2°C Scenario and reaching the "well-below-2°C" goal

Coal and gas power plants generate a significant portion of today's global electricity supply, but they are carbon-intensive relative to the intensity levels needed to limit the average global temperature increase to less than 2°C. Addressing coal plant emissions, particularly those from existing coal plants (emissions that are "locked in"), will be important to reduce global emissions. Carbon pricing and other policies can be used to reverse this lock-in. Shifting to gas can help, as it is a less carbon-intensive power source, but over the medium to longer term even gas becomes a high-carbon alternative. To achieve long-term power sector carbon intensity goals, carbon capture and storage (CCS) will be required. The need for deeper emissions reductions corresponding to the increased ambition of the "well-below-2°C" goal of the Paris Agreement points to the need for extensive mitigation action in the power sector.

2.1 Introduction: Power is key to achieving climate goals

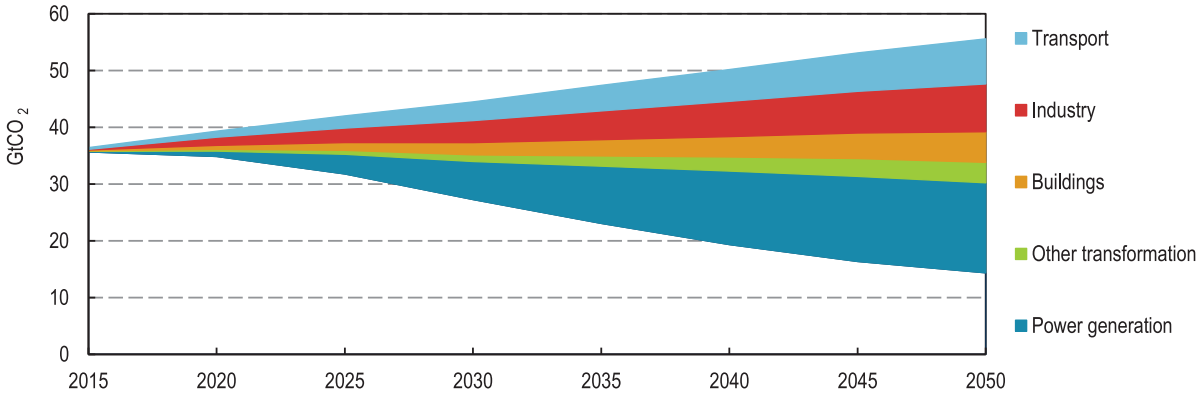
The goal of keeping average global temperature rise below 2°C will require a rapid reduction in carbon dioxide (CO_2) emissions from the power generation sector, which today generates about 40% of energy sector emissions. At present, coal and gas plants account for approximately two-thirds of global power generation. Both have many advantages over other fuels used in the power sector: coal power is abundant and affordable, and provides many jobs in the supply chain; gas power is efficient, flexible and has low capital costs. However, the burning of coal and gas currently generates around 90% of all CO_2 emissions from power generation. Under the IEA *Energy Technology Perspectives (ETP)* 2°C Scenario (2DS), 39% of energy emissions reductions needed to limit global temperature increase to 2°C come from the power sector (Figure 2.1).

The present fleet of coal- and gas-fuelled power plants is large, with coal plants totalling nearly 2 000 gigawatts (GW) and gas around 1 500 GW, and new plants are under construction. These incumbent plants tend to be relatively inexpensive to operate once capital costs have been expended, reinforcing political and market factors that make it difficult to stop using them (IEA, 2016a; Erickson et al., 2015; Platts, 2016). When investments are made in high-carbon assets with long technical lifetimes, the associated emissions can be thought of as "locked in" because they cannot be avoided without stringent policy intervention. This is evident in some Organisation for Economic Co-operation and Development (OECD) countries, where resistance to shutting down coal plants that have exceeded their technical lifetime remains strong.[1]

Government policies can reverse lock-in from unabated incumbent plants – i.e. avoid some of their future emissions. These actions may however also result in the "stranding" of assets, for example by retiring plants prematurely (before

Figure 2.1

Reduced power generation emissions lead reductions to the 2°C pathway



Source: IEA (2016a), Energy Technology Perspectives 2016.

1. Although there are examples of coal plants in certain OECD countries which became uneconomical for a variety of reasons, including market developments, government policies and carbon prices.

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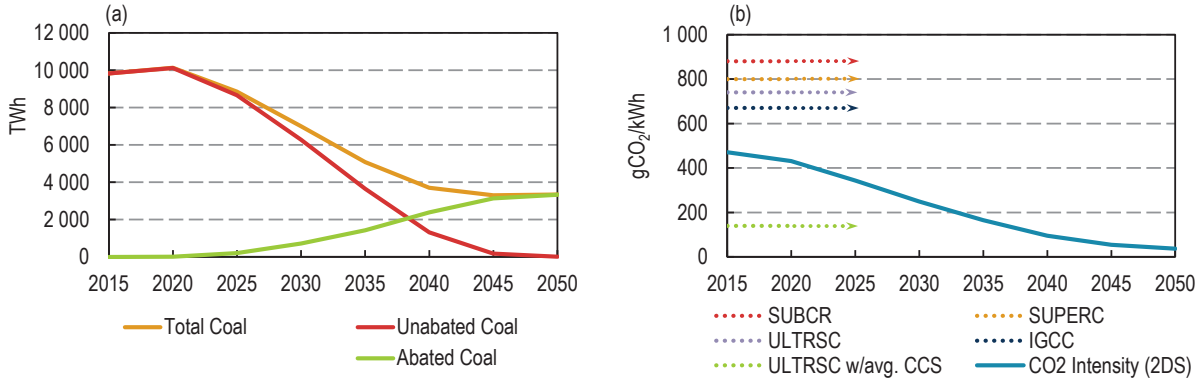
Figure 2.2

(a) Diminishing global coal-fired generation under the 2DS; (b) Low-end CO_2 intensity of various coal-fired technologies relative to average carbon intensity for power generation under the 2DS



Sources: (a) IEA (2016a), Energy Technology Perspectives 2016*; (b) IEA (2012c),* Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation.

the end of their technical lifetime and before they have had the opportunity to repay the initial investment) in order to meet a climate change mitigation objectives.[2] Moreover, new investment in coal and gas plants that generate emissions which exceed levels consistent with the 2DS can create further lock-in. Even more action to reverse lock-in and avoid future lock-in will likely be needed to achieve the increased ambition of Article 2 of the Paris Agreement to limit temperature increase to "well below 2°C". These issues are discussed below.

2.2 Coal power: At the centre of the challenge

Coal is an important power generation fuel, representing around 40% of all generation worldwide. It is also currently the largest contributor to emissions in the power sector, responsible for about 10 gigatonnes of carbon dioxide ($GtCO_2$), or 77% of all CO_2 emissions from power generation (IEA, 2016b). This section looks at the role of coal-fired generation in the 2DS, as well as policies that can be used to reverse the lock-in of emissions from existing plants and prevent the lock-in of emissions from future capacity.

2.2.1 Diminishing role for coal power under the 2DS

Limiting global temperature rise to below 2°C will require a significant reduction in the use of coal in unabated power generation (i.e. from plants without CCS). In the 2DS, coal generation falls to less than 3 500 terawatt hours (TWh) in 2050 from the current level of nearly 10 000 TWh (Figure 2.2a). The share of unabated generation drops to nearly zero in 2050 (10 TWh), while the share of abated generation (i.e. CCS-equipped coal power production) rises dramatically from 2030.

In the 2DS, the average carbon intensity in the power sector falls from its current level of 550 grammes of carbon dioxide per kilowatt hour (gCO_2/kWh) to 40 gCO_2/kWh in 2050 (Figure 2.2b). Achieving this entails a dramatic reduction in coal generation (Figure 2.2a). Different coal technologies have been developed to provide greater efficiency than subcritical (SUBCR) power plants, with corresponding lower carbon intensities. These include supercritical (SUPERC), ultra-supercritical (ULTRSC) and integrated gasification combined cycle (IGCC) technologies. Under favourable conditions, SUBCR technologies still emit more than 880 gCO_2/kWh, while SUPERC technologies emit 800 gCO_2/kWh to 880 gCO_2/kWh, ULTRSC emit 740 gCO_2/kWh to 800 gCO_2/kWh,[3] and IGCC emit 670 gCO_2/kWh to 740 gCO_2/kWh (IEA, 2012c).[4] Currently, around 70%

2. Under the IEA 2DS, 165 GW of new fossil fuel capacity would have to be retired before repaying capital costs, with an unrecovered investment cost of USD 120 billion (IEA, 2013).

3. In theory, SUBCR plants are the least efficient and ULTRSC and IGCC are the most efficient. In practice, numerous factors influence plant efficiency, including coal quality, type of cooling system and pollution control technologies, maintenance schedule and operating conditions. Plant age, short-run marginal costs of other fuels, the amount of variable renewable energy and the policies that are in place to support or limit plant use can also affect plant efficiency.

4. Advanced ultra-supercritical pulverised coal plants (A-ULTRSC), coal-fired power plants designed with an inlet steam temperature to the turbine of 700°C to 760°C, promise to emit around 17% to 22% CO_2/kWh less than subcritical plants (i.e. around 700 gCO_2/kWh) (Weitzel, et. al, 2011). While this is the same gCO_2/kWh range as IGCC, A-ULTRSC plants have not yet come onto the market, nor has their performance been fully analysed.

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of all operating coal plants are SUBCR, 22% are SUPERC and 8% are ULTRSC.[5] However, the carbon intensity of even these most advanced efficient plant technologies (without CCS) today[6] remains high, around 700 gCO_2/kWh, relative to the average required carbon intensity of power generation under the 2DS trajectory.

Coal generation with CCS ("abated") overtakes unabated generation by 2040 in the 2DS. Equipping coal power generation with CCS could potentially lower the carbon intensity of generation by 85% to 95%, enabling these plants to remain below or near the average carbon intensity of the 2DS pathway through 2040 (Figure 2.2b).[7] Accordingly, CCS plays an important role in coal power generation in the 2DS (Box 2.1).

In this scenario, virtually all newly operating coal plants are fitted with CCS before the end of their technical lifetime or are retired prematurely. Production from CCS-equipped coal plants represents more than 90% of coal

Box 2.1

The role of CCS for coal power in the 2DS

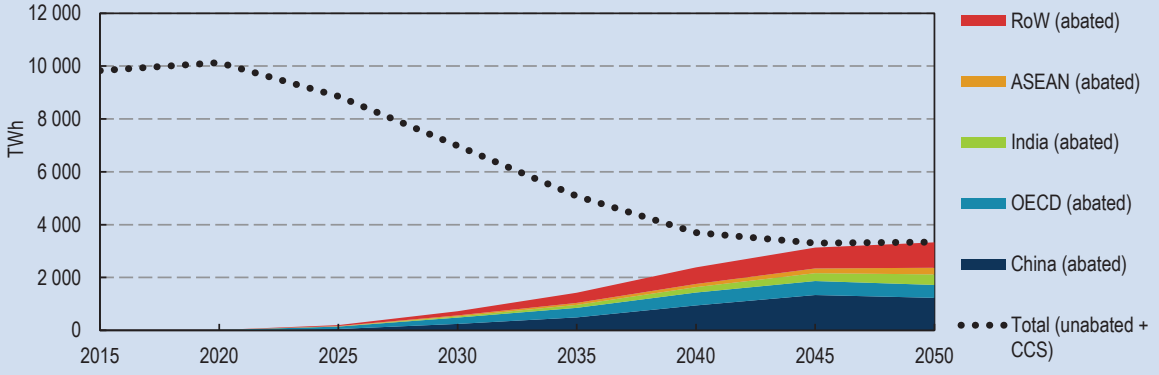
In the 2DS, CCS plays a vital role in decarbonising the power sector, with around 3 300 TWh generated by CCS-equipped coal plants in 2050. This is in contrast to the 4°C Scenario (4DS) with only about 780 TWh. The importance of coal with CCS in the 2DS is clearly seen in non-OECD Asia, with around 56% of all coal-fired CCS power generation coming from China, India and the ASEAN in 2050 (Figure 2.3). China is by far the largest user of CCS-equipped coal power plants in the 2DS.

Depending on the plant technology, the IEA Energy Technology Perspectives *model assumes that around 85% to 95% of CO_2 can be captured from CCS-equipped coal plants today, which means some residual emissions are released into the atmosphere. The amount of emissions from CCS-equipped coal plants totals about 210 million tonnes (Mt) in 2050 (see discussion in Section 2.4 and Figure 2.7).*

However, progress with introducing CCS remains slow and is not consistent with a 2°C pathway. While two new large-scale CCS projects began operating in 2015 and seven more are expected to commence within the next two years – including two projects applying CCS to coal-fired power generation – no investment decisions have been taken on a new CCS project for several years. This reflects a lack of policy and financial support for the technology which must be urgently addressed. The annual IEA Tracking Clean Energy Progress 2016 *highlighted that government support and prioritised development of CO_2 storage resources will be needed to encourage investment and to bring more projects into the development pipeline in order to meet 2DS targets in 2025 and later (IEA, 2016a).*

Figure 2.3

Global abated coal-fired generation under the 2DS



Source: IEA (2016a), Energy Technology Perspectives 2016.

5. *According to* WEO 2014, *the average capital cost of SUBCR plants (USD 1 422/kW) is 25% less than ULTRSC plants (USD 1 900/kW) (IEA, 2014d).*

6. *Future technological improvements could lower the carbon intensity of coal plants (see discussion in the next subsection).*

7. *It is important to note that the 2DS carbon intensity is a weighted average for the entire power sector, including zero-carbon renewables and nuclear. Accordingly, more carbon-intensive coal generation can be accommodated if counter-balanced with lower-emitting complementary sources.*

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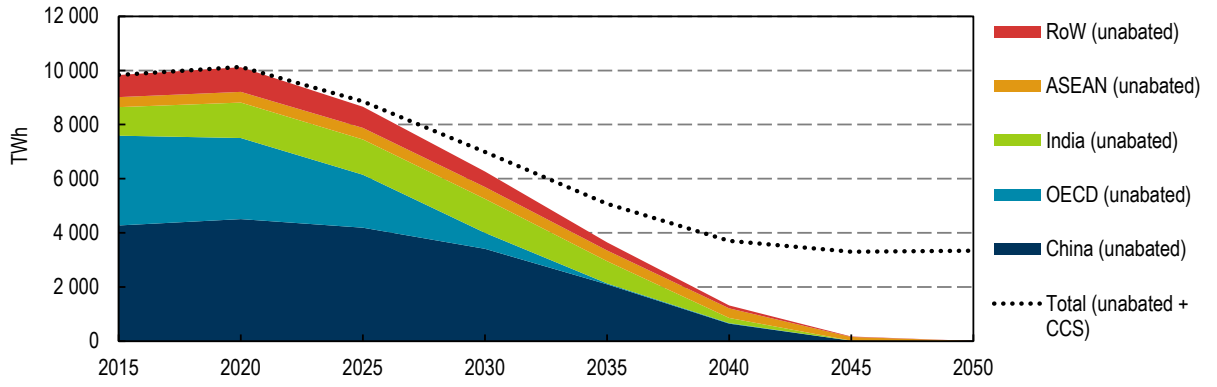
Figure 2.4

Global unabated coal-fired generation under the 2DS by region



Source: IEA (2016a), Energy Technology Perspectives 2016.

power generation beginning in 2045 (Figure 2.3). CCS uptake thus needs to be supported and scaled up for consistency with the 2DS trajectory. Notwithstanding this deployment of CCS, total coal generation still falls by two-thirds by 2050.

Timing of the phase-out of unabated coal-fired generation and the expansion of CCS-based generation in the 2DS differs from region to region (Figures 2.3 and 2.4):

- OECD countries all but phase out generation from unabated coal-fired power plants by 2035 – a major reduction to as low as 8% from the one-third of all power currently generated from unabated coal-fired plants.
- Unabated coal-fired generation in China plateaus in the 2DS to 2025 (at levels slightly above 4 000 TWh) before beginning a period of consistent reductions to 2045, at which point it has shrunk to barely 18 TWh.
- Unabated coal-fired generation in India grows in the short term by 50% to 2020, although it still represents less than 30% of Chinese unabated coal power generation that same year. Production in India largely plateaus at that point, before rapidly declining from 2035 onwards. By 2045, India also generates less than 5 TWh of power from unabated coal plants.
- ASEAN unabated coal-fired generation increases from 255 TWh in 2013 to 396 TWh in 2020, but declines to as little as 5 TWh by 2050. This decline contrasts with total power generation in the ASEAN, which more than triples from around 800 TWh in 2013 to about 2 600 TWh in 2050 (including gas and renewables), an increase which is larger than the current total power generation of India. The 2DS pathway for the ASEAN highlights the importance of retrofitting new coal-fired plants with CCS to prevent stranding of many coal assets.
- While unabated coal-fired generation diminishes dramatically in the 2DS through 2050, total power generation from coal plateaus around 3 300 TWh from 2040 to 2050 as generation with CCS replaces unabated generation. CCS expands substantially during this decade across non-OECD countries outside of China (Figure 2.3).

Further reducing the carbon intensity of coal-fired power plants

As reflected in Figure 2.2, the overall carbon intensity of the power sector falls to 40 gCO_2/kWh by 2050 in the 2DS. Technological and process improvements to reduce the carbon intensity of coal power plants beyond today's more efficient technologies (ULTRSC, A-ULTRSC and IGCC) could enable coal power plants to operate at lower emissions levels. CCS is one option to be pursued, but other technological opportunities operating in combination with or independently of CCS, including increased co-firing where sustainable biomass is available[8] could help to slow the rapid reductions in the use of these power plants projected under the 2DS.

8. Typically, it is possible to co-fire up to 10% of biomass in a pulverised coal-fired power station without major investment. Beyond such a share, additional investment is often required in dedicated biomass equipment (handling, boiler, etc.). A study by VTT highlighted that a very high level of biomass co-firing (70%) in a circulating fluidised bed (CFB) plant could achieve the same CO_2 emissions reduction as with CCS (Kärki and Arasto, 2014). A study of an Australian case showed that 40% co-firing of wood pellets in a subcritical coal-fired power station would reduce the emissions intensity to 500 g/kWh without CCS. With CCS, the same plant could actually achieve close to 600 g/kWh negative emissions (Khorshidi, Minh and Wiley, 2013). As a different concept, a CFB plant is generally considered to have more flexibility regarding composition of the fuel.

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2.2.2 Reversing the lock-in of emissions from existing coal plants: Policy options beyond carbon pricing

The near-total phase-out of unabated coal generation under the 2DS occurs by 2050, which is only three decades away and within the technical lifetimes of much of the incumbent coal power infrastructure. Staying on a below-2°C pathway will therefore require a transition away from unabated assets at a rate faster than that of natural infrastructure replacement. The IEA (2014a) reviewed potential actions to reverse the lock-in of emissions from unabated coal-fired generation, including: regulatory rules targeting the dispatch of plants; retrofitting to improve plant efficiency; retrofitting with CCS; biomass blending or conversion; and the direct phase-out of plants (Table 2.1).

Depending on the characteristics of the power system, changes to dispatch can be driven by price or mandated through regulation. Plant efficiencies can be improved, thereby decreasing the carbon intensity of generation. Policies to drive efficiency upgrades can include direct regulation or GHG emissions regulation of the fleet. China, for example, has made considerable progress introducing regulations to retire small, inefficient plants and replace them with more efficient SUPERC and ULTRSC plants. Many operating plants have the technical potential to be CCS-retrofitted or converted to run on a coal-biomass blend. For example, the IEA found that 310 GW of China's 900 GW of existing coal capacity is suitable for CCS retrofitting at an estimated incremental cost of USD 34/megawatt hour (MWh) to USD 129/MWh (IEA, 2016c). Targeted policies and related transport and storage infrastructure development can help support the retrofits needed for coal-to-biomass conversion. As an alternative to targeting the retrofit or closure of plants themselves, policy makers can also regulate emissions from individual units, which should provide asset managers with an incentive to fuel-switch, retrofit, or retire the least efficient units.

2.2.3 Reversing the lock-in of emissions from existing coal plants: Using carbon pricing

A carbon pricing system could be an effective tool to reverse the lock-in of emissions from existing unabated coal plants. While implementing a robust carbon price has proven difficult in practice (see discussion in Chapter 3), evaluating the dynamics of carbon pricing provides important insights into the financial levers needed to decarbonise the electricity sector. In electricity systems with unused lower-carbon alternative capacity (e.g. surplus natural gas), carbon pricing can lead to a change in dispatch patterns (fuel switching) among existing plants. This is typical of many OECD markets at present. Beyond the gains available from fuel switching the task

Table 2.1

Reversing lock-in actions for existing coal plants and the policies that can drive them

Reversing lock-in action	Policy options		
	Direct regulation of plants	Regulated change in supply/demand balances	Influence markets via price
Retirement of coal plant	• Ownership decision • Regulated lifetime limits • Regulated phase-out	• Fleet-wide GHG emissions performance standard • Regulated increase in renewable capacity • Demand reductions	• Fuel price changes • Carbon pricing • Preferential pricing for renewables
Change dispatch of the existing power generation fleet	• "Clean first" dispatch • Priority dispatch of renewables	• Fleet-wide GHG emissions performance standards	• Carbon pricing • Removal of fossil fuel subsidies
Retrofit of coal plant for CCS	• Regulated lifetime • CCS retrofit mandates	• CCS trading schemes • Fleet-wide GHG emissions performance standard	• Carbon pricing • Preferential pricing for CCS generation • Low cost (or free) capital for construction
Biomass co-firing or conversion	• Ownership decision to convert	• Renewable generation quota • Fleet-wide emissions performance standard	• Carbon pricing • Preferential pricing of renewables

Source: IEA (2014a), Energy, Climate Change and Environment: 2014 Insights, *adapted from Chapter 1, "Policies and actions to 'unlock' high-emissions assets: The example of coal-fired power generation".*

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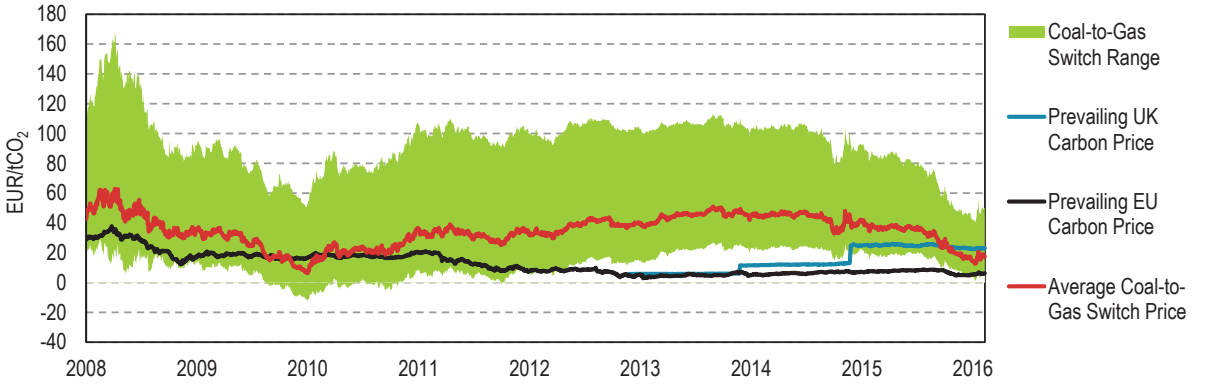
Figure 2.5

Marginal cost of coal-to-gas switching compared with the prevailing EU carbon price



Notes: 1) "Average coal-to-gas switch price" takes into account the actual average efficiency of coal and gas plants, and factors in actual coal and gas prices at that time; 2) Low-range plant efficiencies: hard coal, 32%; gas, 60%. High-range plant efficiencies: hard coal, 44%; gas, 32%; 3) Year-ahead contracts: German Power, TTF Gas, API coal and EUA; 4) This analysis does not include generation from lignite, which typically has lower marginal costs than hard coal.

Source: Bloomberg (2016), "Year-ahead contracts database for German Power, TTF Gas, API coal and EUA".

is more challenging: reversing lock-in of existing coal will require new low-carbon generation to be built to replace it.

How carbon prices can reverse lock-in through coal-to-gas fuel switching

A carbon price can reverse the lock-in of emissions from an existing unabated coal plant by improving the marginal cost of gas-fired generation relative to coal-fired generation. In competitive power systems which have spare capacity, competition between coal-fired and gas-fired plants can result in fuel switching from coal to gas and vice versa. The economic dispatch choices of competitive power systems depend on the marginal cost of each operational plant and, consequently, on plant efficiencies, relative fuel prices and carbon prices.

While economic arbitrage of dispatch typically occurs between coal-fired and gas-fired plants, dispatch of renewables is generally prioritised over both coal and gas due to their low marginal costs and grid priority. For example, in Europe, variable renewable energies have grid priority, meaning the grid must take their electricity first. However, prioritising these sources of generation also makes economic sense because the marginal cost of wind and solar electricity is very low, and the grid would take their electricity first regardless of a regulatory obligation to do so. Consequently, while carbon prices can affect dispatch choices between coal and gas, they will not disturb the priority of wind and solar.

Coal, gas and carbon prices vary across regions and fluctuate over time, so the potential for fuel switching also varies. Taking average unabated hard coal and gas plant efficiencies for Europe, it is possible to identify the average carbon price required to incentivise fuel switching from unabated coal to gas. By comparing the most inefficient unabated hard coal-fired plants with the most efficient unabated gas-fired plants, it is also possible to identify a low fuel-switching price range, and vice versa, for Europe as a whole.[9] Comparing the European fuel-switch price range with the EU carbon price (Figure 2.5) highlights how the combination of low carbon prices, low coal prices (the result of abundant coal availability on the international market) and high gas prices has favoured unabated coal-fired generation in Europe, leading to a gas-to-coal switch from 2012 to 2015.

The reverse situation, coal-to-gas switching, began happening in Europe in 2016 as a result of prevailing gas and carbon prices. This has particularly been the case in the United Kingdom, where since 2013 the government has required power generators using fossil fuels to pay a tax – the "carbon price support rate" – based on the carbon content of fuels. This is paid in addition to the emission allowance price they pay under the EU ETS. In 2015, the carbon price support rate increased from GBP 9.54 per tonne of carbon dioxide (tCO_2) to GBP 18.08/tCO_2 (HMRC, 2013). While there are various factors which can drive the choice of fuels at the operator and system levels, this increase, coupled with declining gas prices, was arguably a key factor in the halving of UK coal-fired

9. The carbon price needed to encourage the owner of a low-efficiency coal plant to switch to an efficient combined cycle gas turbine (CCGT) plant would be lower than the price needed to encourage the owner of a high-efficient coal plant to switch to the same gas plant. This difference establishes a range, with the lowest value being the price needed to encourage a switch between the most inefficient coal plant and the most efficient gas plant, and the highest price applying to a switch between the highest-efficiency coal plant and the least efficient gas plant (Figure 2.5).

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Table 2.2

CO_2 prices needed to make new gas, solar PV and onshore wind competitive with existing unabated coal, 2020

	CO_2 price required to make new gas plant competitive with existing unabated coal plant (USD/tCO_2)			CO_2 price required to make new solar PV plant competitive with existing unabated coal plant (USD/tCO_2)			CO_2 price required to make new onshore wind plant competitive with existing unabated coal plant (USD/tCO_2)		
Discount Rate	*3%*	*7%*	*10%*	*3%*	*7%*	*10%*	*3%*	*7%*	*10%*
United States	20	40	50	20	50	80	0	10	20
Germany	130	150	160	60	130	170	60	80	100
China	70	70	80	20	40	50	10	30	40

Notes: 1) Cost assumptions are based on the expected cost of commissioning these plants in 2020 and the LCOE calculations are based on a levelised average lifetime cost, using a discounted cash flow method; 2) All coal plants are assumed to be ULTRSC apart from in the United States, for which SUPERC technology is assumed. All gas plants are CCGT technology. All solar PV plants are large, ground-mounted plants. Wind plants for China and United States assume 50MW combined capacity and for Germany a 2MW$_e$ unit technology; 3) Coal prices of USD 101/t for the United States and Germany, and USD 112/t for China are assumed. Natural gas prices are assumed to be USD 5.5 per million British thermal units (MBtu) for the United States by 2020, USD 11.1/MBtu for Germany, and USD 11.5/MBtu for China; 4) Technical lifetimes are 25 years for onshore wind and solar PV plants, 30 years for gas plants and 40 years for coal plants; 5) Carbon prices are rounded to the nearest USD 10/tCO_2.

Source: IEA (2015d), Projected Costs of Generating Electricity: 2015 Edition.

generation in the first quarter of 2016, while gas-fired generation increased by around 50% over the same period (DECC, 2016).

How carbon pricing can reverse lock-in by supporting new lower-carbon plants

A carbon price can reverse the lock-in of emissions from existing unabated coal plants by raising the competitiveness of alternative new lower carbon generation. A levelised cost of electricity (LCOE) analysis can give an indication of the carbon price required to allow new lower-carbon alternatives to displace existing unabated coal plants; in Table 2.2, China, Germany and the United States are used to illustrate this relationship.[10] Several salient findings emerge from this analysis. First, the carbon prices required to reverse lock-in from existing coal plants vary across technologies and countries. For example, the carbon price needed to allow a new solar PV or onshore wind plant to be more competitive than an existing coal plant in China or Germany (at either a 3% or 7% discount rate) is lower than that needed for a new gas plant. By comparison, the United States requires a carbon price of only USD 20/tCO_2 to make onshore wind more competitive than an existing coal plant. There are several reasons for the regional variability in carbon switching prices, including but not limited to: the cost of capital; solar radiation and wind speed; and the type of plant technology.

As outlined in Chapter 3, in many regions where high carbon prices are needed to reverse lock-in from coal plants, only moderate carbon prices are currently anticipated and so additional policies and measures are likely to be required, such as a mandatory regulated phase-out of inefficient coal plants. The unique characteristics of a given electricity market, as well as the question of whether or not a plant is government-owned, may affect the responsiveness of energy companies to the pricing incentives embedded in a carbon price. State-owned power companies, in particular those functioning in markets controlled by their government shareholder (which characterises several emerging economies and some OECD countries), often make operating, retirement and new construction decisions based on factors beyond the relative rates of returns of different available technologies, including the broader economic and social impacts of alternative generation choices (Box 2.2).

2.2.4 Avoiding future lock-in of emissions from new unabated coal plants

Many countries (such as India and Indonesia, and many countries in sub-Saharan Africa) have adopted plans to significantly expand electricity capacity to meet projected increasing demand.[11] Regulations and carbon pricing can influence whether this new generation will be in unabated coal or lower-carbon generation alternatives. To achieve

10. A simple LCOE analysis considers the capital, operating, fuel and carbon costs over the projected lifetime and converts these costs into a per-unit cost of generation. The LCOE analysis presented in Table 2.2 identifies the carbon price needed in the United States, Germany and China in 2020 to enable new gas, solar photovoltaic (PV) and onshore wind plants to compete with an existing unabated coal plant under discount rates of 3%, 7% and 10%. As the unabated coal plant is an existing asset, the LCOE in Table 2.2 only includes operating costs, as the capital costs are taken as "sunk". Ongoing financing costs could have been included, but this equity investment approach excludes financing and other similar costs. The gas, solar PV and onshore wind plants are new, and the capital costs are therefore included in the LCOE in addition to operating expenses. Calculations are based on a variety of additional assumptions regarding fuel and other costs (see, for example, notes to Table 2.2).

11. See discussion on New Policies Scenario in IEA, 2015a.

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Box 2.2

How state-owned enterprises might respond differently to carbon pricing incentives than their private-sector counterparts

State-owned enterprises (SOEs) tend to make investment decisions based on economic returns at both the national and provincial levels (reflecting the interests of their shareholders), not simply on financial returns at the company level. This may lead an SOE to reach a different conclusion regarding the economic viability of reversing lock-in at a given carbon price level than would a private company focused on shareholder equity. This difference can also affect the willingness of state-owners to invest in new high-carbon power generation, even in the face of eventual early retirement.

The breadth of SOE influence is illustrated by China's coal sector. About 94% of installed coal power capacity in China is owned or controlled by its SOEs (Hervé-Mignucci et al., 2015). In assessing how to deal with an existing or proposed power plant, these SOEs and their government shareholders might evaluate a broad range of considerations beyond company-level returns, such as associated investments in mining, rail and port infrastructure, as well as the number of jobs provided by these investments. Closing a coal plant affects not only the plant itself, but associated mining and other assets as well as workers, and also has environmental and health implications for the surrounding population. Each of these factors may be weighted differently by a government shareholder than they would be by a private sector owner in deciding whether or not to close a plant.

This broader range of considerations for SOEs and their government shareholders could therefore affect coal plant retirements in different and sometimes unpredictable ways, with carbon pricing potentially having only a muted impact. For example, SOEs may feel more comfortable retiring plants sooner when the wider range of economic benefits already generated by the plant is recognised, rather than just the financial returns of the plant in isolation. This decision would be reinforced by the avoidance of potential environmental impacts going forward. However, SOEs may also be motivated to keep plants operating longer due to the breadth of economic benefits they provide, including employment in associated mining and transportation activities. In the absence of important negative externalities, such as detrimental pollution or climate change, it may be particularly difficult to encourage state-owned coal plants to be retired as long as their continued operation entails significant broader benefits.

In either case, government shareholders can often exercise stronger influence over SOE power assets than over those controlled by private sector companies. This aspect is described in greater detail in Chapter 6.

their climate goals, governments can introduce policies to avoid the future lock-in of emissions from prospective new unabated coal-fired plants whose emission levels are incompatible with the 2DS.

Policy options beyond carbon pricing

There are various policy options to restrict the construction of new unabated coal power plants. The most direct approach to lock out emissions from unabated coal-fired generation is to simply prohibit the construction of unabated coal plants. Banning can be done through owners' decisions or government regulation, but companies are also making similar pledges. For example, Enel, one of the world's largest utilities, has pledged to never build another coal plant (Enel, 2015), while the Danish government banned new coal-fired power plants in 1997 (OECD, 1999). In 2013, as part of its plan to reduce air pollution, the Chinese government announced a ban on new coal-fired plants in parts of Beijing, Shanghai and Guangzhou (MEP, 2013), and in April 2016 directed 15 of its 33 provinces to stop building coal-fired plants.

Plant or fleet-wide emissions performance standards can also effectively ban the construction of unabated coal-fired plants and are being used in number of countries to regulate the market. New coal plants in the United Kingdom have to comply with an emissions performance standard of 450 gCO_2/kWh, which is well below the carbon intensity of all unabated coal-fired technologies (DECC, 2012). Equally, new coal-fired electricity generation units in Canada are required to meet the performance standard of 420 gCO_2/kWh (Environment Canada, 2012). The US Clean Power Plan would regulate CO_2 emissions from existing power plants under the auspices of the Clean Air Act and, as with the United Kingdom, effectively ban the construction of new coal capacity without the application of CCS (EPA, 2014).

Increasing investments in renewable energy and in energy efficiency technologies can also reduce the need for unabated coal-fired generation. *Energy and Climate Change: World Energy Outlook Special Report* (IEA, 2015c) found that increasing investments could reduce global coal capacity by 540 million tonnes of oil-equivalent (Mtoe) by 2030. One study on the European power sector found that since 2008 there have been more than 100 planned coal plants cancelled in the region, mostly due to increased levels of energy efficiency and renewable energy (Carbon

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Tracker, 2015a). Increased investments in low-carbon energy and energy efficiency can send a negative investment signal and curtail construction of new unabated coal capacity because:

- The lower marginal cost of renewable energy reduces wholesale power prices, due to the merit order effect. This reduces the need for operating higher-cost, fossil-fuelled plants, resulting in mothballing or closure of these plants, or using them only as reserve capacity.[12] Policies that support deployment of renewable technologies also bring down capital and operational costs over time, reinforcing their potential to avoid locking in future emissions from new unabated coal plants. There are currently 1 282 policies worldwide that directly or indirectly support renewable energy (IEA, 2016d).

- Increased energy efficiency supresses overall power demand, obviating the need for additional generation – especially from coal-fired plants with the highest operating costs. There are currently 284 codes, incentives and labels for energy efficiency in buildings in 41 countries, and 2 107 energy efficiency policies worldwide (IEA, 2016d).

Several administrative financial decisions should also reduce investment in new coal-fired plants: after two years of negotiations, OECD nations agreed in November 2015 on new restrictions on export credits for the least efficient coal-fired power plants (OECD, 2015). This decision followed a joint statement from the Chinese and US governments in September 2015 to "strengthen green and low-carbon policies and regulations with a view to strictly controlling public investment flowing into projects with high pollution and carbon emissions both domestically and internationally" (White House, 2015). In 2013, the World Bank and the European Investment Bank issued restrictions on coal financing (EIB, 2013; World Bank, 2013), and the Norwegian Parliament unanimously voted to prohibit its pension fund from investing in coal companies in 2015.[13] The fund is forbidden to invest in "coal power companies and mining companies, who themselves or through operations they control, base 30% or more of their activities on coal, and/or derive 30% of their revenues from coal" (Parliament of Norway, 2015).

As reflected in the above discussion, there are a variety of avenues available to restrict the construction of new unabated coal power plants. Some involve direct targeted regulations, while others operate indirectly by affecting supply/demand aspects (Table 2.3). These can substitute for or complement carbon pricing (see also Chapter 3).

Table 2.3

Policies to deter new unabated coal plant construction

Actions to prevent lock-in	Policy options		
	Direct regulation of plants	Regulated change in supply/demand balances	Influence markets via price
Prohibit construction of new unabated coal plants	• Ownership decision to ban new capacity • Regulated ban on new capacity • CCS retrofit and biomass conversion mandates • Moratorium on coal financing by investors	• Plant or fleet-wide GHG emissions performance standard	• Carbon pricing • Fuel price changes
Increase investments in energy efficiency	n/a	• Regulated increase in energy efficiency • Efficiency standards for leading users of electricity (industry, services and residential sectors)	• Carbon pricing • Fuel price changes
Increase investments in low-carbon energy	n/a	• Regulated increase in renewable energy capacity • Plant or fleet-wide GHG emissions performance standard	• Carbon pricing • Fuel price changes

Note: n/a = not applicable.

12. As discussed in Section 2.2.3 and Chapter 3, a carbon price plays an important role in driving decisions for baseload or reserve capacity, and a prevailing low carbon price can also result in reverse switching from gas to coal power.

13. Future portfolio choices made my new investors, such as the Asian Infrastructure Investment Bank (AIIB), can however play an important role in the trend of shifting away from construction of new unabated coal power generation.

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Using carbon pricing to avoid future lock-in

As with reversing the lock-in of emissions, carbon pricing can be an important policy option to avoid the future lock-in of emissions from prospective new unabated generation by making these investments unprofitable compared with low-carbon alternatives. The carbon prices required under an LCOE analysis to favour new low-carbon plants over new unabated coal vary by region and by technology (Table 2.4).[14] For example, in the United States, lower-carbon plants are either already competitive or virtually competitive with new unabated coal. In China, moderate carbon prices of USD 20/tCO_2 or less make onshore wind competitive with new coal across the three discount rates, while solar PV becomes competitive at prices of USD 40/tCO_2 or less. Once again, there are several reasons for the regional variability in fuel switching prices, including, but not limited to: the cost of capital, solar radiation and wind speed, and the type of plant technology. An assessment of the switching prices for Indonesia, India and other markets with projected significant increases in electricity demand is particularly important as these countries will face the choice when building new plants to significantly expand their generation base.

An important finding in comparing Table 2.4 analysis with that of Table 2.2 is that the carbon price required to favour a lower-carbon option does not need to be as high when the choice is between two new plants (PV, wind or gas, versus a new unabated coal plant), compared with favouring construction of a new low-carbon plant to displace an incumbent unabated coal plant. For instance, as shown in Table 2.4, apart from solar PV plants at discount rates of 7% and 10%, the United States does not need a carbon price to make a new gas, solar PV or onshore wind plant competitive with a new coal plant. In contrast, to make a new gas, solar PV or onshore wind plant competitive with an existing unabated coal plant, the United States requires a carbon price in the range of USD 10/tCO_2 to USD 80/tCO_2 (see Table 2.2).

Failing to act on today's "opportunity" may become tomorrow's lock-in challenge

Failing to prevent the construction of new unabated coal plants whose emissions are inconsistent with the 2DS will create a lock-in problem in the future, as these plants become tomorrow's incumbent high-carbon plants.[15] As noted above, the carbon price to avoid future lock-in is generally lower than the cost to reverse it later. Consequently, for many of those countries in which power demand is stagnating or already declining, as is the case in many OECD member countries, new unabated coal plants can prove costly in the transition to low-carbon energy consistent with the 2DS. Even in countries with projected increasing demand, future power demand should be assessed carefully and efforts should be undertaken to minimise lock-in from newly constructed unabated coal plants that would have to be retired prematurely to achieve national climate goals.

Table 2.4

CO_2 prices needed to make new gas, solar PV and onshore wind competitive with new unabated coal, 2020

	CO_2 price required to make new gas plant competitive with new coal plant (USD/tCO_2)			CO_2 price required to make new solar PV plant competitive with new coal plant (USD/tCO_2)			CO_2 price required to make new onshore wind plant competitive with new coal plant (USD/tCO_2)		
Discount Rate	3%	7%	10%	3%	7%	10%	3%	7%	10%
United States	0	0	0	0	20	30	0	0	0
Germany	110	100	90	70	100	130	50	60	70
China	60	60	60	10	30	40	10	20	20

Notes: 1) Cost assumptions are based on the expected cost of commissioning these plants in 2020 and the LCOE calculations are based on a levelised average lifetime cost, using a discounted cash flow method; 2) All coal plants are assumed to be ULTRSC apart from in the United States, for which SUPERC technology is assumed. All gas plants are CCGT. All solar PV plants are large, ground-mounted plants. Wind plants for China and United States assume 50MW combined capacity and for Germany is a 2MW$_e$ unit technology; 3) Coal prices of USD 101/t for the United States and Germany, and USD 112/t for China are assumed. Natural gas prices are assumed to be USD 5.5/MBtu for the United States by 2020, USD 11.1/MBtu for Germany, and USD 11.5/MBtu for China; 5) Technical lifetimes are 25 years for onshore wind and solar PV plants, 30 years for gas plants and 40 years for coal plants; 6) Carbon prices are rounded to the nearest USD 10/tCO_2.

Source: IEA (2015d), Projected Costs of Generating Electricity: 2015 Edition.

14. Table 2.4 uses the same LCOE methodology as Table 2.2. As the unabated coal plant and the low-carbon alternatives are all new assets, the LCOE in Table 2.4 includes capital costs for all plants in addition to operating costs.

15. As discussed in Section 2.2.1 and Box 2.1, coal generation with CCS ("abated") overtakes unabated generation by 2040 in the 2DS (IEA, 2016a). As the current average lifetime of new coal power assets is 40 years, CCS readiness should be an integral requirement for any new coal capacity under consideration to reduce the lock-in of emissions in the future.

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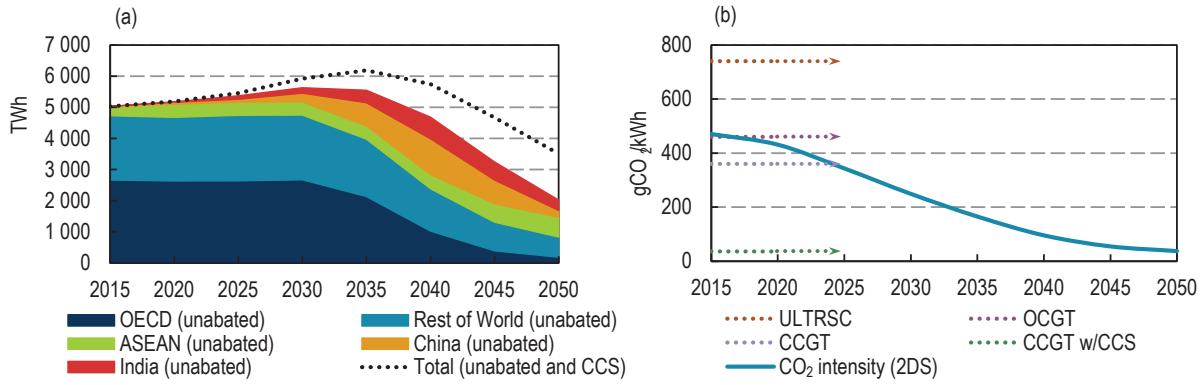
Figure 2.6

(a) Global gas-fired generation under the 2DS; (b) CO_2 intensity of gas-fired technologies



Sources: IEA (2016a), Energy Technology Perspectives 2016*; IEA (2012c),* Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation*; DECC (2015),* "Electricity market reform: Update on the Emissions Performance Standard, Annex D".

2.3 Gas: Managing future emissions

Given its flexibility, gas currently plays a critical role in balancing intraday fluctuations in power demand, and has an important role in the 2DS as a complement to variable renewables.[16] It is also favoured by many over unabated coal because of its relatively lower carbon intensity. However, over the long term, switching to gas-fired generation is not enough to limit temperature rise to 2°C. Unabated gas-fired generation remains relatively flat until 2030 and subsequently declines considerably in the 2DS; policies to increase the use of gas-fired power must therefore be carefully designed. This section examines the extent to which gas can be a transition fuel in the power sector under the 2DS.

2.3.1 The role of gas power in the 2DS

Gas-fired power generation in the 2DS increases through the 2030s, and then decreases towards 2050 (Figure 2.6a). In the 2DS, global gas-fired gas generation (unabated and abated) increases from about 5 000 TWh today, to nearly 6 000 TWh in 2030 and then diminishes to 3 500 TWh in 2050. From 2015 to 2040, the use of gas-fired generation increases rapidly in China and India (albeit from a small base) but gradually declines to 2050. In OECD countries, gas-fired generation remains at present levels to 2030 and then declines significantly from 2030 to 2050. Globally, unabated gas-fired generation decreases from 5 600 TWh in 2030 to 2 000 TWh in 2050. In parallel, gas with CCS expands significantly, reaching 1 485 TWh in 2050 to represent 42% of total gas power generation in that year.

Much of the increase in gas generation over the medium term comes at the expense of unabated coal-fired generation, which gets progressively regulated or priced out of the generation mix due to its high carbon intensity. While coal-fired plants typically have carbon intensities in excess of 700 gCO_2/kWh, CCGT power plants emit around 360 gCO_2/kWh and OCGT plants emit 460 gCO_2/kWh (DECC, 2015) (Figure 2.6b). Accordingly, unabated gas is generally favoured over unabated coal as a lower-carbon solution, with the former surpassing the latter by 2035 in the 2DS. However, unabated gas does constitute a more carbon-intensive power source than coal with CCS.[17]

The operational flexibility of gas-fired generation has important implications for its use in the transition to a low-carbon energy system. Under the 2DS, the role of gas-fired capacity evolves as the generation mix goes from being fossil-fuel based to renewable-energy dominated. Gas-fired generation can be used to balance fluctuations from increased levels of variable renewable energy, and this combination of variable renewable energy backed up by gas-fired generation can compete with other forms of base-load generation, such as coal and nuclear power (IEA, 2014b). Gas-fired power therefore slowly increases to 2030 under the 2DS, reducing emissions by displacing coal-fired capacity. However, as sources of variable renewable energy increase from 2030 to 2050, the capacity factors of gas-fired plants are reduced to back up and balance variable renewable energy. As a result, these plants operate well below their maximum capacities under the 2DS, which potentially means that full amortisation of their capital costs is at risk absent some additional policy support that

16. Gas-fired plants are very flexible, having the ability to operate at base, intermediate and peak loads. The two main types of gas generation technologies are CCGT and open cycle gas turbine (OCGT). The former is more efficient due to heat recovery, and is therefore mostly operated at base and intermediate loads, while the latter has greater technical flexibility and can be operated at peak loads. CCGTs ramp up from zero to full load in two hours, while OCGTs typically take less than one hour (IEA, 2012b).

17. The carbon intensity of coal with CCS is 140 gCO_2/kWh or below (Figure 2.2).

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better remunerates available capacity as distinct from actual power generation.

2.3.2 Avoiding the "gas trap"

Over the short to medium term, using unabated gas instead of unabated coal-fired generation can reduce emissions from power generation because of its comparatively lower carbon intensity (Figures 2.2 and 2.6b). Nevertheless, the global average carbon intensity of power generation under the 2DS falls below the typical carbon intensity of OCGTs in 2020 and CCGTs in 2027. Gas can, of course, remain an important part of the power mix after these dates, since the 2DS figures are averages for the entire system, including zero-carbon renewables and nuclear. In addition, as described above, gas plays an important complementary function in providing a flexible alternative to variable renewables. By 2050, however, the carbon intensity of power in the 2DS passes below 40 gCO_2/kWh, at which point it is difficult to accommodate large amounts of unabated gas; as a result, unabated gas generation under the 2DS drops from more than 5 000 TWh today to 2 000 TWh in 2050. In addition, methane emissions from the production, transportation and use of gas will require careful consideration and management (IEA, 2012b).

As climate and other policies for unabated coal-fired generation tighten, policy makers need to avoid creating a regulatory environment that unconditionally promotes unabated gas-fired generation. It is important to avoid replacing the lock-in of emissions from unabated coal plants with a lock-in of emissions from unabated gas plants. In the absence of long-term regulatory constraints, the cumulative emissions from replacing coal power with gas power will not only prove inconsistent with a 2°C pathway, but could produce more cumulative emissions than retiring existing unabated coal plants at the end of their technical lifetimes (IEA, 2014a; Pfeiffer et al., 2016).

Technological improvements are required if gas is to serve as a long-term fuel in decarbonisation of the power sector. These improvements include the application of CCS, which reduces the carbon intensity of generation to less than 36 gCO_2/kWh (Figure 2.6b) and would therefore allow gas to remain a low-carbon choice relative to the increasingly stringent requirements of the 2DS well beyond 2040.

Given the long-term investment horizon for gas infrastructure development and its long technical lifespan, policy makers need to begin considering today what the appropriate policy signals to investors are, to ensure that the use of unabated gas-fired generation is consistent in the medium to long term with a 2°C pathway. Carbon pricing and other regulatory options will be needed to ensure gas generation, and in particular unabated production, transitions from a base-load source to a flexible resource to balance variable renewable energy.

From an investment perspective, a distinction should be made between gas consumed in self-sufficient regions such as the United States, and in import-dependent regions such as Japan. Many import-dependent regions are increasingly using liquefied natural gas (LNG), which is easy to deliver to countries without gas resources. LNG is, however, particularly capital intensive, with significant lead times and considerable financial risk in the absence of up-front, long-term contracts. Developing an integrated LNG project typically takes about a decade, including permitting, construction, marketing agreements, feed gas supply contracts and shipping arrangements (UNECE, 2013). For example, the Gorgon LNG development in Australia, which has a capacity of 20.8 million tonnes per annum (mtpa), had a capital cost of USD 54 billion and took nine years to complete (IGU, 2015). Moreover, one-fifth of the delivered gas can be consumed in extraction, liquefaction, shipping and regasification. Although a long lead time means particular attention must be paid to long-term policy frameworks, LNG can ultimately often offer greater flexibility than pipeline gas, which is constrained by geographical circumstances. Recognising that not all gas infrastructure is identical can help policy makers design policies that differ depending on the nature of the underlying gas infrastructure investment.[18]

2.4. "Well below 2°C": Implications of the new climate target for coal and gas power

Meeting the goal to limit global average temperature rise to "well below 2°C" implies significantly stronger policy action than provided for in the 2DS. Overall emissions from fossil fuel-fired power generation drop significantly by 2050 under the 2DS, from over 13 $GtCO_2$ today to 1.4 $GtCO_2$ in 2050. A well-below-2°C emission pathway would require an even larger drop in emissions.

While the IEA is currently undertaking robust modelling to develop a scenario that will move beyond a 2°C pathway towards a "well-below" one, reviewing the emissions that remain from coal and gas power technologies in the 2DS can provide an indication of the nature of the challenge and the possible areas to be addressed (Figure 2.7).

Four changes to coal and gas power generation could help reduce emissions to below the 2DS level, to a pathway more consistent with keeping temperature rise well below 2° C.

18. A policy option which could be considered by LNG-importing regions is to bypass switching to gas (as an interim lower-carbon option than coal) and instead explore policy options that would enhance market competitiveness of renewable energy generation.

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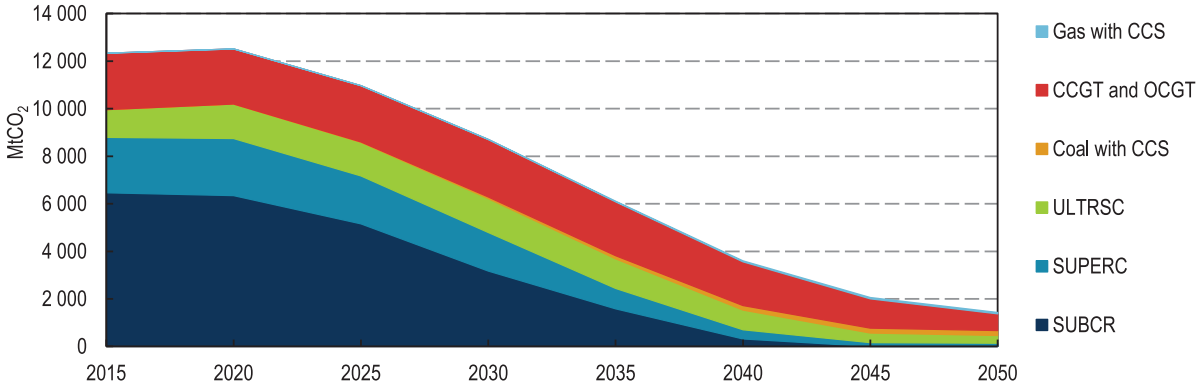
Figure 2.7

Direct remaining CO_2 emissions from coal and gas power technologies under the 2DS



Note: There are nearly 1 Gt in additional power sector emissions from oil generation.

Source: IEA (2016a), Energy Technology Perspectives 2016.

- First, the phase-out of inefficient unabated coal-fired plant technologies would need to be accelerated. About 50% of power sector emissions currently come from the least efficient coal plant technologies, and they continue to generate significant emissions beyond 2030 in the 2DS (Figure 2.4). Moreover, in 2015, almost 30% of new coal power plants installed were still sub-critical and the IEA found that the progress in coal power technology was not on track to remain on the 2DS trajectory (IEA, 2016a). Under the 2DS, these plants should be largely retired by 2040 and their even earlier removal would be needed for a well-below-2°C pathway. Even more efficient coal-fired plant technologies, such as SUPERC or even ULTRSC, collectively generate significant emissions in the 2DS to 2030 and beyond. All these plants have significantly higher carbon intensities than unabated CCGT, let alone coal or gas with CCS. It is therefore probable that significant reductions in power sector emissions beyond the 2DS will require that much of the coal-fired plant fleet not retrofitted with CCS technology or biomass conversion be phased out even earlier, regardless of efficiency.

- Second, unabated gas-fired generation may also have to be reduced. In the 2DS, emissions from unabated gas-fired generation exceed those from unabated SUPERC and unabated ULTRSC combined in 2035. Under a scenario to limit temperature rise to well below 2°C, these emissions from unabated gas could be reduced, potentially through a faster shift to gas generation as back-up for wind and solar generation. However, considering the large share of unabated gas emissions within total emissions in 2050 in the 2DS (about 50% of the 1.4 $GtCO_2$ for the power sector), the role of unabated gas in the electricity system may need to be reconsidered.

- Third, accelerating and expanding the deployment of CCS for coal and gas power beyond what is contemplated in the 2DS could also produce the additional emissions reductions needed to meet the well-below-2°C goal. In the 2DS, CCS for coal and gas plants is deployed at scale from 2030 onwards. With emissions of about 140 gCO_2/kWh or lower for coal with CCS, or up to 36 gCO_2/kWh from CCGT with CCS, replacing or retrofitting unabated coal and gas power plants more quickly can significantly reduce emissions through 2050. Achieving this would require an order of magnitude increase in CCS investment starting immediately, recognising that large-scale CO_2 storage projects can involve lead times of up to 10 years. Governments would have an important role to play in developing CO_2 storage resources and establishing the policy frameworks necessary to encourage investment in CCS.

- Fourth, efforts to reduce emissions from CCS plants should be explored. In the ETP 2DS scenario, an 85% to 95% capture rate is used, leaving residual emissions; emissions are also generated as a result of the additional fossil fuel consumption needed to operate the capture equipment.[19] Emissions from CCS-equipped plants in the 2DS in 2050 total 0.265 $GtCO_2$, representing nearly 20% of total power sector emissions that year. While this is small compared with current emissions levels, deep emissions-reduction scenarios consistent with well-below-2°C targets allow for only net-zero or negative emissions from the energy sector, so even this relatively low level of residual emissions from CCS-equipped plants will be a challenge in the long term. Further technological and process improvements that raise capture rates, reduce the energy penalty, or address other aspects of CCS operations (including co-firing) could help to reduce residual emissions from CCS power plants.[20] Increased attention to CCS in fossil fuel generation can have a potentially positive spill-over impact on the use of CCS in

19. See discussion in IEA (2016e).

20. See IEA (2016e) for discussion of CCS possibilities.

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other power generation technologies, notably its use with bioenergy which can deliver net negative emissions in the energy sector.[21] In the 2DS, bioenergy with CCS applications (BECCS) accounts for around one-quarter of all CO_2 captured in 2050, almost 1 Gt. Most of this capture, however, occurs in fuel transformation rather than power generation. Deploying BECCS at scale in the power sector[22] can help to increase the level of negative emissions which are increasingly important to achieve well-below-2°C targets.

2.5 Conclusion

The reduction of emissions from power generation is central to limiting average global temperature increase to 2°C – let alone to well below 2°C. Policies to reverse lock-in by reducing emissions from incumbent unabated coal and gas plants, and to avoid future lock-in from planned additional unabated plants, are thus essential. Coal-fired generation is the most carbon-intensive form of power, and therefore needs to rapidly decline or decarbonise to be consistent with a 2°C pathway. Over the long term, switching from coal- to gas-fired generation is not enough to limit temperature rise to 2°C. Policy makers need to send a strong enough policy signal to gas investors to ensure that both the construction and use of unabated gas-fired generation are at a level consistent with a 2°C pathway. Pricing and regulation can help achieve these outcomes. The optimal mix of policies will vary depending on national circumstances and the energy resources available. However, all of the tools to manage power sector emissions take on increased importance in light of the increased ambition of the Paris Agreement to limit global warming to well below 2°C. Further modelling and analysis will help clarify what steps are necessary and appropriate to meet this greater ambition while also maintaining the important role of electricity in supporting global inclusive economic and social development.

21. See discussion of bioenergy carbon capture and storage (BECCS) in IEA (2016e), Sections 2.2 and 3.5.

22. Deployment at scale is subject to sufficient sustainable biomass availability.

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Chapter 3 • The role of moderate carbon prices in electricity sector decarbonisation

Modelled scenarios of cost-effective electricity sector decarbonisation rely on high carbon prices to drive the investment and operational changes needed to shift electricity systems towards limiting average global temperature rise to well below 2 °C. However, real-world carbon pricing systems are set to deliver only moderate carbon prices in the short to medium term. Climate policy packages are therefore likely to also rely on non-pricing policies, such as tenders for low-carbon capacity or regulatory mandates, to steer investment toward low-carbon electricity generation. This chapter explores the important role a moderate carbon price can still play in power sector decarbonisation in combination with these other measures.

3.1 Introduction

The IEA has long advocated for strong and predictable prices on carbon, whether set using emissions trading systems (ETSs) or carbon taxes, as a cornerstone of cost-effective emissions reductions. In the power sector, carbon prices can influence the economic choices of investors, technology developers and consumers. They can moderate energy demand, deter new high-carbon investment and encourage low-carbon instead, and curtail the operation of existing high-emitting assets. Carbon pricing also plays a role in shifting corporate behaviour: by making climate change a financial rather than environmental reporting issue, it directly engages top management. Alongside measures to address market barriers (particularly in energy efficiency), and to support low-carbon innovation and infrastructure, carbon pricing is one of the three "pillars" of climate policy packages (IEA, 2011a; Grubb, Hourcade and Neuhoff, 2014).

After more than a decade of using carbon markets globally, however, carbon pricing policies are not delivering their theoretical potential. Realistically achievable carbon prices in the short to medium term do not appear high enough to drive the investment and operational changes needed to decarbonise electricity systems and limit average global temperature rise to 2 °C, or the more ambitious "well below 2 °C", the goal established under the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement in December 2015. In many jurisdictions, policies to guide low-carbon investment are in place either alongside or instead of carbon pricing.

Meanwhile, there are wider challenges for low-carbon investment in the power sector. Power generation is largely dominated by inexpensive coal and natural gas, which remain a default option compared with costlier low-carbon investments. Additionally, in some Organisation for Economic Co-operation and Development (OECD) countries where electricity demand is not growing, a large amount of spare conventional power generation capacity has led to low load factors, low electricity wholesale prices, and mothballing of plants; this also makes the case for market-based low-carbon investment more tenuous. Reducing emissions in line with the Paris Agreement will therefore require strong policy support for both existing and new clean energy generation.

In light of these trends, this chapter explores the role that low or moderate carbon prices can still play in the policy mix for power sector decarbonisation, even as policies include the greater use of complementary measures. The contextual discussion summarises recent developments in carbon pricing, then compares carbon pricing expectations with real-world practice. Current discussions on electricity market design are reviewed, with full awareness that low carbon prices are only one factor among several emerging economic challenges in the introduction of significant variable renewable energy sources. In bringing these elements together, this chapter outlines how moderate carbon prices can still play a role in decarbonising electricity sector generation in liberalised energy markets, in relation to investment and retirement. Several recent International Energy Agency (IEA) studies have examined aspects of this question, including *Aligning Policies for a Low-Carbon Economy* (OECD/IEA/ITF/NEA, 2015) and *RePowering Electricity Markets* (IEA, 2016a); this chapter builds on that work and can be read alongside Chapter 2, which discusses the impact of carbon prices on coal and natural gas power divestment decisions specifically.

3.2 Carbon pricing developments

3.2.1 The global reach of carbon pricing

Carbon pricing is spreading rapidly worldwide. In 2009, carbon market (ETS) arrangements covered greenhouse gas (GHG) emissions of around 2 300 million tonnes of carbon dioxide equivalent ($MtCO_2$-eq) (ICAP, 2016). By 2015, ETSs covering 4 600 $MtCO_2$-eq were operating in 45 jurisdictions which together accounted for 40% of global gross domestic product (GDP) (Figure 3.1).

Key developments since the 2014 IEA *Energy, Climate Change and Environment* report include the linking of California and Quebec ETSs, now the world's third-largest scheme with the inclusion of the transport sector since 2015. Also in 2015, the Republic of Korea launched the first national-level cap-and-trade system in Asia. The People's

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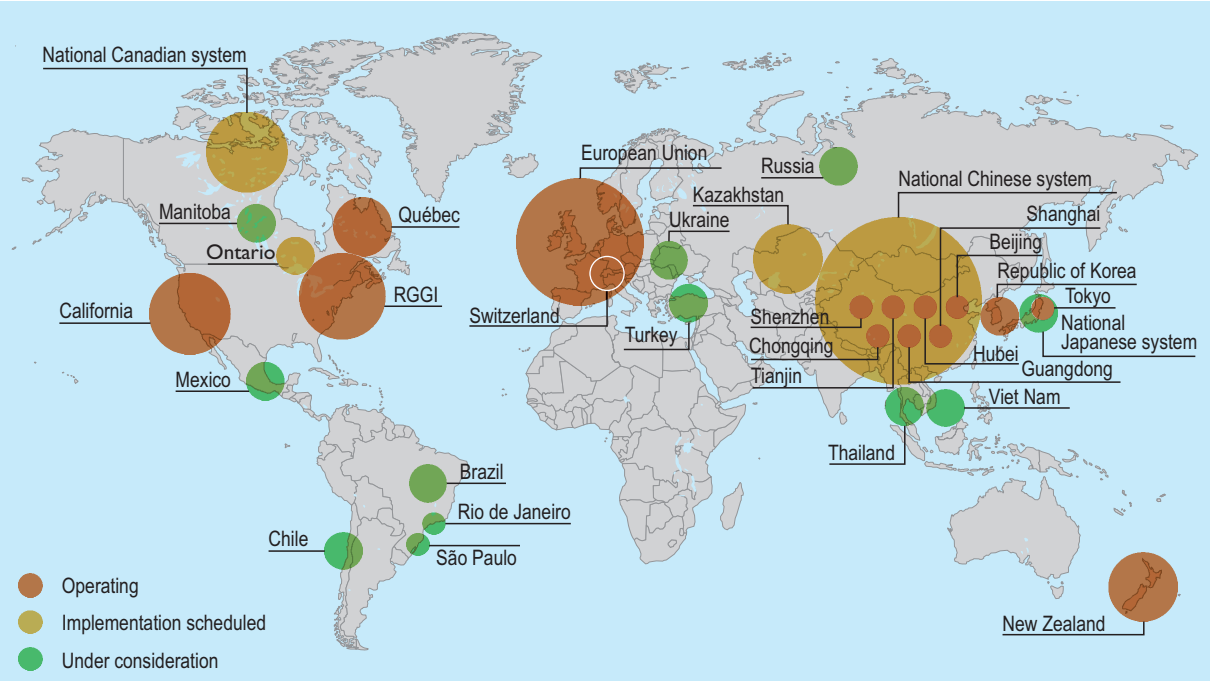
Figure 3.1

Map of emissions trading schemes worldwide, 2016



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

Notes: The size of each circle is approximately proportional to GHG emissions covered. The Canadian federal government has announced that provinces must implement a carbon price of CAD 10/tonne by 2018 rising to CAD 50/tonne by 2022, either in the form of a carbon tax or ETS.

Source: Adapted from country sources and ICAP (International Carbon Action Partnership) (2016), "ETS Map", https://icapcarbonaction.com/ets-map.

Republic of China (hereafter "China") plans to scale up its regional pilots to a national scheme in 2017, and new schemes are under preparation or consideration in Brazil, Canada, Chile, Kazakhstan, Mexico and Turkey. In the United States, the proposed Clean Power Plan regulation has spurred interest in inter-state emissions trading as means of flexible and cost-efficient implementation, building from the existing California and Regional Greenhouse Gas Initiative (RGGI) systems. In October 2016, Canada announced a carbon tax to start in 2018 that will rise to CAD 50/tCO_2 by 2022.

Meanwhile, the largest and oldest emissions trading system, the EU ETS, has undergone a series of reforms aimed at tackling a persistent surplus of permits. The introduction of temporary "backloading" (postponement) of permit auctions and of a new Market Stability Reserve from 2019, aim to strengthen the system, but prices currently remain well below EUR 10 per tonne of carbon dioxide (tCO_2). EU leaders have also agreed to new headline climate targets for 2030, within which the annual linear reduction factor of the EU ETS cap is significantly tightened to give greater long-term visibility to investors to 2030 and beyond (EEA, 2015).

At the international level, the Paris Agreement has sent a strong signal for universal and ambitious climate action, including through emissions trading. Article 6 of the Agreement provides for "internationally transferred mitigation outcomes" (ITMOs) to be used toward national targets, and more than half of the Nationally Determined Contributions (NDCs) submitted by countries ahead of the Paris meeting refer to the potential use of carbon pricing mechanisms. Alongside the formal UN outcome, COP21 instigated a surge in stakeholder demand for – and action on – carbon pricing policies, resulting in the launch of the Carbon Pricing Leadership Coalition and the announcement that an alliance of countries will work to develop standards and guidelines for the environmental integrity of carbon market mechanisms (NZ Ministry for the Environment, 2015). There is potential to link carbon markets globally to support countries' climate targets, and revenue from the auction of emissions permits could be used toward both domestic and international low-carbon finance needs.

3.2.2 Current carbon prices and model assumptions

While carbon pricing is spreading geographically, carbon prices in most jurisdictions are in the range of USD 5/tCO_2 to USD 15/tCO_2, still too low to have a major effect on power system operations or investment. Expected prices in the medium term also remain modest – for example,

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EUR 18/tCO_2 on average in the EU ETS in the 2020s, still below the EUR 20/tCO_2 to EUR 30/tCO_2 reached between 2005 and 2008 (IETA, 2016).

Reasons for low carbon prices differ from region to region, but analysts broadly define three factors. First, the economic downturn has led to lower-than-anticipated emissions, resulting in a surplus of emissions allowances. Second, concerns about industrial competitiveness and rising consumer electricity prices have made it difficult to negotiate political decisions (and maintain political will) to set tight emissions caps or high carbon prices. Third, the positive effect of energy efficiency policies has begun to be felt in flattening or falling electricity demand in many jurisdictions, and has resulted in reduced demand for ETS allowances (EC, 2012). A track record of stop-and-go policy commitments has also damaged the credibility of carbon pricing in some jurisdictions (Matthes, 2010).

By contrast, in the IEA 450 Scenario, which maps an energy pathway consistent with limiting global temperature rise to 2°C, carbon prices in OECD countries reach USD 100/tCO_2 by 2030, and prices in China, Russian Federation (hereafter "Russia"), Brazil and South Africa are USD 75/tCO_2 (Table 3.1). The New Policies Scenario (NPS), which includes signalled policies such as the NDCs under the Paris Agreement, shows much more moderate and less geographically widespread carbon pricing.

In the 450 Scenario, the numerous effects of high and rising carbon prices across all major economies contribute to electricity sector decarbonisation:

- New supply investments are directed toward low-carbon options.
- Operational decisions prioritise the use of available low-carbon options.
- High-carbon supply, in particular coal power, is retired in a timely manner.
- Higher electricity prices lead to greater energy efficiency and conservation by industrial, commercial and household consumers.
- Heating and transport are progressively electrified.
- The operation of electricity systems and markets (e.g. balancing and capacity markets) takes GHG emissions fully into account.
- There is significant innovation in key low-carbon enabling technologies such as electricity storage, smart grids and demand response.

However, current expectations for carbon price levels are closer to the NPS, in which they rise to a high of USD 37 in Europe and USD 23 in China in 2030. If policy makers seek to drive a power sector transition consistent with the 450 Scenario but carbon prices are limited to NPS levels (i.e. moderate or absent), there will be a clear abatement policy gap. This gap is particularly apparent for long-lifespan energy sector assets that will operate into the 2030s and 2040s. In the 450 Scenario, the prospect of rapidly escalating power prices prevents lock-in of high-emissions assets, while ongoing lock-in remains a risk at NPS-level carbon prices.

New work by the OECD reporting on the effective carbon rates today applied across 41 countries, in the form of both taxes and emissions trading systems, to energy used in the power, transport and industrial sectors also highlights a pricing gap. Today 90% of emissions fail the weak test of being priced at a level in accordance with a low end estimate of the climate damage they cause (OECD, 2016).

Table 3.1

Carbon prices in IEA NPS and 450 Scenario, in 2014 USD/tCO_2

	Region	2020	2030	2040
NPS	European Union	22	37	50
	Chile	6	12	20
	Republic of Korea	22	37	50
	China	10	23	35
	South Africa	7	15	34
450 Scenario	United States and Canada	20	100	140
	European Union	22	100	140
	Japan	20	100	140
	Republic of Korea	22	100	140
	Australia and New Zealand	20	100	140
	China, Russia, Brazil and South Africa	10	75	125

Source: IEA (2015b), World Energy Outlook 2015.

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Box 3.1

Supplementary policies still needed if higher carbon prices are consistent with limiting temperature rise to below 2°C

While a carbon price signal can influence investments and operations, it is less suitable – even at high levels – to drive other aspects of electricity sector decarbonisation, including:

1. Investment in smart and flexible power grids, to enable the system-friendly integration of variable renewable energy (VRE) and other distributed resources.

2. Meeting additional policy goals related to climate outcomes, such as the industrial technology policies associated with renewables targets and the cost-efficiency and reduced import dependency objectives associated with energy savings. The limited role of carbon pricing in supporting these outcomes at an efficient level has been discussed in previous IEA publications, including Summing up the Parts *(IEA, 2011a).*

3. Innovation "push" policies for technologies still in development, for which the IEA recommends that in addition to the "pull" effect of carbon pricing it is crucial to have a combination of policy certainty, incentives, regulation and international co-operation.

Packages of policies that span these areas are therefore essential, but care needs to be taken to manage policy interactions so that policies reinforce, rather than undermine, one another. To maintain well-functioning carbon pricing systems, the potential interactions between carbon market design and renewables and energy efficiency measures need to be analysed carefully. Over the longer term, as the share of fossil fuel generation in the system declines, the direct impact of carbon prices on electricity prices will diminish. This reinforces the need for electricity market design to ensure low-carbon generation is appropriately remunerated, with or without a carbon price.

3.3 Electricity sector developments affecting decarbonisation

3.3.1 Challenges facing investment in low-carbon generation

To succeed in decarbonisation, the electricity sector requires large investments in new low-carbon generation. In the European Union, for example, new capacity additions under the 450 Scenario during the period 2015-40 reach 731 gigawatts (GW) of renewable energy sources, plus 64 GW of new nuclear capacity.[1] The *Re-Powering Electricity Markets* (IEA, 2016a) analysis of electricity market design for decarbonisation finds, however, that in the short to medium term, investors in these technologies are facing multiple challenges beyond low carbon prices. First, in Europe, wholesale electricity prices are unattractively low due to overcapacity, which is in part a consequence of policies to drive new investment in low-carbon generation. Second, in addition to the problem of low or absent carbon prices, the level of supplementary support for renewables fluctuates and has been unreliable. And third, in the case of liberalised energy-only markets, renewable generation investments are exposed to fossil fuel price variability through the wholesale electricity price. In these circumstances, capital markets may not want to assume the investment risks of up-front fixed capital investment projects, leaving renewable investors with difficulty raising financing and facing increased capital costs.[2] Fossil fuel price risk is not only a problem in fully liberalised electricity markets: monopoly utilities can also face a form of this risk if they are unable to pass on fuel price rises under regulated retail electricity prices.

3.3.2 Particular challenges in markets with a high penetration of wind and solar

In markets in which high shares of variable wind and solar enjoy first place in the merit order for dispatch (given their low operating costs), investors face additional difficulties in basing investment on short-term marginal electricity prices alone. In these markets, sunny and windy days can produce depressed – or even negative – electricity market prices given the low operating cost of these technologies, while days without sunshine or sufficient wind (when electricity market prices are correspondingly higher) result in relatively low capacity utilisation (load) factors for these technologies, in the range of 9% to 30% for solar photovoltaic (PV) and 20% to 50% for wind. A high up-front investment cost per kilowatt (kW) of installed capacity means that the variable wind and solar investment risk profile will vary significantly depending on whether electricity market arrangements

1. Nuclear power generation does not emit CO_2, but safety concerns have led some countries to phase it out and, unlike renewables, the costs of new nuclear capacity have increased. Carbon capture and storage (CCS) is not yet commercially available at scale.

2. Outside the OECD region, most electricity systems in fast-growing countries remain vertically integrated and do not rely on wholesale electricity markets, even if some degree of electricity unbundling has occurred. It is important to recognise that this combination of fast-growing demand and regulated, vertically integrated utilities poses different challenges for encouraging investment in renewables.

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expose investors to this full market price risk, or provide them with greater certainty of revenues.

3.3.3 Redesigning markets to stimulate investment in low-carbon electricity

Discussions on market design for low-carbon power systems have tended to lead to debate on two contrasting policy options. At one end of the spectrum is sole reliance on wholesale electricity markets and a strong carbon price. Under this liberalised energy-only approach, investment decisions about technology choices and capacity increases are predominantly market-based. At the other end of the spectrum is a transition driven by policy support for specific low-carbon technologies. In this case, competitive procurement mechanisms can be introduced, but the technology mix is not determined by market participants. The IEA considers this dichotomy overly simplistic, and sees a need for combining both stronger carbon prices and technology-specific policies to support renewables investment, progressive electrification, and innovation (IEA, 2016a).

Re-powering Electricity Markets concludes that attracting low-carbon investment at the required system scale, in a timely manner and at low cost, requires providing long-range visibility of revenues to investors through arrangements backed by governments over a longer term, such as tender agreements for new low-carbon capacity additions. This is also a conclusion of *Aligning Policies for a Low-Carbon Economy* (OECD/IEA/ITF/NEA, 2015).

Looking to the long term and a 2°C scenario by 2050, the primacy of carbon price policies may return: *Re-Powering Electricity Markets* explores whether a high carbon price might on its own deliver an adequate signal for low-carbon power generation investments under an energy-only market in an already deeply decarbonised electricity system. At an advanced stage of power sector decarbonisation in which the bulk of high-carbon phase-out has been achieved, results from the IEA *Energy Technology Perspectives* model suggest that a generation mix of renewables, nuclear, CCS and gas power plants, as well as demand response and storage, combined with a strong carbon price of USD 100/tCO_2 could enable the recovery of fixed costs for low-carbon power sources through electricity market revenue.

3.4 Electricity decarbonisation with real-world moderate carbon prices

Even though carbon prices are not sufficiently high to alone catalyse significant decarbonisation of the electricity sector, a moderate carbon price can still play an important role in the policy mix. Although it is a second-best solution, moderate carbon prices can be combined with other low-carbon support policies to help reduce power sector emissions as well as drive investment in new low-carbon generation and retirement of high-carbon capacity. Carbon pricing affects system operations, generation supply (in particular new investment), the rate of retirement of old plants and electricity demand.

3.4.1 Operational decisions in electricity market systems: The dynamics of dispatch

The most important role of carbon prices in competitive electricity markets is to influence generators' fuel choices: higher carbon prices increase the cost-effectiveness of gas-fired generation and more efficient coal plants, and decrease the returns of higher-emitting, low-efficiency coal-fired generation. Switching the dispatch of existing assets is a relatively easy way to reduce short-term emissions, and the reduced use of inefficient coal plants is one of the five pillars of the IEA Bridge Scenario to reduce emissions at zero net-GDP cost (IEA, 2015c). If CCS is installed, higher carbon prices are also a critical incentive to run this equipment.

As explained in Chapter 2, the carbon price level needed to effect a significant switch from coal to gas generation varies across electricity systems, depending on the plant mix and prevailing fossil fuel prices. In European electricity markets, extremely low carbon and coal prices have led to natural gas power plants being a less cost-effective generation option since 2012; this has resulted in gas plants rather than coal plants being mothballed in response to excess capacity in the system. Some European utilities have argued that a carbon price of around EUR 40/tCO_2 in the EU ETS would have produced the opposite result, leading instead to coal-to-gas switching in 2012-14 (Eurelectric, 2013; Barclays, 2016). As these are system averages and actual operational costs fall across a spectrum (shown in Chapter 2, Figure 2.4), a modest carbon price would begin to shift dispatch, with greater effects seen with further carbon price increases. If carbon prices are likely to remain below the coal-gas switching price for a long time, policy makers could consider whether additional measures are needed, such as dispatch rules that favour lower-emissions plants, or the use of a higher shadow carbon price in dispatch decisions. However, there are as yet few real-world examples of alternatives to carbon pricing used to drive fuel switching.

A moderate carbon price could also promote the dispatch of CCS-equipped fossil fuel generation. CCS in power generation provides a significant share of the emissions reductions demonstrated in low-carbon scenarios – 12% of cumulative reductions to 2050 (IEA, 2016b). The incremental cost of adding CCS to a fossil fuel electricity plant comes from two main sources: the increased capital cost for the initial installation of the equipment, and ongoing increased plant running costs due to the energy required to power the CCS equipment. While a moderate carbon price on its own would not be sufficient to make the case for CCS investment, if the CCS equipment were

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already installed (e.g. supported by a subsidy), then only a moderate carbon price would be needed to make it cost-effective to operate it. The CCS operating efficiency penalty translates to an increased generation cost of USD 7 per megawatt hour (MWh) to USD 9/MWh for coal with CCS in 2020 (IEA, 2016b), a difference that could be easily bridged with a moderate carbon price.

There are few alternatives to carbon pricing to change power companies' short-term operational decisions. Carbon pricing is therefore a key element of electricity market design for decarbonisation, and even at modest price levels plays an important role in liberalised electricity markets. With appropriate regulatory arrangements, carbon prices can also be applied in non-liberalised markets (Box 3.2).

3.4.2 Low-carbon generation investment

While emissions trading and carbon taxes provide signals to which operators can respond flexibly in dispatching electricity from existing plants, new-generation investments that typically involve high up-front capital and long repayment periods require a clear indicator of long-term direction. A price pathway for future carbon prices could improve investment certainty, but would need to be highly credible – set in legislation rather than simply being part of a government budget process. If there is a low level of trust in the reliability of future carbon prices, governments may need to take more direct action to support new investment. The challenge for policy makers is to provide government support without distorting the market-based price signals for efficient operational decisions. Many jurisdictions have so far employed a variety of non-pricing investment support mechanisms with success, including feed-in tariffs (FITs) and renewable portfolio standards (RPSs); adding moderate carbon pricing can improve efficiency by helping expose low-carbon generators to market signals.

Low-carbon support policies such as FITs stimulate increased investment

Governments have responded to the need for low-carbon investment by introducing targeted support policies. For example, in virtually all EU member states, the EU ETS is complemented by renewables investment support in the form of FITs offering a guaranteed electricity price and priority grid access, or capacity auctions that use price discovery via auction bids to set a guaranteed price level for winning bidders (Figure 3.2). Similarly, the primary policy drivers of renewable energy installation in the United States are 30 state-level RPSs, which require a certain amount of load to be provided by renewable energy. The vast majority of renewable energy installed in the United States has also benefited from tax schemes to support the industry, including the Production Tax Credit, which provides a tax credit based on the kilowatt hours produced; the Investment

Box 3.2

Decarbonising regulated electricity systems: China case study

Many electricity systems in both developed and developing countries are not fully liberalised, so the textbook model in which the carbon price is passed through to marginal electricity prices, driving dispatch decisions, does not directly apply.

China's electricity system is dominated by five state-owned enterprise (SOE) generators, which compete to establish new capacity which must be approved by the government. The tariffs paid to generators and consumer end-prices are both regulated, while dispatch hours of each plant are essentially allocated on a quota system, with an annual plan for the number of hours each plant will supply. A further complicating factor is the SOE ownership model, which creates a different context for the implementation of a carbon price, in part because SOEs do not always respond to economic incentives the way that profit-maximising enterprises do, due to state energy security, social development and employment goals, and other strategic objectives (see discussion in Chapter 6 on SOEs).

As long as generators are allowed flexibility to optimise production within their own generation portfolios, a carbon price can play an important role in reducing emissions even within such a highly regulated system. This potential was explored in an ETS simulation the IEA conducted in 2013 with the China Electricity Council, China Beijing Environmental Exchange, and the Environmental Defense Fund, which found that participating generators were good at finding optimal solutions for cost-effective compliance using the flexibility of the carbon market, and that the ability to switch dispatch among plants based on price is central to achieving the most efficient response (IEA, 2014b). Even without changes to dispatch, the carbon price would have some effect, as it reduces the profitability of coal generation.

Recognising the inefficiencies in its current system, in its 13th Five-Year Plan the Chinese government is moving towards a greater role for market-based prices in the electricity system. At the same time, it has established seven city and regional pilot ETSs, with the goal of building on these to establish a national system from 2017.

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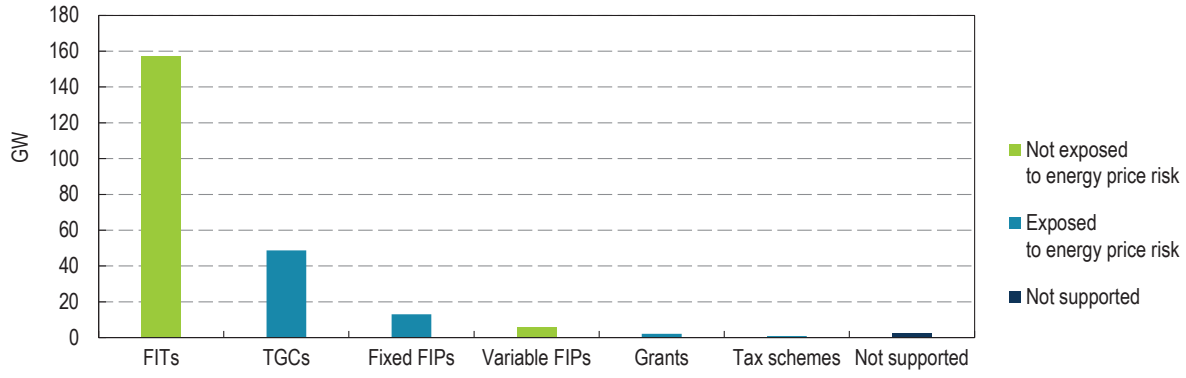
Figure 3.2

Renewable capacity built by support instruments, OECD Europe, 2005-14



Notes: TGCs = tradable green certificates; FIPs = feed-in premiums.

Source: IEA (2016a), Re-Powering Markets: Market Design and Regulation during the Transition to Low-Carbon Power Systems.

Tax Credit, which provides a tax credit based solely on up-front investment; and accelerated depreciation schedules for renewables investments (IEA, 2014a; 2015a; 2016a).

Carbon pricing can help make investor exposure to market prices more feasible

Re-Powering Electricity Markets found that it is undesirable for mature renewable generation technologies to receive all their revenue through policies insulated from the wholesale market (such as fixed FITs) – and, moreover, that this would probably be economically untenable on the mass scale required for deep decarbonisation. Conversely, revenues earned in the "energy-only market", to some degree exposing investors to electricity price uncertainty, can provide important feedback revealing the value of different wind and solar technologies[3] and thus an incentive for low-carbon projects to maximise their value to the system overall.[4] In principle, if support schemes were designed to partially expose low-carbon investors to electricity market prices, a modest carbon price could increase their certainty of market revenue and protect the viability of the investment by adding a component to electricity prices that does not vary when fossil fuel prices fluctuate (i.e. provide a minimum backstop).

Over time, the expectation is that a rising carbon price would enable direct low-carbon subsidies to diminish, making them more sustainable for public budgets. However, further analysis is required in this area, as the need for subsidies will depend not only on the carbon price, but on other factors that depress electricity prices such as oversupply of generation and strong energy efficiency policies. The introduction of lifetime limits on coal and natural gas power plants could, in principle, improve the supply-demand balance, restoring electricity market prices and reducing the need for direct subsidisation of low-carbon generation (Climate Institute, 2016).

The role of moderate carbon prices in driving clean power investment is less clear than in the case of system operations. Other investment drivers will be needed in addition to a carbon price, at least in the presence of fluctuating fossil fuel prices, and for deep decarbonisation scenarios with high shares of renewables and zero short-term marginal costs.

3.4.3 Retirement of high-carbon generation

The introduction of low-carbon support policies has led to an imbalance in supply and demand in electricity markets, as the rate of new low-carbon generation additions has outpaced the need for new investments to meet either growing demand or to replace ageing or retired high-emitting infrastructure. Carbon pricing can play an important role in driving plant retirement to correct this imbalance: optimally, a high carbon price would make high-emissions generation uncompetitive due to high operating costs. A modest carbon price alone will not effect this change, but could, nonetheless, help ensure that more inefficient high-emissions plants are the first to be mothballed or retired, by causing lower-emissions plants to be dispatched preferentially. Although carbon pricing is not the only system which can drive retirement, alternatives result in a less technology-neutral approach. The role of carbon pricing and alternative policies in driving the retirement of high-carbon surplus capacity is discussed in depth in Chapter 2.

Certain features of carbon pricing mechanisms can impede or reverse the retirement incentive, for example free allocation of ETS emission allowances to power generators when they also operate in a competitive electricity market with carbon cost pass-through. The EU ETS provides special

3. This would, for example, benefit technologies that integrate energy storage.

4. For example, scheduling maintenance at times when electricity prices are expected to be low.

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free allocations to power generators for high-carbon assets in certain countries in which electricity systems lack interconnection and diversity of generation sources[5] – providing additional revenue that is not available for cleaner power plants and thereby distorting retirement decisions.

A more subtle effect of carbon pricing is that it underpins the sound functioning of capacity markets or strategic reserve mechanisms. These are implemented to ensure security of electricity supply,[6] by providing extra revenue to generators when needed. In the absence of a strong carbon price, capacity mechanisms tend to keep fossil fuel plants operating which would otherwise have been retired. An explicit, strong carbon price would raise the costs of fossil fuel capacity options (coal, gas), giving low-carbon flexibility options (such as battery or pumped hydro storage) an advantage and removing the conflict between energy security policies and climate objectives. As with dispatch decisions, a moderate carbon price would have a less pronounced effect than a high one, likely shifting the balance towards supporting gas-fired rather than coal-fired capacity. In the absence of a higher carbon price, however, further policy intervention may be needed to ensure that low-carbon flexibility options such as battery storage are appropriately remunerated. A useful question for policy makers to consider when designing capacity markets is whether the capacity mix supported would be different in the presence of a high carbon price (consistent with the 450 Scenario), and if so, whether a shadow carbon price or adjustments to the capacity market regulation should be adopted.

3.4.4 Electricity demand: Also affected by carbon pricing

A final critical pillar of electricity sector decarbonisation is to moderate energy demand, reducing reliance on high-emissions power plants and decreasing the quantity of new low-carbon investment required. When carbon prices are passed through to electricity consumers, they should promote greater efficiency and conservation in energy use, particularly in price-sensitive, energy-intensive industries. In competitive market settings that allow the pass-through of carbon costs, this downstream effect of carbon pricing could be significant, even at a moderate price. A modest carbon price would be expected to partially deliver the savings that would result from a higher carbon price. Barriers to energy efficiency measures do, however, need to be addressed by complementary measures: carbon pricing is complementary to energy efficiency regulations which generally address non-price barriers (IEA, 2011b).

Nonetheless, price incentives for efficiency can be blunted by policies designed to protect industrial competitiveness that compensate industry for the electricity price rises associated with carbon pricing, meaning that in practice, a greater reliance on regulatory policies may be needed to meet energy efficiency objectives. One example of this type of regulation is to apply shadow carbon prices when designing energy efficiency standards, such as the social cost of carbon applied by the US Environmental Protection Agency (EPA) in its regulations (EPA, 2015).

With high carbon prices, heating and transport would be expected to shift from the direct use of fossil fuels (e.g. natural gas for heating and gasoline for transportation) to greater use of electricity. Modest or absent carbon prices actually produce the opposite effect: current renewables support policies are raising the price of electricity, while reduced demand for fossil fuels lowers their price. This tends to drive heating and transportation away from electrification, rather than towards it. This situation would be improved by applying at least a modest carbon price to heating and transportation fuels, as is done in the California-Quebec ETS and under Nordic carbon taxation. In these systems, the carbon price plays an important role not only in reducing fossil fuel demand in the heating and transport sectors, but also in increasing electricity demand (or maintaining demand as improved efficiency and greater electrification balance each other) and in enhancing flexibility in the low-carbon electricity system by boosting potential for load-smoothing through demand response.

3.5 Use of revenue from moderate carbon pricing

A final consideration regarding moderate carbon prices is that they generate revenue, albeit less than high carbon prices do. For example, auctioning of allowances in the EU ETS delivered EUR 6.8 billion (USD 7.5 billion) in 2013-14, in spite of low allowance prices.

This revenue could support the low-carbon transition by funding other pillars of the decarbonisation policy package: technology innovation, energy efficiency, social equity, or low-carbon infrastructure. The RGGI in the north-eastern United States has had a low carbon price, but has helped achieve substantial emissions reductions by funding energy efficiency. In Canada, the carbon price in Alberta funds CCS demonstration, while in British Columbia the carbon tax is transparently recycled to individuals and businesses through tax reductions. Use of revenue in this way can enable greater acceptance of carbon pricing and scale-up over time.

5. Directive 2009/29/EC, Article 10c.

6. For example, conventional dispatchable power plants which act as back-up to variable renewable generation may run at an annual load which is too low to be economical; this has led many jurisdictions to develop capacity remuneration in the form of reserves or capacity mechanisms. In other regions, the motivation is to ensure adequate supply at times of peak demand.

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3.6 Conclusions

High carbon prices would theoretically help to drive a fast and cost-effective electricity sector transition. The real-world performance of carbon pricing today, however, shows a significant abatement policy gap. Meanwhile, discussions on market design for a low-carbon power system are moving towards the view that a combination of carbon pricing, electricity markets and technology-specific support policies are needed to promote renewables investment, progressive electrification, energy efficiency and innovation.

Governments should continue efforts to introduce and strengthen carbon prices, recognising that they play an important role even if they never reach "optimal" levels. Modest carbon prices can partially produce many of the outcomes expected of high carbon prices, particularly by supporting a degree of energy market integration for mature renewable generation, by shifting dispatch and retirement decisions, by moderating energy demand, and as an element in the design of climate-compatible capacity mechanisms.

Maintaining a modest carbon price as part of the policy mix in the near term also keeps the door open for carbon pricing to have a stronger influence at a later date. Over the long term, it may be difficult to sustain a complex mix of low-carbon technology support policies on government balance sheets. A steadily rising carbon price would be helpful to underpin a slow transition away from targeted subsidies, making some of them unnecessary over time. In a fully decarbonised system, it may be possible to eventually phase out targeted support in favour of an energy-only market with carbon pricing.

This chapter and the previous one are the beginning of IEA analysis on the implications of low-to-moderate carbon prices for implementation of the Paris Agreement in the electricity sector. Future work could consider shadow carbon prices as part of low-carbon electricity market design, for example within capacity/strategic reserve mechanisms or in merit order dispatch calculations. Another study could assess the different abatement outcomes of carbon price/tax policies compared with alternative direct regulation of emissions, for instance through performance standards or bans on certain categories of high-carbon generation.

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Chapter 4 • Renewables surge after COP21

The progress in global deployment and cost reduction of renewables, particularly in onshore wind and solar photovoltaics (PV), helped pave the way for the ambitious targets of the Paris Agreement. Further robust growth in renewables is one of the pillars upon which the International Energy Agency (IEA) 2 °C Scenario (2DS) is built. In the lead-up to COP21, over 90 United Nations Framework Convention on Climate Change (UNFCCC) parties submitted Nationally Determined Contributions (NDCs) that included explicit references to renewables, and the Paris Agreement itself has helped to spur further commitments to renewables. Policy makers have a vital role to play in expanding the use of renewables by providing policy support for maturing renewables (like solar thermal electricity), facilitating the integration of high shares of variable renewables into electricity systems, and expanding the use of renewables in heat and transport. Providing consistent, reliable support mechanisms and appropriately accommodative regulatory frameworks can help renewables reach the levels of expansion required to meet our shared climate goals.

4.1 Introduction: Historic growth, but policy and pricing challenges

The past five years have been a period of unprecedented growth and development for renewable energy worldwide. Global renewable power capacity additions totalled over 150 gigawatts (GW) in 2015, exceeding the previous record of 130 GW set in 2014. Contracts to build new onshore wind farms and utility-scale PV plants were announced at lower-than-ever costs on all continents, confirming the economic viability of both technologies. The Paris Agreement set ambitious long-term temperature targets, establishing a pathway to advance renewable energy deployment worldwide, as over 90 parties proclaimed renewable energy a priority in their NDCs, and over 70 mentioned specific domestic targets for renewable energy deployment.

Despite this progress, significant policy and market uncertainties remain. The People's Republic of China (hereafter "China") currently leads the world in wind power generation, but due to a shortage of transmission capacity, as much as 15% of this energy is lost to curtailment. European renewable energy targets for 2030 still lack a strong, supportive framework. Grid integration of large shares of variable renewables remains a point of both real and perceived concern among many key stakeholders. Although in many jurisdictions wind power and solar PV no longer require the high levels of subsidisation they did less than a decade ago, many electricity markets need structural reform to deliver investment in capital-intensive renewables and enabling technologies.[1]

Since 2014, prices for oil, coal and natural gas have fallen to their lowest levels in more than a decade, and are not expected to significantly increase over the near to medium term. Although energy efficiency improvements and the increasing share of renewables in the global energy mix are not the only factors in this low price environment, together they will continue to exert downward pressure on fossil fuel demand into the future. However, low fossil fuel prices in the absence of carbon pricing or appropriate regulatory frameworks could undermine the deployment of renewables by reducing their cost-competitiveness relative to conventional heat and transport fuels.

1. *See discussion in Chapter 3.*

4.2 A track record of increasing growth and falling prices

4.2.1 Renewable energy dominates power capacity additions

Grid-integrated renewable energy capacity grew at a record pace in 2015, with 150 GW of net new capacity installed globally, surpassing the 130 GW installed in 2014. On average, this new capacity will generate about 350 terawatt hours (TWh) annually, equivalent to the annual consumption of a country like Italy or the United Kingdom (IEA, 2016a). This robust growth in grid-integrated renewable deployment was supported by a variety of policies addressing energy security, local pollution concerns and climate objectives. In 2015, renewables accounted for over 50% of net yearly additions to power capacity for the first time; nearly 80% of these additions were from non-hydro renewables (Figure 4.1).

4.2.2 Further declines in renewable energy costs

Indicative global onshore wind generation costs for new plants fell by an estimated 30% on average between 2010 and 2015, while costs for new utility-scale solar PV installations declined by two-thirds (Figure 4.2). New onshore wind costs are expected to fall 15% by 2021, and new utility-scale solar PV by 25%.

Market intelligence on long-term contracts signed for wind and PV plants to be built in the near future confirms this trend and indicates that cost reductions could be

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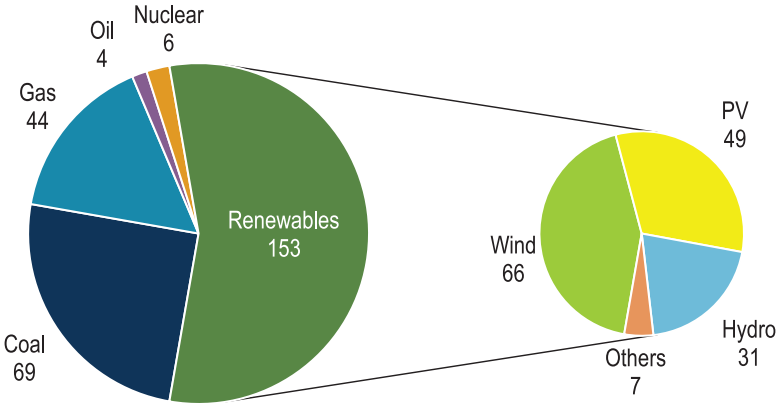
Figure 4.1

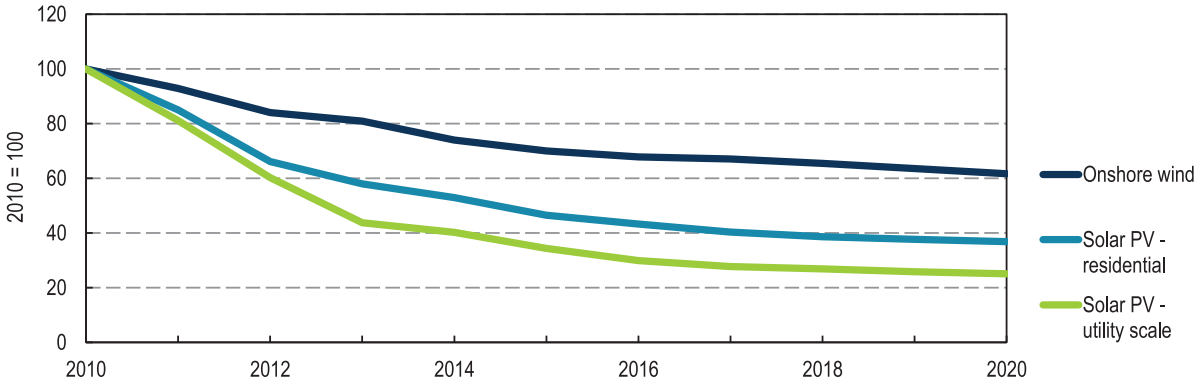
Net additions to power capacity (GW), 2015



Sources: IEA (2016b), Medium-Term Renewable Energy Market Report 2016*; IEA (2016c),* World Energy Outlook 2016.

Figure 4.2

Falling indexed generation costs for renewables



Source: Adapted from IEA (2015a), Medium-Term Renewable Energy Market Report 2015.

more rapid than previously thought. In Morocco in 2015, bids for onshore wind generation reached world-record lows of just USD 30 per megawatt hour (MWh). Similar record lows were reached for utility-scale PV at just USD 35.5/MWh (plus a time-of-delivery factor of approximately USD 5/MWh) in Mexico in April 2016, and at around USD 30/MWh in Dubai (May 2016) and Chile (August 2016). Worldwide, a wealth of new renewable energy projects below USD 100/MWh are due to be commissioned within the next three years, mainly in the USD 50/MWh to USD 80/MWh range for onshore wind, and USD 60/MWh to USD 90/MWh for solar PV (Figure 4.3). The lowest generation costs are achieved in markets that benefit from both abundant resources and competitive procurement of long-term contracts, providing guaranteed income streams backed by secure long-term policy and market frameworks. These conditions create low-cost financing opportunities, a critical dimension of overall cost competitiveness.

4.2.3 Untapped potential and strong prospects for growth

The IEA *Medium-Term Renewable Energy Market Report 2016* (*MTRMR 2016*) forecasts a 41% increase in global cumulative renewable capacity between 2015 and 2021 (IEA, 2016b). This increase of 825 GW is more than twice Japan's current total installed capacity. Renewables are thus expected to generate 7 672 TWh in 2021, 36% more than the 5 660 TWh generated in 2015. The share of renewables in global electricity generation is expected to increase from 23% in 2015 to almost 28% in 2021 as renewable power output is expected to grow much faster than global generation from coal, natural gas and nuclear.

These projections surpass the deployment of renewables forecast months before COP21 in the main case of the *MTRMR 2015* (IEA, 2015a), which would in fact have

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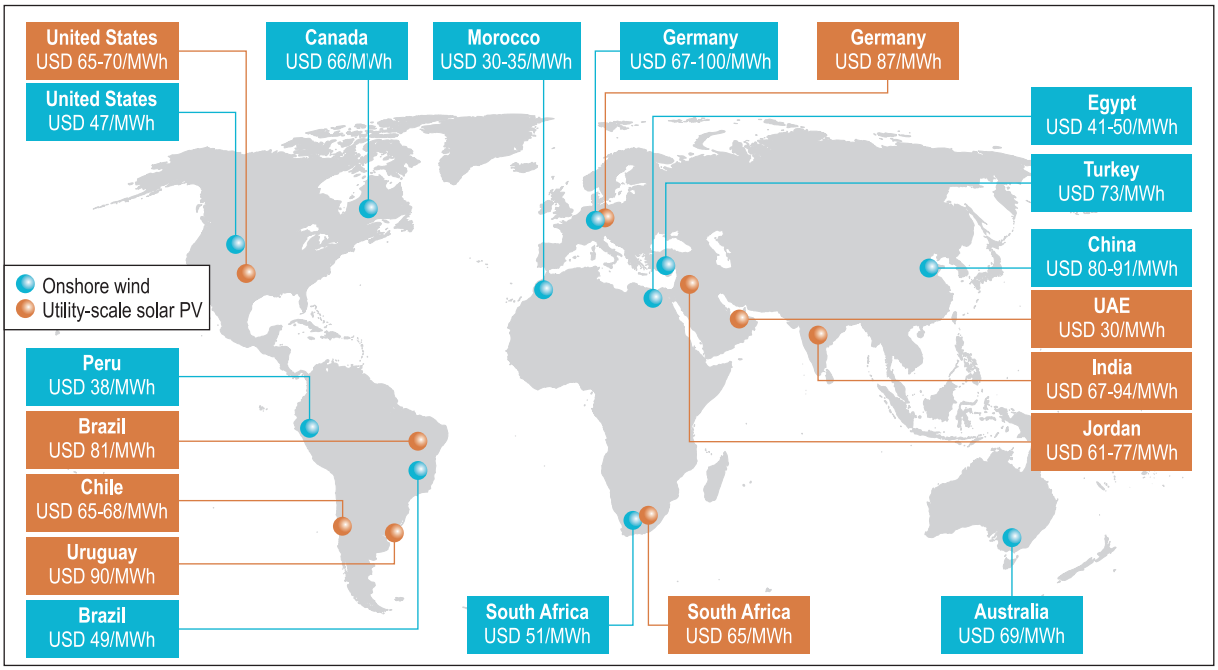
Figure 4.3

Long-term contract prices for new renewable power to be commissioned, 2016-19



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

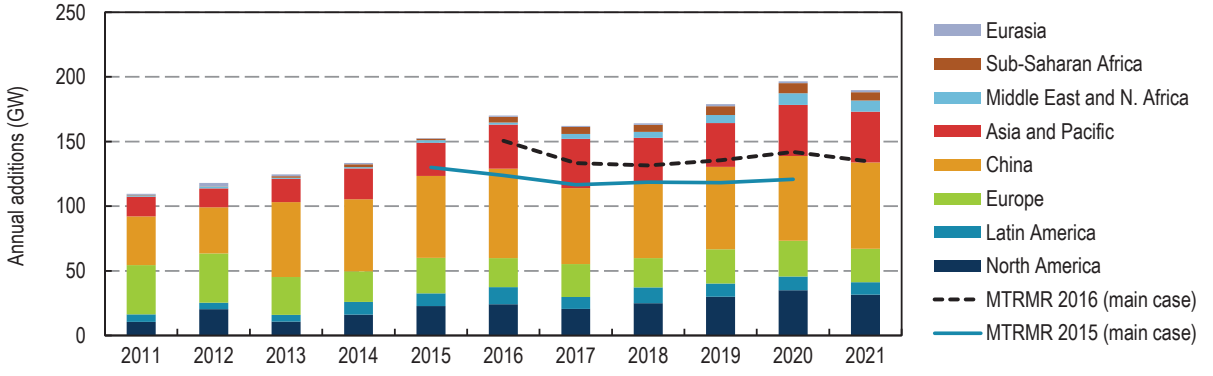
Notes: Values reported in nominal USD include preferred bidders, power purchase agreements (PPAs) and feed-in tariffs (FITs); US values are calculated excluding tax credits; Delivery date and costs may be different than those reported at the time of the auction.

Source: Adapted from IEA (2015a), Medium-Term Renewable Energy Market Report 2015.

resulted from a plateauing of the growth rate of recent years (Figure 4.4, solid line). However, the *MTRMR 2016* main case forecast is more optimistic (Figure 4.4, dashed line; see below for discussion of potential impacts of Paris Agreement on increased deployment). The *MTRMR 2016* also illustrates that an accelerated growth case with enhanced policy measures (Figure 4.4, bars) could restore consistent year-over-year increases in the rate of deployment. This accelerated renewables deployment scenario is consistent with the early emissions peak and downward trajectory required to stay below a 2°C temperature increase.

Figure 4.4

World grid-integrated renewable power capacity growth: historical and projected (accelerated case)



Note: Bars represent historical data through 2015 and projections during 2016-2021 (accelerated case).

Sources: IEA (2016b), Medium-Term Renewable Energy Market Report 2016*; IEA (2015a),* Medium-Term Renewable Energy Market Report 2015 *(for "MTRMR 2015 [main case]" only).*

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4.3 A push from Paris

The NDCs submitted in the months leading up to COP21 generated real momentum for renewables development and deployment worldwide. Today, the momentum continues for policy makers to set more ambitious renewables targets and to undertake concrete policy actions aimed at further advancing the global energy transition.

4.3.1 NDCs and the lead-up to COP21

In the lead-up to COP21, many of the world's major economies began laying the groundwork for the Paris Agreement with the announcement of ambitious new targets for renewable energy deployment. In a November 2014 joint announcement with President Obama, President Xi stated that China would aim to peak CO_2 emissions around 2030 or earlier, and increase the country's non-fossil fuel share of total energy to 20% by 2030. In a second joint statement in September 2015, President Xi announced that China would provide priority dispatch to renewables, and implement a national emissions trading system in 2017. India's NDC submitted ahead of COP21 includes a pledge to increase the country's solar capacity by twenty-five times to 100 GW, and to more than double wind capacity to 60 GW by 2022. Many other countries not belonging to the Organisation for Economic Co-operation and Development (OECD) also pledged to invest in the development of renewables, including Brazil, which announced its intention to increase the share of non-hydro renewables in power generation to 23% by 2030, up from approximately 9% today.

Among OECD member countries, Japan, Australia, Chile, Israel, New Zealand and Turkey all included domestic renewable electricity targets in their NDCs. Several other countries announced new renewable power targets, both in advance of and following COP21. In September 2015, Mexico's Ministry of Energy released new guidelines for electricity and clean energy certificate markets, with a schedule of auctions for long-term power purchase agreements. The first agreements, for plants expected to become operational in mid-2018, were awarded in March 2016 at new record-low price levels for solar PV. The Mexican government will hold annual auctions to achieve its 35% target for low-carbon energy generation (including nuclear) by 2024. France's Energy Transition Law, adopted 22 July 2015, set a new goal of 40% renewable power by 2030. In June 2015, the United States and Brazil jointly pledged to increase the share of renewables in electricity generation (excluding hydropower) to 20% by 2030.

4.3.2 The post-COP21 policy landscape

In jurisdictions around the world, the Paris Agreement has already proven to be a major catalyst for re-evaluation of existing climate targets and the acceleration of emissions reduction timelines. Encouragingly, the Agreement seems to have also inspired a number of concrete policy actions aimed at supporting renewables development and deployment.

In December 2015, Japan's Ministry of Economy, Trade and Industry (METI) announced the launch of an auction system for utility-scale solar PV projects, with the first rounds to be held in the 2017 fiscal year. The auction is expected to attract more cost competition than the current FIT system and provide a better planning framework for generators, particularly in areas of grid congestion. Also in December, the US Congress voted to extend the Business Energy Investment Tax Credit (ITC) and Renewable Electricity Production Tax Credit (PTC), which play a significant role in encouraging the development of solar and wind energy.

In February 2016, India released state-level targets to achieve the country's Renewable Purchase Obligation (RPO) target of 17% by 2022, setting out a long-term trajectory which includes an 8% minimum purchase obligation from solar energy. India's Ministry of New and Renewable Energy has accelerated the approval of large-scale solar PV projects and announced its intention to add 48 GW of new solar capacity by early 2019.

Various other initiatives announced during the Paris climate conference may push renewable energy deployment faster and further. Promising initiatives include the International Solar Alliance launched by India and France; the Iceland-led Global Geothermal Alliance promoted by the International Renewable Energy Agency (IRENA); the African Renewable Energy Initiative backed by African heads of state, France and Germany; and Mission Innovation, a shared commitment of 20 countries and the European Union to double public investment in clean energy research and development (R&D) over the next five years.[2]

4.4 Beyond COP21: New opportunities and challenges for worldwide renewable energy deployment

To fully bridge the gap between current trajectories and the accelerated case needed to achieve the 2DS, further policy changes will be required to address persistent issues and focus on opportunities in emerging economies and other developing countries. These include increased support for renewables such as offshore wind, solar thermal electricity

2. Other efforts include the Breakthrough Energy Coalition of 28 business leaders from 10 countries to mobilise both private and public investment in innovative, early-stage clean energy companies; the Clean Energy Ministerial (CEM) forum on clean energy innovation, which comprises energy ministers and business leaders from over 25 countries; and the World Business Council for Sustainable Development Low-Carbon Technology Platform Initiatives.

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(STE) and geothermal that have yet to achieve the commercial maturity of solar PV and onshore wind; mechanisms to facilitate better grid integration of high shares of renewables; further expansion of renewables in heat and transport; and managing competition from low fossil fuel prices.

4.4.1 Policy action needed around the globe

Looking ahead, development will increasingly shift away from OECD member countries and toward emerging economies and developing countries, which are projected to account for two-thirds of worldwide growth in renewable capacity by 2021 (Figure 4.5). OECD power systems are generally growing slowly, and require significant market and regulatory reforms as well as infrastructure upgrades to integrate higher proportions of renewables. These challenges are particularly relevant in Europe, though in absolute terms the European Union remains the world's second largest single market for renewables. Fast-growing power demand, diversification needs and local pollution concerns have greatly accelerated renewable energy deployment in China, which represents 37% of the total global increase in capacity (2015-21), and these same factors appear to be driving deployment in India and Brazil.

There are a variety of policy deficiencies around the globe which, if remedied, would help accelerate the deployment of renewables. They have been enumerated in a number of IEA and IRENA publications (including the *MTRMR*):

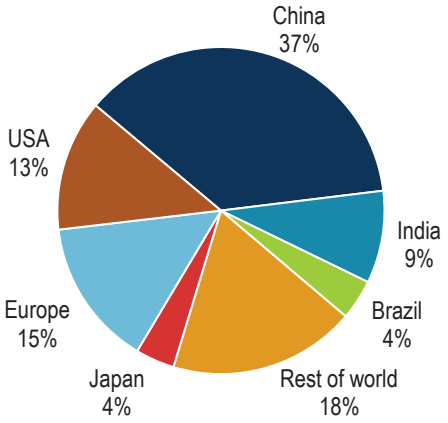
- China's 13th Five-Year Plan, released in March 2016, announced ambitious targets for wind and solar deployment, but curtailment of renewables remains a challenge, with wind power curtailment reaching an average of 15% in 2015.
- The EU NDC 2030 targets currently lack a robust mechanism to spur state compliance. Progress in increasing grid interconnection across Europe may be too slow to raise the value of variable renewable generation, leaving investors and generation companies lacking sufficient regulatory certainty.
- In the United States, uncertainty persists in implementation of the Clean Power Plan, with the US Supreme Court pausing the Plan's implementation in the midst of an ongoing legal challenge.
- In India, uncertainty over state-level implementation of national targets, financial factors, and persistent risks related to the certainty of policy incentives, offtake, land acquisition and grid connection may keep the cost of capital high even as renewable energy technology costs fall.
- In many developing countries, grid integration and the availability of affordable financing remain the most important challenges.

4.4.2 Renewables beyond onshore wind and solar PV

Sustained technological progress and innovation, constant expansion into new markets, and improved regulatory and financing conditions have helped onshore wind and solar PV generation achieve (or be on the verge of) cost-competitiveness with fossil fuels in many jurisdictions worldwide. Maintaining and enhancing existing policy support for these technologies remains critical for decarbonisation of the global energy system. However, looking beyond onshore wind and solar PV, there are a number of renewable technologies, including offshore wind, geothermal and STE, with enormous potential for growth and cost reduction, provided the right regulatory frameworks and economic incentives are in place to support them.

Figure 4.5

Shares of net additional renewable capacity, 2015-21



Source: Adapted from IEA (2016b), Medium-Term Renewable Energy Market Report 2016.

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- Unlike solar PV, STE from concentrating solar power (CSP) plants with thermal storage systems can provide peak, intermediate or base-load electricity. STE is therefore highly complementary to PV generation, but at present most power markets and government support frameworks do not fully remunerate the value that plants with thermal storage can provide to power systems. As a result, investment in the technology is slowing and the cost decreases needed to bring the technology to full commercial scale have not been realised. Designing power markets in a way that incentivises generator flexibility as well as capacity additions will be critical for the future growth and development of STE.

- Geothermal energy is a non-variable source of low-carbon electricity generation, but despite having been deployed at commercial scale for more than a century, it remains marginal. Geothermal's main disadvantages compared with other renewable technologies are the high up-front costs of drilling exploratory wells and the risk that a well will prove non-productive. By providing appropriate financing guarantees and reliable economic incentives, governments can catalyse the technological progress and economies of scale needed to permanently reduce investor risks and bring down geothermal development costs. Founded in 2008, the Government of Kenya-backed Geothermal Development Corporation (GDC) funds research and development, and mitigates investor risk by assuming a share of the up-front exploration and drilling costs (IEA, 2015a). Since the launch of the GDC, Kenya has emerged as a world leader in geothermal deployment, with capacity expected to grow by 310 megawatts (MW) by 2020.

- Despite ongoing technological innovation and some significant improvements in supply chain efficiency, offshore wind deployment remains below potential in many key markets as a consequence of regulatory uncertainty and insufficient economic incentives. OECD Europe continues to lead the world in offshore wind deployment, with growth fuelled by rapid investment cost reductions, low-cost financing and the prospect of substantial grid interconnection upgrades. However, in other markets, deployment would be supported by simplifying and shortening the permitting process, expanding the grid and providing greater financial support.

For all renewable technologies, continued and enhanced support for innovation remains important. For offshore wind, for example, innovation funding can catalyse design experimentation and field testing of new turbine prototypes with longer blades, higher towers and larger generators. Further innovation can unlock even greater energy outputs and cost efficiencies for all renewables, including for onshore wind and solar PV.

4.4.3 Integration of variable renewables in existing electricity systems

The 2DS provides for renewables to grow to over 50% of electricity capacity by 2030 and 72% of electricity capacity by 2050, with wind and solar representing 30% by 2030 and 50% by 2050 (IEA, 2016d). Wind power and solar PV, the more dynamic renewables sectors, could provide 30% of global electricity generation by 2050 in climate-friendly scenarios, and significantly more in some regions (IEA, 2016d). This inevitably raises questions as to the fitness of existing power systems to handle the variability of these generation sources.

Expanding variable renewable energy (VRE) shares beyond a relatively small percentage of total capacity can affect the power system at all time scales: from several years (system planning), to days, hours and minutes (system operations), to seconds (system stability). This may be due to the variability of the generation itself, but may also be a consequence of uncertainty, location constraints, modularity and reduction of rotating inertia – all properties shared by variable renewables such as solar PV and wind power. The impact of high shares of VRE can also be seen at all geographic scales, from system-wide impacts (affecting entire continental power grids) all the way down to individual lines of the distribution grid.

Variability and uncertainty are not new to grid operators and electric utilities. Electricity demand varies significantly depending on the time of day and the season. Conventional power plants and transport lines fail unexpectedly, and power systems hold generating "reserves" to avoid brown-outs. Moreover, some countries have already integrated significant volumes of electricity from variable renewables, and are preparing to integrate more (Figure 4.6). Enabled by its grid integration with the other Nordic countries, Denmark achieved a record-breaking average contribution of over 50% of total generation from wind and solar PV in 2015. In Germany, the contribution of variable renewables to total annual electricity generation jumped to 19% in 2015; in Spain and Portugal it reached 21%, and in Ireland 23%. In Portugal, for a few hours on 28 December 2015, wind generation actually exceeded the country's total electricity demand. It is important to bear in mind that grid integration of large shares of renewables is far easier in jurisdictions with high levels of interconnection, such as the European Union, while jurisdictions that lack cross-border grid interconnection face a greater challenge in managing variable electricity generation.

Given the increasing proportion of variable renewables in the electricity system under the 2DS, the IEA has continued to analyse the challenges of integrating large shares of VRE, based partly on lessons learned from leading countries (Box 4.1). Successful grid integration is determined by the interaction of two principal factors: the inherent properties

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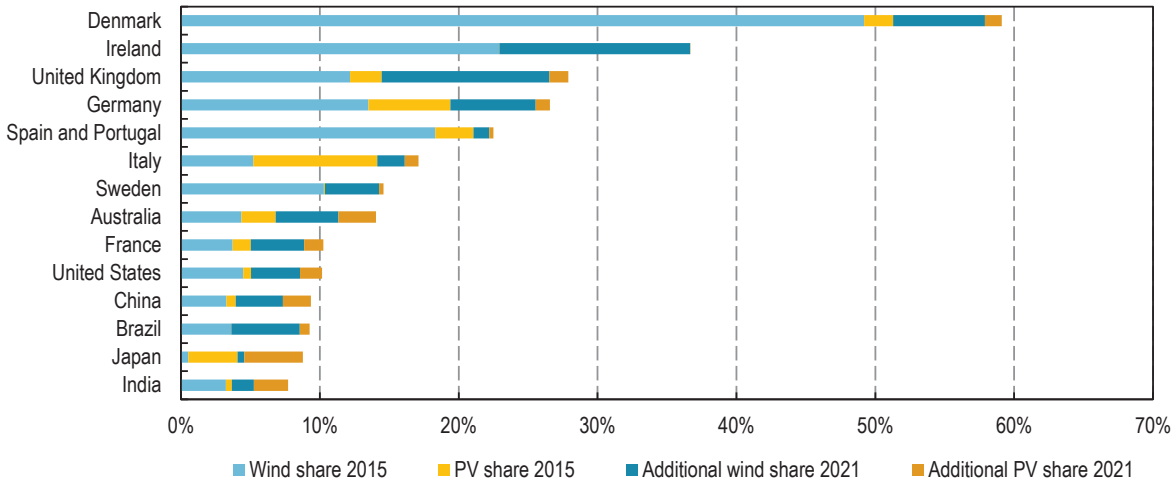
Figure 4.6

Shares of variable electricity generation in 2015 and 2021



Source: Adapted from IEA (2016b), Medium-Term Renewable Energy Market Report 2016.

Box 4.1

IEA analysis on integrating large shares of VRE into electricity systems

In 2014 the IEA published The Power of Transformation – Wind, Sun and the Economics of Flexible Power Systems *(IEA, 2014), which looked at the challenges and possible mechanisms to integrate high shares of renewables. This topic was subsequently analysed in* Projected Costs of Generating Electricity *(IEA/NEA, 2015), which includes a chapter on system costs, and in* Energy Technology Perspectives 2015 *(IEA, 2015c), which examines policy and market frameworks to facilitate integration of large VRE shares. In parallel, the IEA has been working on an Electricity Security Action Plan. This Plan encompasses a wide range of investment models and best practices for wholesale and retail power market design for the transition to decarbonised electricity systems. The publication in early 2016 of* Re-powering Markets: Market Design and Regulation during the Transition to Low-Carbon Power Systems *(IEA, 2016e) is a result of collective IEA research efforts on renewable energy integration. The latest publication in the field of system integration is* Next Generation Wind and Solar Power – From Cost to Value *(IEA, 2016f). The publication discusses how wind and solar power can contribute to their own integration and how policies can be designed to unlock this contribution.*

of VRE, and the flexibility of the power system into which the VRE is integrated. This includes the flexibility of existing power plants (how well they can adjust their output), the short-term responsiveness of demand, the availability of electricity storage, and the quality and responsiveness of the transmission and distribution grid. The size and degree of interconnection are also relevant, with larger and more interconnected grids being generally better at facilitating integration.

Given the broad impacts that high VRE shares can have, a comprehensive and systemic approach is appropriate for resolving system integration challenges. IEA analysis indicates that a co-ordinated transformation of the entire system can reduce integration costs.

- From a technical perspective, changes are needed in the way that VRE is deployed ("system-friendly" VRE deployment). Existing power systems will require greater flexibility, and system operations may need to be revised to ensure that best practices are implemented.

- From an economic perspective, the remuneration schemes governing financial returns to generators must be reformulated to better accommodate the financing requirements of VRE development. Due to the capital-intensive nature of these generation sources, market arrangements need to provide sufficient long-term certainty to keep financing costs low. At the same time, investors in wind and solar power need to be exposed to price signals that reflect the value of their generation for the overall system, which depends on the location and time of power generation. New financing systems may have to be developed specifically to ensure sufficient investment in the flexibility measures required for power system transformation.

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- From a political perspective, VRE is changing the role of existing stakeholders and simultaneously allowing new stakeholders to enter the power sector. These changes require political leadership to address institutional resistance, and to establish new regulatory frameworks for new stakeholders. For example, controlling distributed power generation capacity remotely will require regulation to address data ownership rights, and the rise of international grid interconnection will require cross-border co-ordination and diplomatic engagement.

- Finally, this transformation will require engagement with civil society. Lack of broad public acceptance may delay or even prevent the development of new power generation and grid infrastructure, and complicate power system transformation significantly. A high level of social acceptance, fostered through meaningful engagement and consultation, will be critical for the deployment of demand-side response technologies to enable grid integration of VRE.

4.4.4 Untapped potential of renewables in heat and transport

While electricity currently accounts for approximately 40% of total primary energy consumption and is responsible for roughly the same percentage of energy-related CO_2 emissions, the other 60%, mostly fossil fuels directly consumed in the industry, transport and building sectors, should not be overlooked. Although the development of renewables for heat and transport energy needs has not kept pace with the remarkable progress seen in the power sector in 2015, the year was marked by several promising milestones in this field, particularly for solar heat in industrial processes, and for the development and deployment of advanced biofuels.

The future of renewable heat

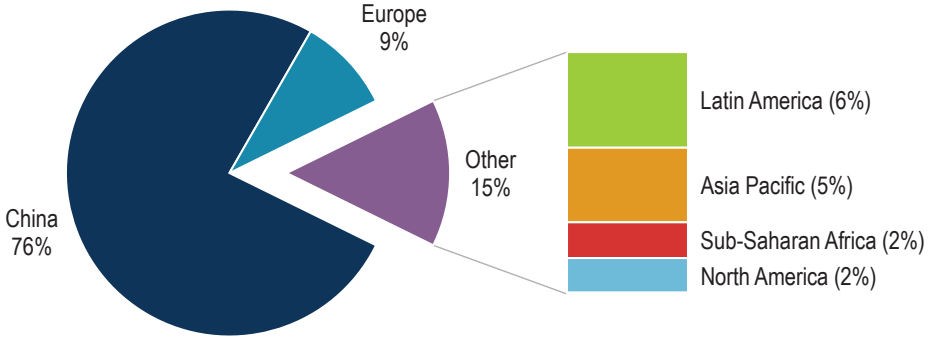
The production of heat accounts for almost half of global final energy consumption, with approximately 75% of this demand currently met with fossil fuels. Heat is therefore responsible for one-third of global energy-related CO_2 emissions, but has not received the policy attention that is needed to address its emissions. While over 110 countries worldwide have renewable electricity support mechanisms in place, only 40 have implemented renewable heat support mechanisms, and these are often small grants or tax incentives. Very few countries have renewable heat targets and/or comprehensive heat decarbonisation strategies. Solar thermal heat capacity continues to increase, especially in China (Figure 4.7), but at a slower pace than before 2014 (IEA, 2016b).

However, there are some signs that renewable heating (and cooling) are gaining policy attention. The EU Renewable Energy Directive has driven renewable heat deployment in a number of member states, and the European Commission published a heating and cooling strategy in early 2016 which includes a major focus on renewables. In countries such as Germany, the United Kingdom and the United States, the most progressive policy approaches to encourage renewable heating and cooling have been implemented at the sub-national level. Most of these strategies or policies, however, focus on space heating and do not adequately address industrial heat, which is almost as significant a share of total energy demand in cold and temperate countries, and a larger share in warm countries.

Both industrial heat and sanitary hot water applications may be better suited to substitution with renewable energy technologies than space heating. Whereas space heating demands are prone to significant seasonal variation, industrial heating (with the exception of agro-industries) and hot water demands tend to be relatively constant over the course of the year. This is particularly true in the case of solar energy, due to the temporal mismatch between demand and maximum resource availability. In 2015, there were some indications that businesses are awakening to the possibilities of deploying solar heat for industrial processes. One notable example is Petroleum Development

Figure 4.7

Share of new solar heating capacity installed by geographic region, 2015



Source: Data from IEA SHC Technology Collaboration programme (IEA SHC, 2016).

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Oman's decision to build, with California-based Glasspoint, a 1gigawatt thermal (GW_{th}) concentrating solar thermal plant. Once completed, the plant, which is currently under construction, will generate steam for enhanced oil recovery, vastly reducing the natural gas demands and CO_2 emissions of the company's operations.

However, solar heat remains a minor contributor to industrial energy needs compared with bioenergy (notably in the pulp and paper industry), which has significant technical potential for larger uptake to support heating processes in industry, as well as possibilities for feedstock-related uses. An additional opportunity for renewable energy uptake in industry may be to use more renewable electricity to power a variety of efficient process or heating technologies such as electrowinning, microwaves, Foucault currents, electric ovens, electric arcs, induction, plasma torches, etc. At a workshop on renewables for manufacturing industries held at the IEA in May 2015,[3] participants suggested that the increased use of renewables-based electricity in industry could provide additional grid flexibility and facilitate the integration of larger shares of variable renewables into the electricity system, as could partial electrification of the transport sector.

New opportunities for renewable energy in transportation

Biofuels and the electrification of vehicle transport using renewable electricity are two major opportunities for renewable energy deployment in transportation. Global biofuel production increased by just over 1% in 2015 and biofuels accounted for around 4% of total road transport fuel worldwide. Biofuel mandates proved effective in protecting the industry from direct competition with lower-priced gasoline and diesel, and these policies have been strengthened in key markets such as Brazil and India. Current low oil prices have undermined opportunities for discretionary blending above mandated levels, but have also facilitated the reduction or removal of fossil fuel subsidies, for example in Indonesia and Malaysia, making biofuels more competitive.

Advanced biofuels such as cellulosic ethanol and renewable diesel, produced using non-food agricultural residue and waste feedstocks, have undergone a notable scale-up in recent years. Seven new commercial-scale plants using biomass waste and agricultural residue feedstock were commissioned in 2014-15, bringing the total number of facilities worldwide to ten. Cellulosic ethanol, which accounts for the majority of newly commissioned facilities, is still in the early stages of development and therefore entails higher production costs.

3. See www.iea.org/workshops/renewable-energies-for-manufacturing-industries.html for more information.

There is significant potential to reduce both production and investment costs in the biofuel sector, while additional value is expected from co-products. Achieving these cost reductions will improve prospects for expansion, but strengthened policy support, including dedicated advanced biofuel quotas, would likely also be needed. The residual 3% share within the EU target of 10% renewable energy in transport, which cannot be met from conventional fuels, could be the opportunity for an increased contribution from advanced biofuels.

4.4.5 Fossil fuel price challenge

The IEA *Medium-Term Coal Market Report 2016* (IEA, 2016g) signalled that coal prices are likely to remain historically low into the future, and questions whether they will ever fully recover. Gas prices are also predicted to remain low throughout the decade, with projected global demand growth for natural gas revised downward to just 1.5% annually up to 2021. Oil prices are likely to remain low until 2017, though they may then recover as production capacity declines due to the current lack of investment. While some of the downward pressure on natural gas demand was likely due to the collapse in coal prices, IEA analysis suggests that a higher-than-expected level of renewables deployment was also an important factor.

Renewable electricity faces competition from gas and coal rather than oil, while persistent low oil prices are a greater concern for renewable heat deployment and advanced biofuel development. In the medium term (up to 2020), policy measures are predicted to largely shelter the deployment of renewables from the impacts of reduced fossil fuel prices. However, significant policy discontinuities could occur in 2020, with the EU Renewable Energy Directive (2009) subsidy and regulatory support framework drawing to a close, along with the PTC in the United States (followed by the ITC in 2022). There are also many uncertainties regarding implementation of the US Environmental Protection Agency (US EPA) Clean Power Plan, and whether current renewable deployment targets in China will be met.

- While persistently low fossil fuel prices raise the risk of weakening policy support for renewables, there is little evidence that this is occurring thus far, and the Low Oil Price Scenario projections in the *World Energy Outlook 2015* (IEA, 2015b) do not suggest that this will occur in the future. In fact, the way the oil price translates into lower wholesale electricity prices may reduce the likelihood of a political backlash against the cost of subsidies to renewables in the power sector. That said, for national governments to fulfil their Paris Agreement commitments, a holistic, long-term view will be needed in addition to the continued implementation of shorter-term policy measures to accelerate the low-carbon energy transition.

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- These measures include further phasing out of fossil fuel subsidies, as well as appropriate carbon pricing mechanisms and specific policy and market measures to stimulate investment in renewables, energy efficiency and other carbon-reducing technologies. The current low-fuel-price environment provides an ideal opportunity to remove fossil fuel subsidies without imposing onerous impacts on consumers.

4.4.6 Even more effort needed to move from the 2DS to "well below 2°C"

Much of the foregoing discussion has been based on the 2DS. Additional efforts will be needed to identify policy pathways to limit global average temperature increase to the more ambitious target of "well below 2°C" adopted at COP21, and to achieve a balance between anthropogenic emissions sources and removals in the second half of this century. While there is little doubt that renewables will play an ever greater role in climate change mitigation in the coming years, the increased ambition of the Paris Agreement will likely require the integration of even larger shares of renewables into the global energy system than previously considered necessary or possible.

As described in Chapter 1, cumulative emissions in the 2DS from power, transport and industry total around 870 gigatonnes of carbon dioxide ($GtCO_2$) during 2015-2050, and represent 86% of the actual emissions in the scenario. Achieving the well-below-2°C target will require eliminating many of these emissions. Renewables have a potentially significant role to play across these three sectors in addressing remaining emissions, including faster and larger deployment of renewables for power to replace fossil fuel generation, as well as greater use in transport and industry (see discussion above regarding renewables for heat). Moreover, shifting end-uses to electricity (e.g. greater deployment of electric vehicles in transport) that is already largely decarbonised can also be an important indirect means of lowering emissions. It can help to reduce emissions from transport and industry, as well as buildings and the other non-power sectors that together with transport and industry account for the majority of CO_2 emissions outside of power in the 2DS, namely over 70% through 2050 and over 90% in 2050.

4.5 Conclusion

Renewables continue to demonstrate they can rise to the challenge of powering the world economy and delivering clean and affordable energy to a growing global population. However, with significant challenges looming on the horizon, governments must sustain and complement existing policies to support renewables deployment. High-level subsidies are no longer needed for onshore wind and solar PV, but other technologies still face substantial barriers to economic viability. Furthermore, the new affordability of renewable technologies does not mean the market can be completely relied upon to deploy them. These technologies have low running costs but require significant up-front investment, and sufficient security must be provided to investors for these capital costs to be affordable. Realising the enormous potential for deployment of renewables in the heat and transport sectors will require the right blend of incentives and regulatory reform, as well as effective collaboration with industry stakeholders. The greater ambition of the well-below-2°C target will require larger and faster deployment of renewables to substitute for fossil fuel combustion, and likely a more aggressive shift of end- use consumption to decarbonised electricity. Enabling renewables to deliver on economic growth and low-emissions goals requires policy consistency, determination and vision – the vision that was shared at the COP21 conference in Paris.

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Chapter 5 • A central role for energy efficiency and other demand-side actions to reduce emissions

Energy efficiency contributes the largest share of total emissions reductions toward limiting temperature increase to 2 °C in International Energy Agency (IEA) analysis, surpassing even the role of renewables and revealing the importance of demand-side interventions. Energy efficiency, as well as structural changes and targeted energy conservation, are critical instruments to reduce emissions while supporting national targets for economic growth, poverty alleviation and improved standards of living through greater energy productivity. Keeping within reach the enlarged collective ambition of the Paris Agreement to mitigate climate change will require greater attention from governments to energy efficiency and other demand-side interventions.

5.1 Importance of energy demand in emissions reduction efforts

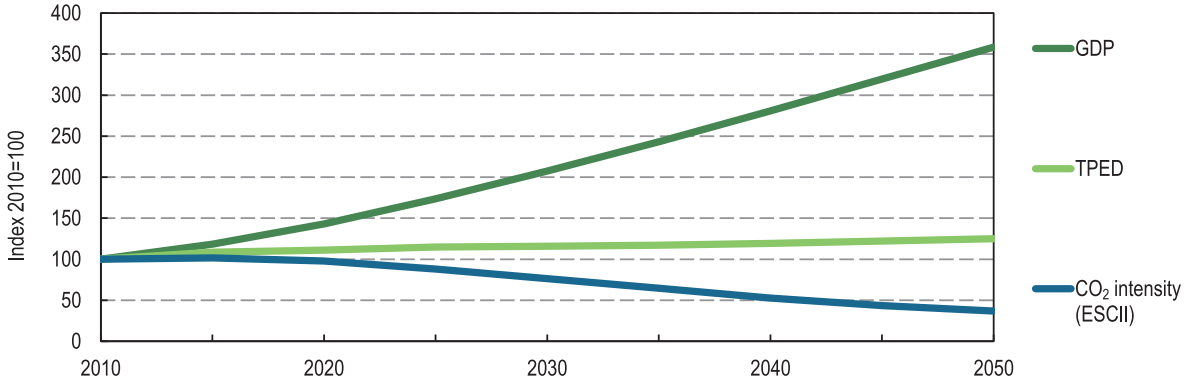
The two drivers of energy-related emissions are the carbon intensity of energy supply (the mix of different energy sources, such as renewables, nuclear and fossil fuels) and the amount of energy consumed. IEA analysis of emissions reductions under the 2 °C Scenario (2DS)[1] is based on the assumption of continued, robust global gross domestic product (GDP) growth, supported by an energy demand that plateaus as it decouples from GDP growth, and an energy mix with declining carbon intensity (Figure 5.1). To promote continued economic and social development with reduced greenhouse gas (GHG) emissions, the world in the 2DS not only decarbonises energy, but also decouples economic growth from energy consumption.

Under the 2DS, the energy intensity of the global economy (i.e. how much energy is needed for each unit of GDP) and the carbon intensity of energy supply (expressed through the Energy Sector Carbon Intensity Index [ESCII])[2] both decline by about 60% to 2050 (Figure 5.2). The weighted average energy intensity[3] in the 2DS from 2015 to 2050 is 3.2 petajoules (PJ) per billion 2014 USD at purchasing power parity (PPP), 40% lower than the 2013 level of 5.4 PJ/billion 2014 USD PPP (IEA, 2016b); the weighted average carbon intensity in the 2DS is 43 kilotonnes per petajoule (kt/PJ), 28% lower than the current level.

The effect of the interaction of these two levers on emissions under IEA modelling is illustrated in Table 5.1. If energy demand were 10% higher than in the 2DS, carbon intensity would need to decrease by a similar rate. If, on the contrary, energy efficiency and other policies were more successful in decoupling GDP growth from energy demand than assumed in the 2DS, a similar emissions reduction could be achieved with a higher carbon intensity (e.g. accommodating a higher

Figure 5.1

GDP growth in the 2DS, and related primary energy and CO_2 pathways



Note: TPED = total primary energy demand.

Source: Adapted from IEA (2016a), Energy Technology Perspectives 2016.

1. *See description of the 2DS and other IEA scenarios in Chapter 1.*

2. *See discussion of the ESCII in Chapter 1, section 1.1.*

3. *The weighted average for energy intensity and carbon intensity is based on energy demand in that year.*

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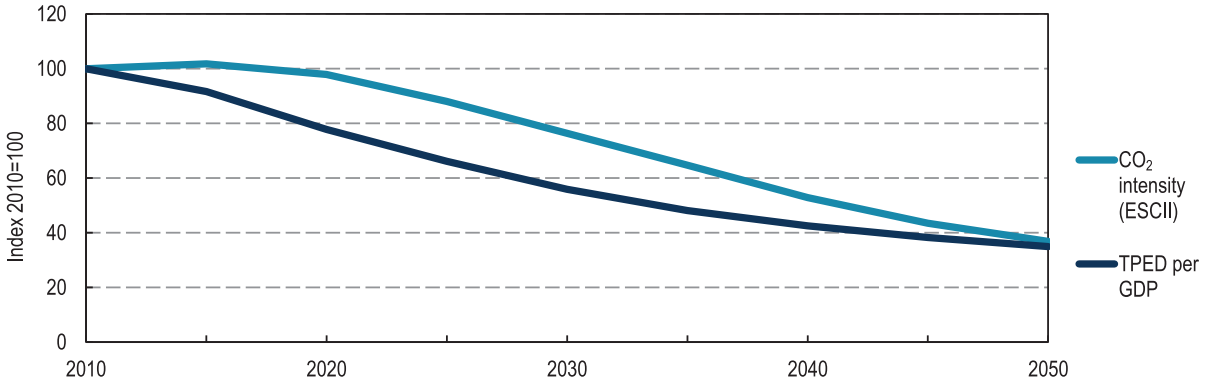
Figure 5.2

Rate of improvement in energy intensity and carbon intensity in the 2DS



Source: Adapted from IEA (2016a), Energy Technology Perspectives 2016.

Table 5.1

Effect of demand and carbon intensity interaction on emissions: Variation in 2DS, 2015-50

	Actual (2013)	2DS (base case)	2DS +10% demand	2DS -10% demand	Impact of -10% demand with 2DS carbon intensity
Average TPED per year (EJ)	567	616	678	555	535
Weighted average energy intensity (PJ/2014 USD billion PPP)	5.4	3.2	2.5	2.9	2.9
Weighted average carbon intensity ($ktCO_2$/PJ)	60	43	39	48	43
Total emissions 2015-50 (Gt CO_2)	33.9	1013	1013	1013	912

Notes: $ktCO_2$/TJ = kilotonne of carbon dioxide per terajoule; Weighted averages are calculated by weighting either energy intensity or carbon intensity against energy demand in that year; GDP figures are from the 2DS; Assumptions are in italics, and variable factors in bold.

Source: Adapted from IEA (2016a), Energy Technology Perspectives 2016.

share of fossil fuel power production).[4] When efforts to decarbonise the energy sector face difficulty (as reflected in the lack of movement in the ESCII described in Chapter 1), measures to decouple GDP growth from energy demand could compensate for shortfalls. Similarly, greater success in decoupling GDP growth from energy demand with the carbon intensity level of the 2DS would reduce emissions (e.g. a 10% reduction results in a commensurate drop in emissions), yielding an outcome that would limit global temperature increase to further below 2° C.

Demand assumptions: How demand differs in the 6DS, 4DS and 2DS

In 2014, global primary energy demand was 570 exajoules (EJ), 20% higher than it had been a decade earlier, while the energy intensity of the global economy decreased by approximately 5% over the same period (IEA, 2016a). In the 2DS, energy demand increases to 663 EJ by 2050, a 16% increase over 2014. By comparison, under the business-as-usual trends reflected in the 6°C Scenario (6DS), energy demand reaches 940 EJ in 2050, 42% higher than in the 2DS. The cumulative difference in demand between the 6DS and the 2DS through 2050 is 5 266 EJ. Even when compared with the 4°C Scenario (4DS), primary energy demand in the 2DS is approximately 170 EJ lower in 2050, and is cumulatively 3 265 EJ less through 2050, a total difference equal to nearly six years of current energy demand.

One of the major impacts of lower energy demand is a lower fossil fuel requirement: the 2DS projects about 280 EJ less in 2050 than the 4DS (300 EJ versus 580 EJ). In parallel, the contribution of renewables and nuclear is 113 EJ higher in the 2DS (Figure 5.3). Under a simplified analysis, 113 EJ of the 280 EJ reduction in fossil fuel consumption can be attributed to the expansion of renewables and nuclear, while the remaining 167 EJ drop is corresponds to the lower energy demand in the 2DS.

This is well illustrated by *World Energy Outlook 2015* (*WEO 2015*) analysis of different demand and emissions

4. Various actions influence both energy demand and carbon intensity simultaneously. For example, switching to electric from internal combustion engine vehicles not only improves efficiency but reduces carbon intensity (unless the power system is very carbon-intensive).

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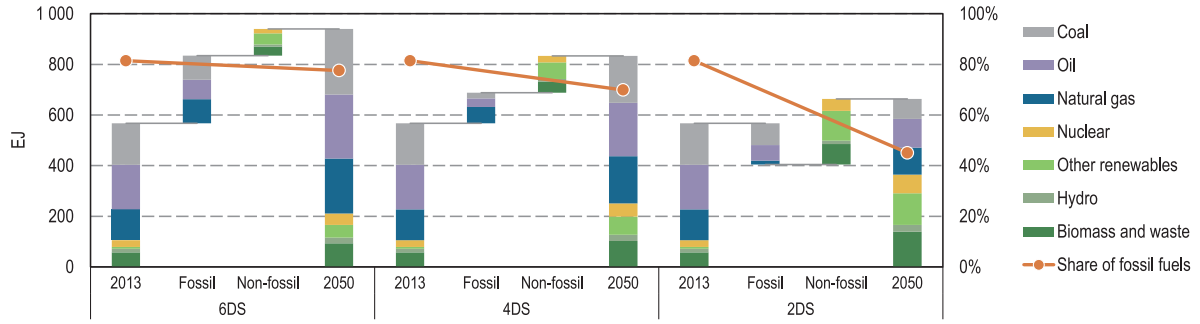
Figure 5.3

Changing primary energy demand and energy mix in the 6DS, 4DS and 2DS, 2013-50



Source: IEA (2016a), Energy Technology Perspectives 2016.

scenarios. Primary energy demand in 2040 in the Current Policies Scenario (CPS) is 19 600 million tonnes of oil-equivalent (Mtoe) (820 EJ), 17 900 Mtoe (750 EJ) in the New Policies Scenario (NPS) and 15 200 Mtoe (636 EJ) in the 450 Scenario, corresponding to energy sector CO_2 emissions of 44.1 gigatonnes of carbon dioxide ($GtCO_2$) in the CPS, 36.7 $GtCO_2$ in the NPS and 18.8 $GtCO_2$ in the 450 Scenario (Figure 5.4). Lower energy demand corresponds to lower CO_2 emissions.

5.2 Managing demand through efficiency and structure

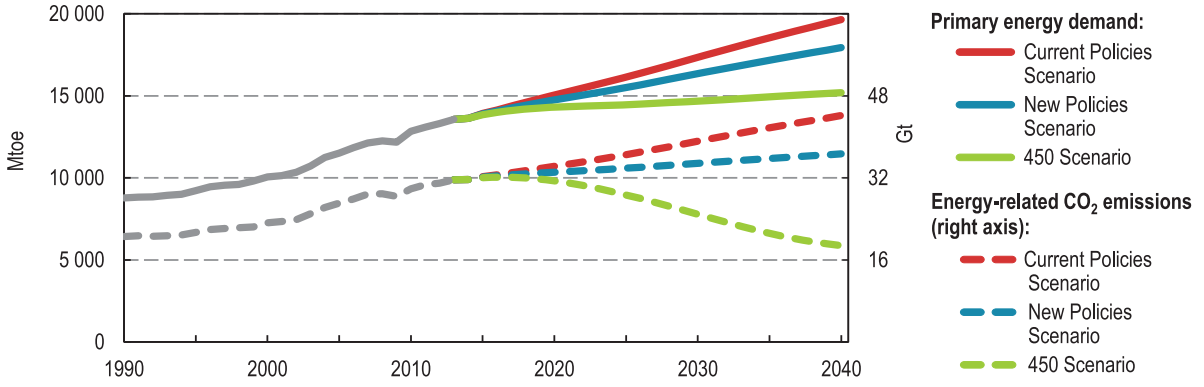
Other than the overall level of economic activity, there are two principal drivers that can alter energy demand[5]:

- Energy efficiency - referring to energy intensity improvements that result from measures in residential buildings, passenger and freight transport, and industry and services.
- Structural change - referring to shifts in the mix of activity levels across different sectors and sub-sectors of the economy, with different activity types having different energy intensities.

The potential role of energy efficiency, which is the focus of this chapter[6], has been highlighted by the IEA in the context of emissions reductions; however, structural change is becoming an increasingly relevant factor in energy demand. There are also numerous programmes designed to encourage consumers to reduce energy consumption, i.e. conserve energy, while maintaining their standard of living. These programmes encourage consumers to, for example, adopt more informal business attire during the summer to reduce

Figure 5.4

Energy demand and related CO_2 emissions by scenario



Source: IEA (2015a), World Energy Outlook 2015.

5. *See IEA (2016b), Energy Efficiency Market Report 2016, Box 1.3.*

6. *This chapter focuses on the use of energy efficiency to reduce overall demand. Demand-response measures are also used for other purposes, such as load smoothing or shifting (e.g. to reduce peak load) which may in fact have no impact on overall demand or can even in certain circumstances lead to an increase in demand.*

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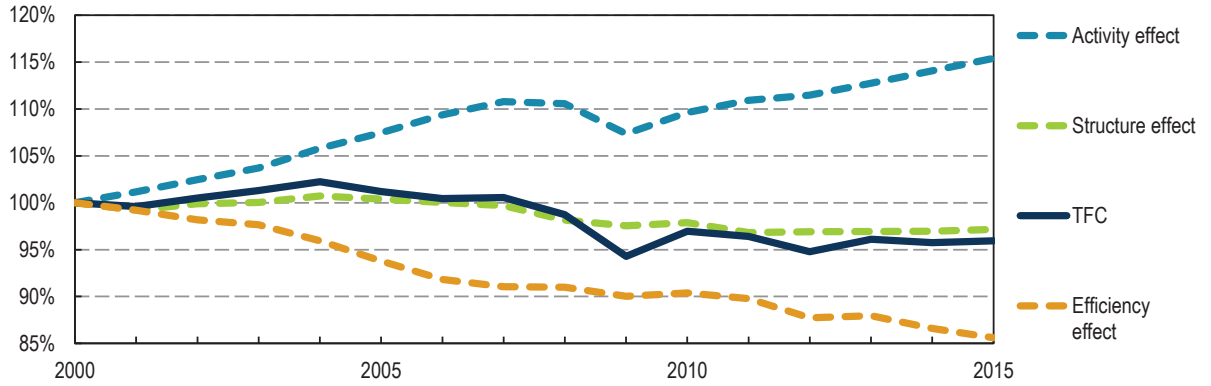
Figure 5.5

Decomposition of TFC for IEA member countries, showing efficiency and structure effects



Notes: TFC in this analysis encompasses the following sectors: residential, industry and services, and passenger and freight transport. It does not include agriculture, non-energy, and energy supply sectors. The energy consumption decomposed in this analysis represents 90% of TFC in IEA member countries in 2015.

Source: IEA (2016b), Energy Efficiency Market Report 2016, *based on the IEA* Energy Efficiency Indicators database *(2016 edition).*

demand for air conditioning, or to switch to more energy-efficient modes of transport. These conservation actions are described in more detail in Section 5.5.

An analysis of energy consumption for IEA member countries in the *Energy Efficiency Market Report 2016* illustrates the impact of both efficiency and structural changes on total energy consumption together with changes in activity.[7] TFC in 2015 for IEA member countries was nearly 5% lower than in 2000, even though the activity level has increased by 15% since then.[8] Energy efficiency improvements and structural changes compensated for the impact of increased activity, with the former driving consumption down by nearly 15% compared with 2000, while structural changes in sectors across the economy lowered consumption by about 3% (Figure 5.5).

Efficiency effects and structural effects can operate even in the context of rising energy demand. This is particularly relevant for many emerging economies in which energy demand has risen substantially since 2000 and is expected to increase further as a result of population and economic growth. For example, an analysis of recent trends in a set of major emerging economies (Brazil, India, Indonesia, Mexico and Thailand), and separately for The People's Republic of China (hereafter "China"), illustrate this dynamic: Since 2000, TFC has nearly doubled in this set of emerging economies, and more than tripled in China, but there were also important energy efficiency gains, while the structure of these economies remained relatively flat with respect to energy consumption (Figure 5.6).

As illustrated in Figure 5.5 above, efficiency and structure effects can both reduce energy demand. However, they differ in certain important respects. While energy efficiency improvements typically systematically reduce demand,[9] different types of structural changes to an economy will exert either downward or upward pressure on energy consumption. For example, while structural shifts toward less energy-intensive service sectors in IEA member countries since 2000 have lowered demand (IEA, 2016b), energy intensity and consumption can increase in rapidly growing developing countries as they shift from less energy-intensive agricultural activities to manufacturing. In addition, although energy efficiency improvements in one country typically produce an emissions reduction benefit at the global level,[10] it is important to determine whether a shift in structure that leads to reduced emissions in one country is accompanied by a related increase in another country (e.g. services taking the place of manufacturing in China, with the manufacturing activity relocating to another developing country). Finally, while policy makers can influence structural change (e.g. adopting fiscal policies to promote expansion of the services sector, or

7. The IEA uses decomposition analysis to quantify how different factors in an economy (called "effects") influence total final consumption (TFC). Three main factors are distinguished: (i) ***Activity*** *is the level of action that drives energy use; it is broken into sectors and is measured based on different factors, such as value-added output in the industry and services sector and by population in the residential sector; (ii)* ***Structure*** *reflects the mix of activity levels within a sector: e.g. the share of production represented by each sub-sector of industry or services; by floor area per person, number of dwellings per person and appliance ownership rates in the residential sector; and by the modal share of vehicles in passenger and freight transport. Because different activity types have different energy intensities, shifts in the structure of activity will impact energy demand; (iii)* ***Efficiency*** *is the amount of energy used per unit of activity.*

8. TFC refers to actual consumption by consumers; total primary energy supply is the amount of fuel consumed to produce that energy. The most significant distinction for the purposes of this chapter is that more energy is required in fossil fuel power generation than is produced and consumed by consumers, because a portion of the fuel combusted dissipates in the form of heat.

9. This positive impact can be limited by the rebound effect, in which energy efficiency benefits encourage some increase in energy consumption which then limits anticipated energy savings. See discussion of rebound effect in IEA, 2015e.

10. See previous footnote on rebound effect.

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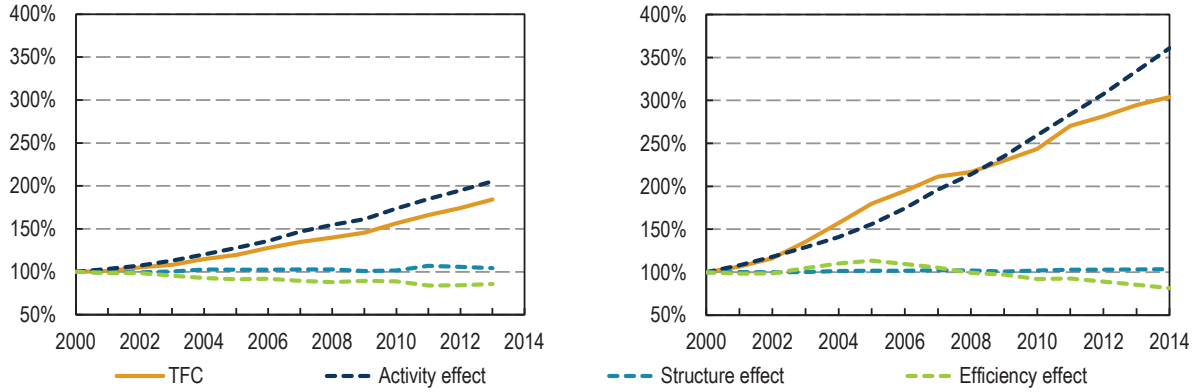
Figure 5.6

Decomposition of TFC in Brazil, India, Indonesia, Mexico and Thailand (left) and China (right)



Notes: A) Left graph: Energy use decomposed in this analysis covers the industrial, services, passenger and freight transport sectors for Brazil, India, Indonesia, Mexico and Thailand combined. The intensity effect depicted in the chart is aligned with the efficiency effect depicted in the decomposition for IEA member countries. However, end-use energy consumption data are more aggregated than for IEA countries. B) Right graph: This figure illustrates the results for China of three detailed decomposition analyses: (1) decomposition of energy consumption in the productive economy in 21 sub-sectors including agriculture, construction, manufacturing and services; (2) decomposition of energy consumption in passenger and freight transport; (3) decomposition of energy consumption for residential heating in northern China.

Source: IEA (2016b), Energy Efficiency Market Report 2016.

policies to promote modal shifts to less energy-intensive forms of transport), much of the change in structure is driven by exogenous market forces. Notwithstanding these differences, energy efficiency and structural change are both areas in which policy makers can act to influence energy demand.

5.3 Climate goals help drive increased importance of demand-side action

As described in Chapter 8, 143 countries mention energy efficiency in their Nationally Determined Contributions (NDCs) submitted to the UNFCCC in advance of COP21. Moreover, of the 35 countries[11] that frame goals in their NDCs in terms of energy metrics, 15 refer to energy efficiency or energy demand targets.[12] Under the INDC Scenario established by the IEA, which projects energy sector emissions based on the submitted NDCs (see Chapter 1), energy intensity through 2030 improves three times faster than during the last decade.

At the same time, many of the largest IEA member country economies are shifting focus from a model that seeks to expand energy sources to increase GDP, to one in which increased GDP is decoupled from energy demand. Germany's Energiewende, which targets a 50% reduction in primary energy consumption by 2050, is an example of this emerging trend. Japan and the European Union are other jurisdictions that have adopted policies to reduce aggregate energy demand while supporting continued economic growth. While these policies may be motivated by a variety of objectives beyond climate change mitigation (including enhancing energy security), the decoupling of GDP from energy consumption in a manner that reduces energy demand in absolute terms can, when combined with lower carbon intensity of supply, dramatically reduce energy sector emissions.

5.4 Energy efficiency and emissions reductions

5.4.1 A long-term contributor

Energy efficiency measures are among the most cost-effective actions that can be deployed to reduce emissions in the short, medium and long term. In the 2DS, energy efficiency improvements in end uses make the largest contribution (38%) to global emissions reductions through 2050, compared with the 6DS; renewables (the second largest contributor) provide 32% of reductions. The energy efficiency contribution results from avoided energy consumption: just as there are emissions typically associated with energy consumption, there are corresponding notional emissions that are avoided with reduced consumption, producing a reduction in energy sector emissions relative to the reference case.

The energy efficiency contribution to the 2DS is the result of substantial efficiency gains in all end-use sectors through the implementation of measures such as higher fuel economy

11. Antigua and Barbuda, Bahamas, Belize, Brunei, Bolivia, Cabo Verde, China, Ecuador, El Salvador, Fiji, Guinea, Guinea Bissau, Guyana, India, Jordan, Lao PDR, Lebanon, Liberia, Malawi, Mongolia, Myanmar, Nepal, Niue, Palau, Panama, Papua New Guinea, Samoa, Sudan, Suriname, Swaziland, Tonga, Uganda, United Arab Emirates, Uruguay and Vanuatu.

12. Belize, Brunei, Cape Verde, El Salvador, Guinea, Guinea Bissau, Lebanon, Liberia, Malawi, Mongolia, Myanmar, Niue, Palau, Sudan and Tonga.

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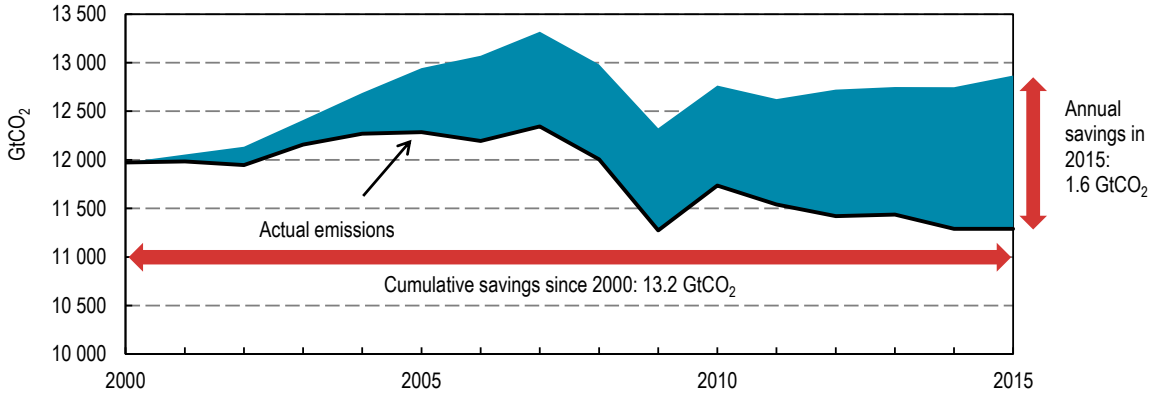
Figure 5.7

IEA member country emissions from fossil fuel combustion and end-use emissions savings from energy efficiency improvements, 2000-15



Source: IEA (2016b), Energy Efficiency Market Report 2016, *based on the IEA* Energy Efficiency Indicators *database (2016 edition).*

standards in the transport sector; the adoption of highly efficient technologies to provide process heat and steam in the industrial sector; and improved efficiency standards in appliances and other residential products, all of which act to reduce the demand for electricity and other energy sources. The impact of these measures on energy-related emissions is large as they reduce energy consumption under the 2DS relative to a business-as-usual reference case: as noted above, total primary energy demand is about 277 EJ lower in the 2DS than in the 6DS, equivalent to nearly half of today's total global energy demand.

Avoided primary energy demand and final fuel consumption[13] from energy efficiency improvements have significantly reduced GHG emissions to date. For example, the avoided emissions in 2015 in IEA member countries from energy efficiency improvements made since 2000 was 1.6 $GtCO_2$ (Figure 5.7). Cumulative avoided emissions since 2000 from these improvements are 13.2 $GtCO_2$ – more than the combined emissions of all IEA countries in 2015.

5.4.2 An important contributor in the short-term Bridge Scenario

Under IEA analysis, a critical first step toward reaching the below-2°C target is to achieve a peak in global energy-related CO_2 emissions by around 2020, something which does not occur under the INDC Scenario. *Energy and Climate Change: World Energy Outlook Special Report 2015* shows that this short-term goal could be delivered under a "bridging" scenario with proven technologies and policies, and without changing the economic and development prospects of any region. This Bridge Scenario consists of five key actions that collectively reduce global GHG emissions significantly through 2030 to below the level of the INDC Scenario; energy efficiency alone contributes nearly half (49%) of the reductions (Figure 5.8).

The Bridge Scenario generates this reduction in emissions through various specific energy efficiency measures, with a focus on minimum energy performance standards (MEPS) for lighting, appliances, equipment and vehicles. These selected measures rely on proven policies and technologies that can have a rapid impact on energy demand. They are applicable to varying degrees in all countries, and build on current country practices (see Box 5.1 for example of China):

Industry

- MEPS for electric motor systems, including motors and driven equipment.
- Mandatory adoption of variable speed drives where applicable.
- Mandatory energy audit programmes to exploit system-wide savings in motor systems.
- Incentives for heat pumps providing low-temperature heat.

Buildings

- MEPS to support phase-out of least-efficient refrigeration, cleaning appliances (e.g. washing machines, dryers and dishwashers), televisions and computers by 2030.
- Ban on incandescent bulbs by 2020 and halogen lights by 2030 in residential and commercial buildings.

13. Although energy efficiency is often expressed from an end user's perspective, i.e. impact on TFC, it is primary energy demand that is a more relevant measure for climate change purposes since it covers the total fossil fuel combustion (and corresponding GHG emissions generated) to meet that demand.

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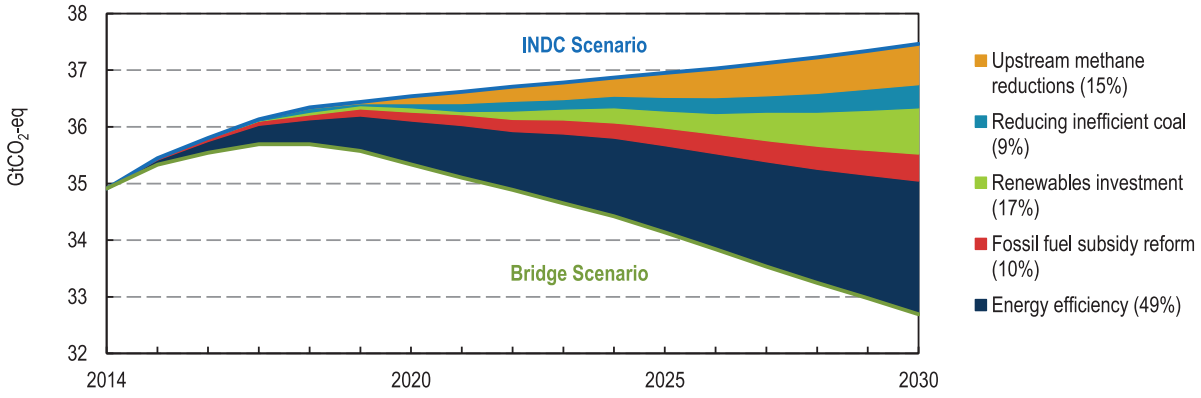
Figure 5.8

Global energy-related GHG emissions reductions under the INDC Scenario and Bridge Scenario, 2014-30, and share of emissions savings by measure by 2030



Source: IEA (2015c), Energy and Climate Change: World Energy Outlook Special Report.

Box 5.1

Energy efficiency in China's industry sector

During the 11th Five-Year Plan (FYP) (2006-10), China implemented several energy efficiency policies in the industry sector, estimated to have collectively avoided total final energy consumption of 13 EJ and related emissions of 760 million tonnes of carbon dioxide ($MtCO_2$) compared with business as usual (IEA, 2015b). One of the policies implemented during this period was the Top-1 000 Programme. It was expanded to the Top-10 000 Programme in the 12th FYP (2011-15) to cover approximately 15 000 of the highest energy-consuming industrial enterprises with consumption levels above 293 terajoules (TJ) per year. The Top-10 000 programme aimed to reduce energy consumption by 7.3 EJ by 2015 by requiring enterprises to implement energy audits and energy management systems, and set energy saving targets. If the enterprises failed to meet their targets, energy audits became mandatory and the energy efficiency measures identified were required to be implemented within a short time frame. The government supported the programme through training and capacity building, promoting efficient technologies, and providing fiscal and financial incentives for investment in energy efficiency projects and to support energy service companies (IIP, 2016).

- MEPS for heating and cooling equipment
- Increased insulation levels for new buildings to help move towards near-zero-energy buildings

Transport:

- Mandatory fuel economy standards for new light-duty vehicles
- Adoption of fuel efficiency standards for new freight trucks

The Bridge Scenario generates important emissions reductions from energy efficiency for all regions. The largest impact is in China, followed by India, the European Union and the United States (Figure 5.9). Substantial GHG emission reductions are obtained under the Bridge Scenario in China, India and Africa through improved energy efficiency of industrial motor systems, while in the Middle East savings relate mostly to gains in cooling efficiencies. Globally, approximately 43% of efficiency measures are implemented in buildings, 39% in industry, and 18% in transport.

5.4.3 A need for more investment, with room to grow

The emissions reductions set out in the IEA scenarios require large investments in energy efficiency that far exceed current levels. Under the INDC Scenario, the investment required to implement the scenario's energy efficiency measures in the transport, buildings and industry sectors through 2030 is estimated at USD 8.3 trillion. While the additional reductions under the Bridge Scenario would be achievable without adversely affecting the development prospects of any region, these reductions necessitate a larger total investment of USD 10.5 trillion over the same period. Moreover, to reduce emissions even further to a level consistent with limiting

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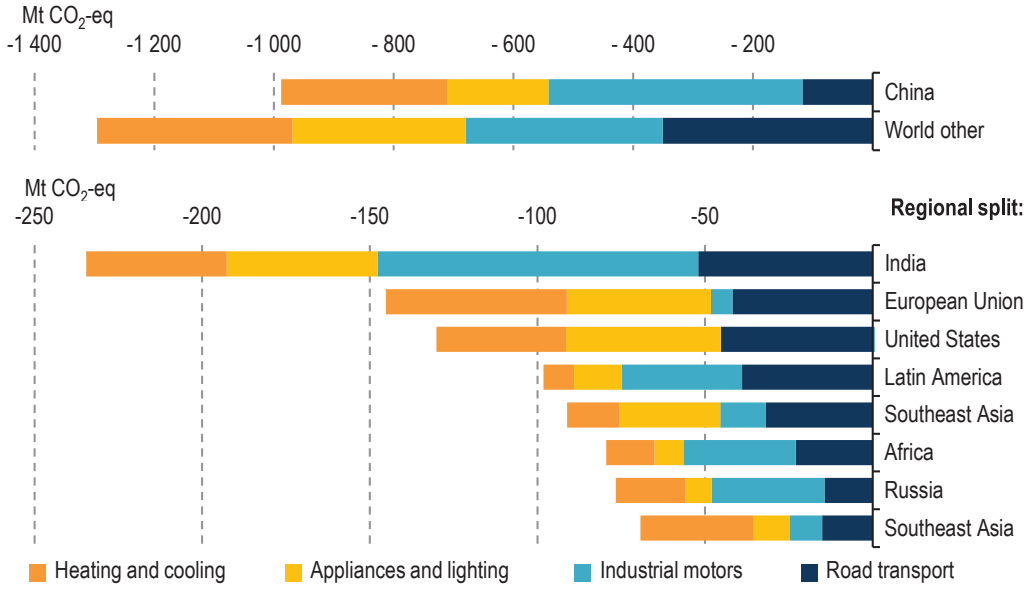
Figure 5.9

Energy-related GHG emissions reduction by energy efficiency measure and region in the Bridge Scenario relative to the INDC Scenario, 2030



Note: "World other" represents all countries except for China. TWh = terawatt-hour.

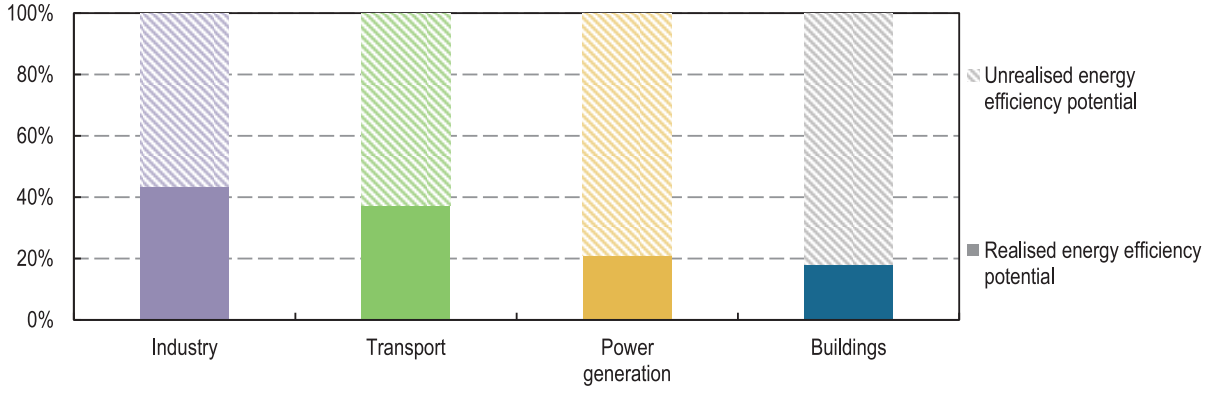
Source: IEA (2015c), Energy and Climate Change: World Energy Outlook Special Report.

temperature increase to 2° C, the IEA estimates that over USD 13 trillion in energy efficiency investments would be required over the next 20 years (IEA, 2014b). Each of these cumulative figures average well above USD 500 billion per year – an amount that far exceeds current estimates of annual spending on energy efficiency (e.g. USD 221 billion in the IEA *Energy Efficiency Market Report 2016*).

Despite its important role in reducing global CO_2 emissions, and the opportunities available for cost-effective energy efficiency deployment, two-thirds of potentially profitable energy efficiency investments over the next 20 years have been projected to remain untapped (Figure 5.10). There has been extensive analysis of the possible suite of policies and the appropriate price signals needed to mobilise this

Figure 5.10

Unrealised long-term energy efficiency economic potential based on NPS, 2011-35



Source: Adapted from IEA (2012), World Energy Outlook 2012.

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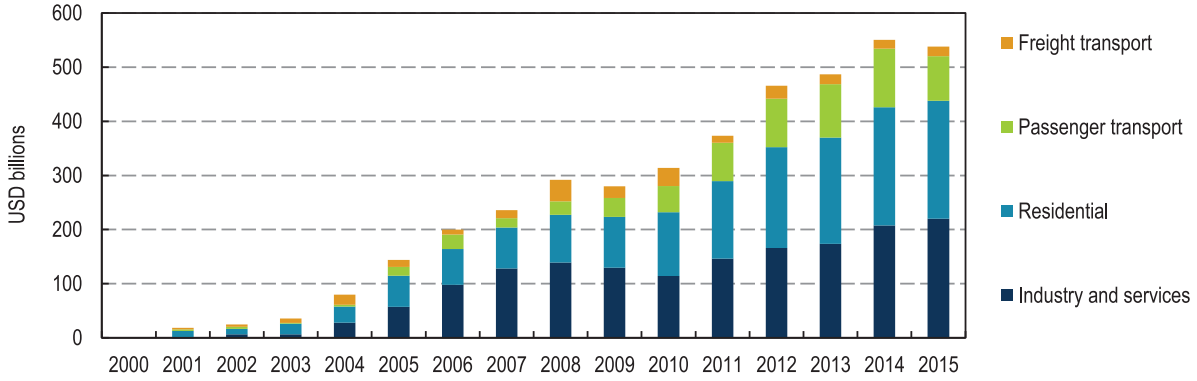
Figure 5.11

Annual avoided expenditures on end-use fuels in IEA member countries (by sector) from energy efficiency improvements since 2000



Source: IEA (2016b), Energy Efficiency Market Report 2016.

untapped potential;[14] growing political will to combat climate change can be expected to generate increased interest in deploying strong energy efficiency policies.

5.4.4 Generating interest in energy efficiency through non-climate benefits of energy efficiency

Energy efficiency delivers multiple benefits beyond GHG emission reductions, such as energy and financial savings, reduced pollution and improved health. These benefits are described in greater detail in the IEA's *Capturing the Multiple Benefits of Energy Efficiency* (IEA, 2015e).[15] Programmes to mitigate climate change can capitalise on these other benefits to promote energy efficiency and its attendant emissions reductions, rather than relying solely on climate-related ambitions.

Fuel savings from energy efficiency translate into avoided expenditure on energy. Energy efficiency improvements since 2000 have resulted in USD 540 billion in avoided expenditures on energy in 2015 for households, businesses and governments across the IEA's member countries (Figure 5.11). Cumulative savings in energy expenditures from these improvements total over USD 4 trillion over the 2001-15 period.

The benefits of energy efficiency extend well beyond financial savings to consumers. Energy efficiency can lead to improved energy security, lower energy system costs, lower fuel import expenditures, higher productivity for businesses, increased access to energy and improved health. For example, avoided fuel imports in 2015 for IEA member countries as a result of energy efficiency improvements since 2000 totalled 203 Mtoe (8.5 EJ), or 7% of total actual energy imports to these countries. Crude oil made up the largest share of these avoided imports at 42%, followed by natural gas at 35%. The European Union, the world's largest energy importing region, accounted for half of energy import savings at 101 Mtoe. Avoided imports in Japan were the next largest, at 61 Mtoe, then Korea at 25 Mtoe and the United States at 12 Mtoe. The impacts of energy efficiency on national trade deficits are significant. For example, Japan's expenditure of USD 128 billion on fuel imports in 2015 would have been USD 20 billion higher without energy efficiency improvements undertaken since 2000 (IEA, 2016b).

What is more, energy efficiency can have positive spill-over impacts on other climate-related issues, such as resilience. By reducing the need for energy infrastructure, including transmission and distribution facilities, energy efficiency can reduce the amount of energy assets exposed to extreme weather events, thereby boosting resilience of the energy system as a whole. Energy efficiency measures can also help reduce demand in a supply crisis caused by droughts affecting hydropower production or other climate-related events (for example, by lowering electricity demand through emergency distribution programmes to substitute compact fluorescent lamp [CFL] light bulbs for less efficient incandescent bulbs).

5.5 Structural changes and energy conservation can affect energy demand

5.5.1 Structural change

Structural change can also reduce energy demand. For example, as described in Section 5.2 above, structural modifications since 2000 have reduced TFC in IEA

14. See, for example, the IEA "25 Energy Efficiency Policy Recommendations" (update 2011) and policy descriptions in the Energy Efficiency Market Reports *from 2013 to 2016, as well as publications by the European Council for an Energy Efficient Economy (ECEEE), the American Council for an Energy-Efficient Economy (ACEEE) and others.*

15. Which highlights the positive impacts of energy efficiency on GDP, public budgets, health and well-being, industrial productivity and the utilities sector.

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member countries; the cumulative reduction over the 2000-15 period was about 26 EJ (offsetting in part the increase in TFC that should have resulted from increased activity [Figure 5.5]). As described in the *Energy Efficiency Market Report 2016*, this impact is due primarily to changes in the industry and services sector, in which the trend has been towards less energy-intensive sub-sectors on average across IEA countries. Certain structural changes can also increase consumption; for example, the structural effects of larger homes in the residential sector and a shift to more energy-intensive modes of transport are exerting upward pressure on energy consumption in these countries. However, taken in its entirety, the impact of structural change in IEA member countries since 2000 has been to reduce energy demand. This structural effect in IEA member countries has been small compared to the impact of energy efficiency improvements; for example, the structural effect in 2015 from changes since 2000 has been only 3%, compared with a 15% efficiency effect from energy efficiency improvements over the same period (Figure 5.5).

The structural change impact in China, as well as in various other large emerging economies (e.g. Brazil, India, Indonesia, Mexico and Thailand as a group) has been minimal (Figure 5.6). However, China's recently adopted 13th FYP illustrates the significant potential in this area, as the projected impact of proposed structural changes on energy demand is twice as large as the anticipated impact from energy efficiency improvements (Box 5.2). China's strategy in the 13th FYP of extensively using structural change measures to manage energy demand sets an interesting precedent for other countries, in particular for other emerging economies that are at or nearing a similar developmental stage. It may also prove an important additional approach to address GHG emissions while supporting continued economic growth and poverty alleviation.

As with energy efficiency improvements (see Figure 5.7 above), avoided primary energy demand and final fuel consumption resulting from shifts in structure in IEA member countries has reduced GHG emissions. For example,

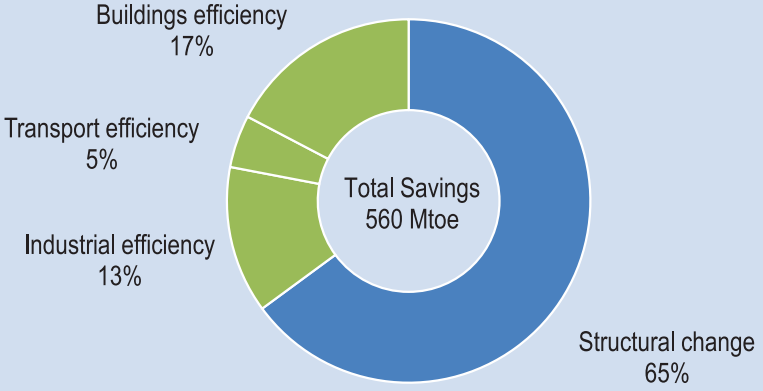
Box 5.2

Targeting structural change under China's 13th Five-Year Plan

For the first time, the 13th FYP sets a cap on energy consumption, at 3 500 Mtoe. In addition to this cap, China wants to reduce energy intensity to 44% below 2005 levels by 2020 – a 15% reduction between 2015 and 2020. China expects to meet its carbon and energy intensity targets largely by shifting the structure of its economy from manufacturing to services, by implementing energy efficiency measures, and by extending the emissions trading scheme to the entire country by 2017. The investment required to achieve the targets is estimated at USD 270 billion, which would save approximately 560 Mtoe annually by 2020 (Figure 5.12). The bulk of this energy savings will come from two shifts in the structure of the economy: one from industry to services, and the other within industry from high-intensity manufacturing (such as chemicals and steel) to lighter manufacturing (such as consumer products).

Figure 5.12

Contribution of structural change to energy savings under China's 13th FYP



Source: IEA (2016b), Energy Efficiency Market Report 2016, *and related IEA analysis.*

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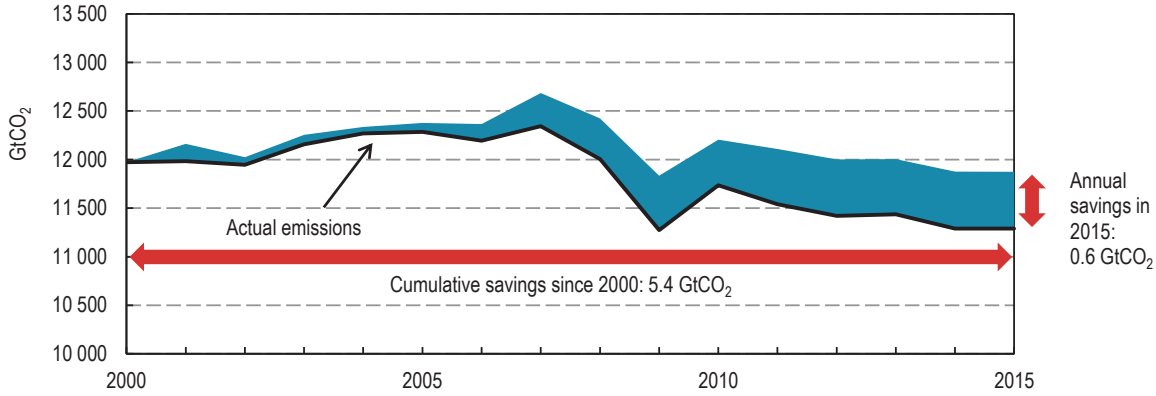
Figure 5.13

IEA member country emissions from fossil fuel combustion and end-use emissions savings from structural changes, 2000-15



Source: Adapted from IEA (2016b), Energy Efficiency Market Report 2016.

in 2015 the avoided emissions in IEA countries from structural change since 2000 was 0.6 $GtCO_2$ (compared with 1.6 $GtCO_2$ from energy efficiency improvements) and 5.4 $GtCO_2$ cumulatively over the 2000-15 period (Figure 5.13), greater than the annual emissions of China's power sector.

5.5.2 Energy conservation

Many countries have programmes that encourage consumers to reduce consumption by changing behaviour. An important element of the programmes described in this section is that they are not adopted as emergency measures to respond to an energy supply crisis, but rather are promoted as ways to ultimately improve standards of living.[16] As a result, they are designed to create a new "normal" with respect to energy consumption behaviour.

For example, Italy has a programme to encourage employees to take the stairs rather than the lift on certain days, which not only reduces energy consumption but improves worker health.[17] India's Bureau of Energy Efficiency has an advertising programme in which children teach parents and teachers how to save energy (e.g. opening the curtains and turning off the lights, etc.).[18] China's 13th FYP also includes various conservation elements, such as promoting behavioural change in terms of consumer purchases and lifestyle habits (IEA, 2016b). Japan's Super CoolBiz campaign encourages changes in clothing habits, to enable workers to consume less air conditioning during the summer months (IEA, 2011).

Avoid and shift programmes for transport can also encourage consumers to change their travel preferences and demand fewer energy services. For example, transport energy demand is "avoided" when consumers opt to walk to their workplace or are able to telework from their homes. "Shifting" involves moving to more energy-efficient transport modes, for instance by encouraging commuters to take mass transit rather than their personal cars. These programmes can require changes in physical infrastructure, such as creating bicycle lanes or siting housing sufficiently close to office space to enable commuters to walk or cycle, but the positive impacts of avoid and shift policies on emissions can be substantial (Figure 5.14).

*16. Numerous energy conservation programmes are designed to alter consumer behaviour in a supply shortage. For example, in 2015 Brazil launched a national campaign called "Lift that Flag" to raise consumer awareness about electricity use in response to the extreme drought which resulted in lower-cost hydropower generation being replaced with higher-cost thermal power generation. The result was higher electricity production costs and higher prices for consumers. The campaign was promoted by the national electricity regulator and the association of electricity distributors under the Energy Efficiency Programme (*Programa de Eficiência Energética das Concessionárias de Distribuição de Energia Elétrica*). Consumers receive a flag on a website, and in the monthly utility bill, that forecasts price changes, together with energy savings tips. The flag colours in the utility bills reflect the actual costs of electricity generation. If the flag is green, the electricity tariff will remain the same; yellow, the tariff will rise by BRL 2.50 per 100 kWh (without tax); and red, the tariff will rise by BRL 4.50 per 100 kWh (without tax). The expectation was that consumers would alter their consumption behaviour based on the tariff forecast illustrated by the flag system; see www2.aneel.gov.br/hotsite/energiaconsciente.*

17. Programme described at www.iea.org/media/workshops/2015/eeuevents/behave1103/S7LindaCifolelliEnea.pdf.

18. See presentation at www.youtube.com/watch?v=fJxpyqN1SPg.

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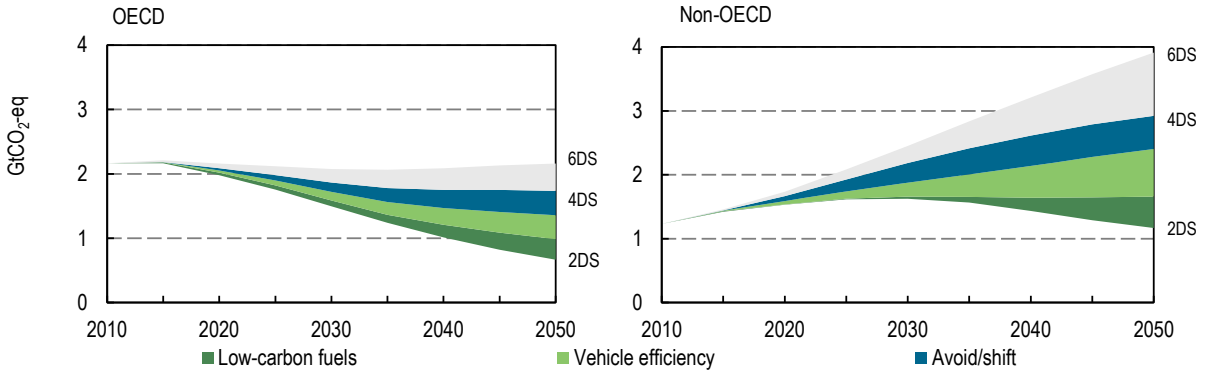
Figure 5.14

Avoid/shift policies can reduce emissions in urban areas



Source: IEA (2016a), Energy Technology Perspectives 2016.

5.6 Well below 2°C: An enhanced role for energy efficiency and other demand-side levers

As described in Chapter 1, achieving the well-below-2°C target will require even lower emissions than those modelled in the 2DS. Two sectors, industry and transport, are the dominant sources of emissions in the period to 2050 (i.e. during the energy transition), as well as in 2050 when the energy sector is largely decarbonised. These two sectors generate nearly 575 $GtCO_2$ through to 2050 (57% of emissions) and over 11.2 $GtCO_2$ in 2050 itself (over 76%). In seeking mechanisms to reduce emissions, the alternatives to energy efficiency in industry are currently limited.[19] In transport, expanding on the "avoid, shift and improve" actions of the 2DS (IEA, 2016a) should provide a basis for deeper emissions reductions. Although power is largely decarbonised by 2050 in the 2DS (with emissions dropping to 1.4 $GtCO_2$ that year), the sector still generates 29% of emissions to 2050. Although renewables and nuclear provide low-carbon supply options, reducing demand by raising energy efficiency in end-use sectors could help to further lower power sector emissions. In fact, reducing emissions to a level consistent with keeping temperature rise well below 2°C will likely require action across all sectors, including in buildings and agriculture where energy efficiency and other measures can help.

Limiting global average temperature increase to well below 2°C is also likely to require even greater decoupling of economic growth from energy consumption. It is highly probable that reducing emissions beyond the 2DS projections will require not only more aggressive reductions in the carbon intensity of the energy mix, but also in the level of energy consumption. For instance, a 10% drop in average energy demand over the 2DS period without adjustment to the carbon intensity generates a corresponding drop in total emissions, from 1 013 $GtCO_2$ to 912 $GtCO_2$ (Table 5.2).

Table 5.2

Interaction of demand and carbon intensity to limit temperature rise to below 2°C

	2DS (base case)	Impact of -10% demand with 2DS carbon intensity	Reduced carbon budget with 2DS demand	Reduced carbon budget with 2DS carbon intensity
Average TPED per year (EJ)	616	535	616	**486**
Weighted average energy intensity (PJ/2014 USD billion PPP)	3.2	2.9	3.2	**2.5**
Weighted average carbon intensity ($ktCO_2$/PJ)	43	43	**34**	43
Total emissions 2015-50 (Gt CO_2)	1013	**912**	800	800

Notes: $ktCO_2$/TJ = kilotonne of carbon dioxide per terajoule; Weighted averages are calculated by weighting either energy intensity or carbon intensity against energy demand in that year; GDP figures are from the 2DS; Assumptions are in italics, and variable factors in bold.

Source: Adapted from IEA (2016a), Energy Technology Perspectives 2016.

19. *For a fuller explanation, see the discussion on limited alternatives to carbon capture and storage (CCS) in industry in Chapter 2 of the IEA's* 20 years of Carbon Capture and Storage.

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As described in Section 5.1, the carbon intensity of the energy sector (as reflected in the ESCII) already drops by over 60% through 2050 in the 2DS (Figure 5.2). While further reductions are possible and will be needed to achieve the well-below-2°C target (see discussion in Chapter 4 for avenues to increase renewables contribution), achieving a very low carbon intensity of energy supply over the next two decades will be extremely challenging (particularly given the incumbent fossil fuel power plants discussed in Chapter 2). Efforts to address energy demand through energy efficiency, as well as through structural changes and other measures, will need to be enhanced to establish a new development path in which continued economic growth and poverty alleviation are further decoupled from energy demand, allowing for even lower energy emissions than in the 2DS.

5.7 Conclusion

Managing energy demand together with decarbonising the energy mix will remain keys to reducing energy sector emissions. Energy efficiency and its multiple benefits will be vital for the transition to a low-carbon energy sector and meeting global climate goals while supporting economic growth. Fortunately, much of the profitable energy efficiency potential is untapped, so countries have an opportunity to raise their ambitions for energy efficiency beyond the NDC pledges. Although this will require substantial political commitment and investment in the short term, it can be done with today's efficient technologies and implementation of best practices. Targeting more ambitious goals beyond 2°C will require even greater attention to energy efficiency investments and, more generally, to decoupling economic growth from energy consumption. Structural changes will likely gain in prominence in mitigation analysis with increasing climate ambition.

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Chapter 6 • Measures beyond pricing and regulation to motivate state-owned enterprises and private businesses

Energy sector decarbonisation measures have traditionally focused on carbon pricing mechanisms and other government regulations, but additional measures to reduce greenhouse gas (GHG) emissions are also being used with businesses to complement these more traditional policy approaches. Private sector complementary measures include voluntary actions, programmes and agreements, sometimes involving government. In the public sector, government influence on state-owned enterprises (SOEs) is exercised through a variety of channels. As the enlarged ambition of the Paris Agreement requires decarbonisation throughout the entire energy sector, the active participation of both SOEs and private sector businesses is essential. Effectively designed complementary measures can be pivotal in motivating businesses to undertake this necessary decarbonisation.

6.1 Introduction: Public and private businesses are key

Traditional climate policy discussions have focused on the implementation of a carbon price and other regulatory approaches to achieve stated climate goals.[1] In some countries, imposing a robust carbon price or stringent regulations has not been feasible due to institutional and/or political constraints. In others, the presence of state-owned enterprises (SOEs) in emitting industries may weaken the impact of a carbon price, partly because SOEs do not always respond to economic incentives the same way that profit-maximising private sector enterprises do. In practice, businesses and governments around the world – in The People's Republic of China (hereafter "China"), Japan, Europe, the United States and elsewhere – have been undertaking a range of complementary measures to reduce energy GHG emissions, beyond carbon pricing and regulations, and these deserve more attention. This chapter highlights two distinct sets of these complementary measures: (i) government action in wielding shareholder influence over SOEs, and (ii) voluntary measures pursued by private sector businesses that recognise the advantages of proactive engagement in the low-carbon transition. Given the depth of decarbonisation required, and the central role that all businesses (both private and publicly-owned) will need to play, strengthening complementary measures that target business engagement in emissions mitigation should be a priority.

6.2 SOEs: Big players in the low-carbon energy transition

Perhaps one of the most important – and overlooked – means by which governments promote decarbonisation action is through their capacity as public shareholders of state-owned energy and energy-intensive enterprises, as well as of low-carbon power sources, and their authority to direct or otherwise influence SOE actions. In China, India, Latin America, Europe and elsewhere, many electric utilities and fossil fuel producers, as well as large energy users, are state-owned. The decarbonisation actions of these SOEs have often been driven by formal and informal directives, and targeted financial and other incentives from their government shareholders – an avenue for advancing the low-carbon transition that merits greater attention and analysis.

6.2.1 SOEs are dominant in both high- and low-carbon energy

SOEs account for a significant share of the global energy sector. The International Energy Agency (IEA) estimates that SOEs own about 70% of oil and gas reserves (IEA, 2014a). In the electric power sector, which accounts for over 40% of energy sector carbon dioxide (CO_2) emissions globally, SOEs own about 42% of fossil fuel power generation capacity[2] (Figure 6.1). SOEs owned an even larger share of the new fossil fuel generation capacity commissioned in 2015 (54%), of which nearly three-quarters was coal (IEA, 2016a).

In many emerging economies, SOEs are responsible for a high share of energy sector emissions. In China, for example, half of energy sector CO_2 emissions are emitted by an electric power sector dominated by state-owned electricity producers and other energy companies.[3] In India, SOEs generate over 40% of total thermal electricity (which emits half of India's energy CO_2) and they also dominate in coal and oil production (OECD, 2015a).

Even in Organisation for Economic Co-operation and Development (OECD) member countries in which the

1. For example, see discussions on carbon pricing in the electricity sector in Chapter 3, and on regulatory actions in promoting renewables and energy efficiency in Chapters 4 and 5.

2. For capacity ownership estimates in this section, state ownership is defined as majority owned or controlled by governments

3. Emitting 4 405 $MtCO_2$ in 2013, China's power sector produced more CO_2 than the total GHG emissions of the 28-member European Union, which as a group is the world's third largest energy sector emitter. Half of total electricity generation capacity has been concentrated in five large SOEs (Wang and Chen, 2012).

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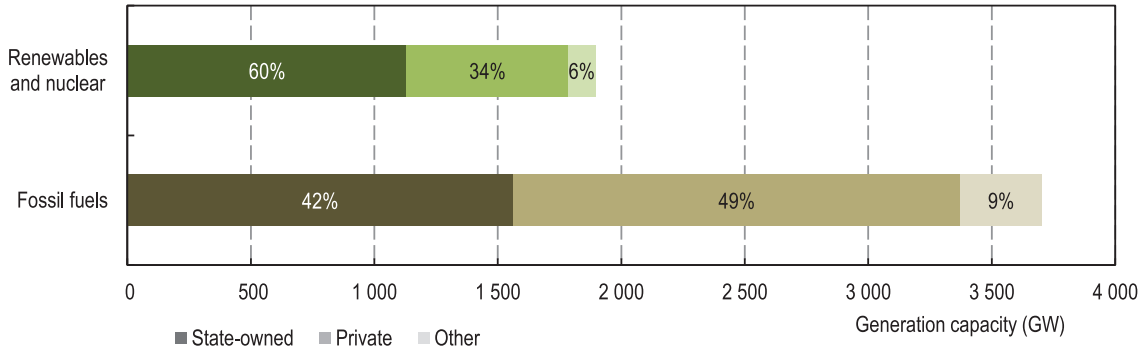
Figure 6.1

Ownership of global generation capacity (2012): Fossil fuels and renewables and nuclear



Notes: "Other" refers to auto-producers, communities and households; "Renewables" includes utility-scale renewables and distributed generation.

Source: IEA (2014a), World Energy Investment Outlook.

size of the state-owned sector has declined following decades of privatisation, SOEs remain influential actors in sectors of strategic importance, notably energy. Overall, the approximately USD 2.2 trillion of enterprise value in the SOE portfolios of OECD member and affiliated partner countries is concentrated in energy-intensive sectors such as oil and gas, electric power, transportation and extractive industries, as well as in finance (OECD, 2014). For example, France's electricity sector is dominated by *Électricité de France* (EDF), 85% owned by the French government; state-owned *Comisión Federal de Electricidad* (CFE) is the principal electric utility in Mexico, serving over one hundred million people; and Korea Electric Power Corporation (KEPCO), majority owned by the Korean government, produces 93% of the country's electricity.

Decarbonisation not only requires reduced investments in fossil fuel generation, but additional investments in clean energy technologies – once again, this is an area in which SOEs are active, and in certain cases are dominant. Globally, 60% of generation capacity in renewables and nuclear is state-owned (Figure 6.1). Of the new renewable and nuclear capacity commissioned in 2015, 45% was state-owned (IEA, 2016), with hydropower, wind, and nuclear accounting for over 90% of this capacity. In Brazil, China, Mexico and elsewhere, SOEs own the majority of large-scale hydropower generation, including the world's largest sites such as Three Gorges Dam and Itaipu. SOEs have also played important roles in the development of wind and solar power: Chinese SOEs, for example, have been major developers, spurred partly (in the case of wind) by government mandates requiring that a certain percentage of SOEs' new generating capacity come from this low-carbon technology.

State ownership is also important in other energy-intensive industries such as steel and cement, as well as other large energy consumers, such as municipal transit systems. From the Steel Authority of India Limited (SAIL) and the Emirates Steel Industries (ESI) to PT Semen Indonesia Tbk (SMGR) and China's Anhui Conch Cement Company, SOEs are important parties across industries that consume large quantities of energy or generate CO_2 emissions as part of their industrial processes (the case for cement). When SOE industry emissions are added to those of the energy supply sector, total GHG emissions attributed to SOEs grows; a selected group of 50 SOEs operating in power, oil and gas, iron and steel, and cement from around the world have emissions that total more than 4 gigatonnes of CO_2 ($GtCO_2$) in a year, which is higher than the energy-related emissions of every country other than China and the United States, and higher than that of the European Union and Japan combined (Figure 6.2).

The government is also present in the energy sector through publicly owned banks which provide financing to energy producers and users. Much of the financing for energy investments in emerging economies has come from public resources, and domestic state-owned financial institutions are likely to play an important role in financing low-carbon investments in the future (Benoit, 2012). These banks are major providers of finance for SOEs, but also for the private sector. Brazil's *Banco nacional do desenvolvimento* (BNDES), for example, provided over USD 6.5 billion in 2014 in financing for private and public sector borrowers for renewables and energy efficiency (OECD, 2015b).

Given the weight of SOEs in the energy sector (as emitters, operators of low-carbon generation, and financiers of investment), in particular in the emerging economies where much of the decarbonisation will need to take place,[4]

4. Under IEA 2°C Scenario (2DS) modelling, which relies primarily on cost-optimisation drivers, about 70% of the emissions reductions (relative to the reference case) take place in emerging and developing countries (IEA, 2016c). Although different allocations are possible under different burden-sharing approaches, the IEA has estimated that over 90% of future energy demand growth will occur under the business-as-usual case in these countries (IEA, 2014b); similarly, this is where the majority of emissions-reduction efforts take place under the IEA scenarios to limit global temperature increase.

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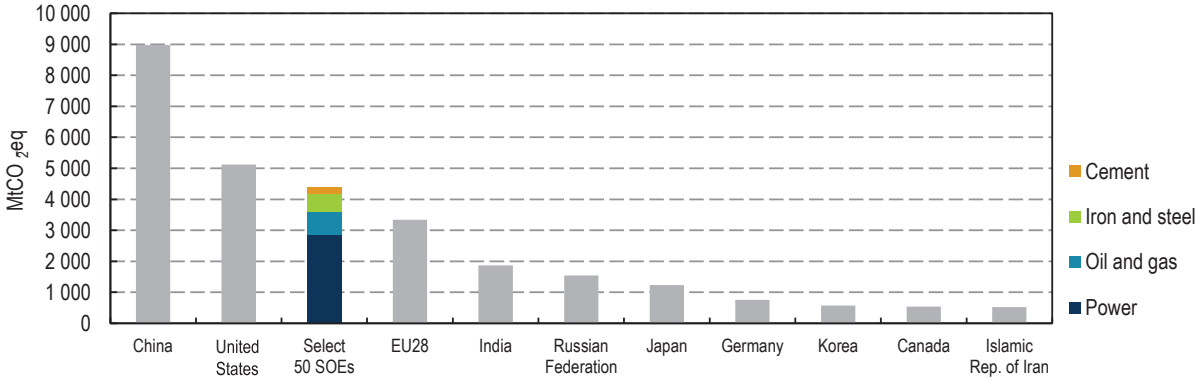
Figure 6.2

CO_2-equivalent emissions of 50 selected SOEs across various sectors and countries, compared with the top 10 emitting countries/regions



Note: Country emissions are CO_2 emissions from fuel combustion for 2013 (IEA, 2015).

Sources: Due to challenges with data collection of company-specific data in many non-listed SOEs, CO_2e emissions have been sourced from a variety of sources, including company annual reports, industry association reports, Carbon Disclosure Project country reports, CARMA database, F2000 database and others.

it is important to explore what incentives are best suited to prompt these actors to advance low-carbon objectives.

6.2.2 Channels for government influence over SOEs: Wielding public shareholder power

SOEs operate in a variety of sectors in many different country and market contexts, which can be distinguished by various criteria. For example, electricity, urban transport, airlines, cement and oil are very different businesses involving distinct products and particular commercial situations. While some SOEs produce internationally traded goods in vibrant markets, others produce for a dedicated domestic market. Some companies operate in regulated markets while others conduct business in more competitive ones. In certain cases, governments exercise close control or influence over their SOEs or the market in which they operate, while in others they remain distant. Although there is great variability among SOEs, certain common elements that affect SOEs to varying degrees are pertinent to efforts to reduce energy-related emissions.

Governments create or acquire companies to serve a variety of governmental objectives, typically to serve various economic and social development goals. As a result, SOEs are frequently motivated by factors beyond profit maximisation, such as promoting economic activity, energy security, social development, electricity access, employment and other strategic objectives. The context in which SOEs operate is generally characterised by greater political access than that experienced by private sector counterparts, softer budget constraints, and various financial support mechanisms including access to low-cost capital and subsidised input prices (Earnhart, Khanna and Lyon, 2014); they are often subject to greater political influence as a result of their ownership structure.

Governments, as sole or primary shareholders, may control or influence decarbonisation of SOEs through a variety of direct and indirect channels:

- Adopting and implementing clear, consistent and predictable policy directives to influence short-term operations (e.g. shifting electricity dispatch patterns to favour low-carbon sources) and long-term planning. These policies can be supported with informal dialogue to reinforce policy messages.
- Exercising authority to appoint (and change) senior management, which can strongly influence SOE action (balanced with the need to avoid excessive political interference).
- Leveraging cadre evaluation systems that target middle management (e.g. China's system for top-down bureaucratic personnel assessments) (Wang, 2013).
- Influencing investment patterns in specific energy technologies as a supplier/facilitator of funding for SOEs (including funding through state-owned financial institutions).
- Providing both formal and informal signals to SOEs, which are more likely than private enterprises to follow government signalling because of their shareholding structure (e.g. encouraging greater SOE engagement in fledgling emissions trading systems).
- Adopting regulations and pricing mechanisms that target the economy more broadly, including private sector actors. These are not typically viewed as SOE-specific, but at times the mode of adoption and implementation of this type of action may be influenced by government ownership of key companies (e.g. simplified consultations

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Box 6.1

China's use of SOEs to promote environmental reform

Since the 11th Five-Year Plan (2006-10), a shift in central leadership priorities has elevated environmental reform as key to growth and social stability. This has led to consolidation of market shares of large SOEs in energy and heavy industry, and increased state support of SOE investment in clean energy technologies and less-polluting industries. These measures have been implemented through ordered shutdowns of small, inefficient power and steel plants, as well as by selective investment approvals, credit controls and influence through the Chinese bureaucratic structure or nomenklatura system (Bersager and Korppoo, 2013). It is argued that accommodating SOE interests is an effective route to environmental reform in China, including meeting low-carbon objectives, as fewer market, legal and political reforms are required (Wang, 2015).

with industry). Governments may also encourage more active SOE participation in low-carbon mechanisms (e.g., encouraging trading activity under emissions trading systems).

The ability and willingness of governments to influence and direct the corporate actions of individual SOEs often depends on the market structure and prevailing business culture in which an SOE operates – notably, the extent to which the SOE is expected to operate in a profit-driven manner subject to market forces. SOEs in different sectors often have different social and economic mandates beyond profitability, particularly in the power sector, as electricity supply has both national economic and social dimensions. These factors can affect how a government decides to influence its SOEs.

The exercise of public shareholder power may in some circumstances influence SOEs more than the use of price signals alone, especially when the impact of financial drivers on these enterprises is diluted by non-financial mandates (such as expanding energy access and other national and regional development goals). Governments can also exercise shareholder power to encourage their SOEs to engage more in technology innovation and development programmes (for carbon capture and storage [CCS], for example[5]) and in international collaborative efforts.

Given the central role of SOEs in generating energy sector GHG emissions and their expected role in decarbonisation (reducing emissions and providing clean energy alternatives), further analysis of how complementary measures can influence SOE action is needed. These complementary measures are especially relevant because many SOEs – particularly in various emerging economies that are central to decarbonisation – operate in contexts in which government shareholder direction may outweigh liberalised market signals (Box 6.1). While there are common elements that characterise SOEs, their heterogeneity across sectors and countries requires a variegated approach.

5. SOEs own about one-third of the CCS projects under operation or under construction; see 20 Years of Carbon Capture and Storage, *Section 1.5 (IEA, 2016b).*

6.3 Voluntary actions, programmes and agreements involving private businesses

Businesses are increasingly recognising that commercial and profit interests can converge with decarbonisation efforts, and are therefore pursuing a variety of approaches to reduce energy use and emissions. These approaches fall into two main categories: 1) voluntary business programmes and agreements that involve government, and 2) actions that businesses are pursuing on their own or in collaboration with other businesses or civil society.[6]

6.3.1 Voluntary business programmes involving government (joint public-private approaches)

Governments and businesses are working together on voluntary programmes in several principal forms (Table 6.1). Government-sponsored voluntary programmes are indeed voluntary as there is no requirement for private entities to join and no penalty for non-participation. Participation is incentivised through government support such as rewards and recognition, technical assistance and training, and information sharing. Voluntary agreements as major complements to mandatory government regulations are also used. Participants in these agreements (widely used in Europe) can use them as a mode of partial compliance with a larger mandatory policy, for example to gain carbon tax or levy reductions, or exemptions from binding energy regulations.

Third, voluntary agreements as policy instruments in government mitigation plans involve a wide range of

6. To promote learning and disseminate information about these approaches, the IEA organised workshops in January and June 2015 that brought together speakers and participants from the private sector, government, non-governmental organisations (NGOs) and the research community. Agendas and workshop presentations available at: http://www.iea.org/workshops/industrybusiness-use-of-complementary-measures-for-decarbonisation.html and http://www.iea.org/workshops/technical-workshop-on-climate-energy-policy-approaches-for-the-industrial-sector.html.

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Table 6.1

Voluntary programmes and negotiated agreements

Type of programme/agreement	Examples	Defining attributes
Government-sponsored voluntary programmes	US EPA-led programmes (e.g. Energy Star, CHP Partnership)	Public agencies define eligibility, rewards, obligations, etc.; low-cost incentives encourage participation.
Voluntary agreements as major complements to mandatory government regulations	UK Climate Change Agreements; Dutch Long-Term Agreements	Terms of agreement are negotiated; a mix of positive incentives for participation and penalties for non-compliance is used.
Voluntary agreements as policy instruments in government mitigation plans	Japanese Voluntary Action Plan (Keidanren); Chinese Taipei voluntary GHG reduction agreements	Terms of agreement are negotiated; consultation between government and industry associations is ongoing.

Source: Adapted from Somanthan et al. (2014), "National and sub-national policies and institutions".

companies and industries, and have been employed as a major policy instrument (as in Japan and Taiwan). Moreover, governments and businesses have established separate but complementary programmes designed to operate in tandem to create synergies, for example between government support for research and development (R&D) and private sector innovation.[7]

What motivates this action and approach?

Businesses and governments may adopt voluntary programmes and agreements for distinct reasons. By participating in government-sponsored voluntary programmes, businesses may benefit from technical support, information-sharing and peer learning, as well as public recognition for measures undertaken. Industry association agreements can help raise the profile of leading companies within a sector, and can enable businesses to play a more active role in determining the scope and direction of their decarbonisation actions. Such programmes and agreements may also defer mandatory government regulation, providing an avenue for businesses to participate in the design of future regulation. Governments may see such partnerships as a way to achieve results quickly, keep administrative costs low and gather useful data, and more generally to advance their objectives when regulatory or pricing mechanisms are not feasible. Furthermore, these partnerships may build regulatory capacity and trust, which can benefit both governments and businesses.

How effective have these measures been?

Assessments of the effectiveness of voluntary programmes and agreements show mixed results. One set of selected voluntary programmes in the United States, Europe and Japan was found to have reduced energy use or GHG emissions between 0% and 10% over the programme period (Morgenstern and Pizer, 2007). Other international experience with voluntary programmes has shown them to be an innovative and effective means to improve energy efficiency and reduce emissions, particularly programmes that combine participation incentives and non-compliance penalties with the prospect of future regulation or taxation (Price, 2005). In general, the prospect of regulatory action can be important in spurring programme participation and subsequent compliance (in some cases, voluntary programmes are developed with the potential for firmer government regulation if the voluntary approach is unsuccessful). Other elements that increase the likelihood of success are the presence of capable and influential industry associations, government involvement in implementation review, and accompanying measures such as technical and financial assistance for energy audits and equipment (Somanthan et al., 2014). In some societies, a tradition of close co-operation between government and industry provides a foundation upon which to build voluntary programmes, and peer pressure among companies can increase programme effectiveness. This, for example, is the case in Japan (Box 6.2).

6.3.2 Individual and collaborative action by businesses without government involvement

Businesses are increasingly pursuing emissions reduction actions on their own initiative (Table 6.2). These programmes vary in scope, from measuring and reporting GHG emissions to setting actual emissions reduction goals. Some actions are pursued by individual businesses acting alone, while others are accomplished through business coalitions or partnerships with NGOs that encourage companies to commit to climate-friendly initiatives. Many businesses target their own operational emissions, while others may promote decarbonisation along their supply chains.[8] In

7. The government Mission Innovation programme and the private sector Breakthrough Energy Coalition, announced at COP21 are examples of this type of public-private partnership; see http://www.breakthroughenergycoalition.com/en/index.html.

8. Emissions can be classified as: (i) direct emissions from business operations (Scope 1); (ii) indirect emissions from purchased electricity and heat (Scope 2); and (iii) other indirect emissions from upstream materials/fuel production and downstream end uses (Scope 3).

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Box 6.2

Japan's voluntary action plan: Bringing industry and government together

The Keidanren Voluntary Action Plan (VAP) was initiated in 1997 by the Japan Business Federation (Keidanren) and played an important role in Japan's strategy to meet its Kyoto Protocol commitments. Under the VAP, industry-wide targets were set by the respective industry associations, in consultation with industry sector companies and government, and collaboration and peer pressure were used to motivate action. A recent evaluation found that while some industries' energy intensity and consumption increased, CO_2 emissions per unit of output were 14% below the 1990 level during the first Kyoto commitment period (2008-12) (Tezuka, 2015). It highlighted the importance of effective target-setting and evaluation mechanisms – specifically through the Plan-Do-Check-Action (PDCA) cycle – in reducing emissions. This process led 29 of 61 participating industry associations to strengthen their targets in 2012. In a follow-on development, the Keidanren Commitment to a Low-Carbon Society was initiated, covering 80% of emissions from industrial and energy conversion sectors and establishing industry-specific CO_2 emissions reduction targets for 2020. In 2015, Japan indicated in its national contribution to the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement that "promotion and enhancement of industries' action plans towards a low-carbon society" are measures that underpin its national GHG emissions reduction target for 2030.

Table 6.2

Voluntary actions by businesses

	Actions and examples
Operational emissions	Measuring and reporting emissions (e.g. CDP, formerly the "Carbon Disclosure Project")
	Tracking performance (e.g. the "climate strategy" component of Dow Jones Sustainability Index)
	Setting targets: reducing absolute emissions; reducing emissions intensity; renewable energy targets (e.g. RE100 pledge to use 100% renewable energy)
	Developing strategies and tools: internal carbon price (e.g. Shell's USD 40/tonne of CO_2 project screening value)
	Implementing actions: energy efficiency, fuel switching, recycling and renewable energy (e.g. BMW's use of solar photovoltaic [PV], biogas and hydrogen fuel cells)
Supply chain	Measuring and reporting supply chain emissions (e.g. GHG Protocol Product and Supply Chain Initiative)
	Setting targets: reducing supply chain emissions (e.g. Diageo reducing supply chain emissions 30% by 2020)
Investments	Fossil fuel divestment and positive investment in green companies and projects (e.g. AXA selling EUR 500 million of coal assets and tripling green investments to EUR 3 billion by 2020)

some sectors, such as retail, upstream supply sources and downstream end uses can account for the bulk of a firm's emissions; influencing partners along the supply chain can therefore achieve larger emissions reductions than simply focusing on direct emissions. Business collaboration can be especially important for R&D of low-carbon technologies. For example, the European Cement Research Academy (ECRA), established by the European cement industry in 2003 exclusively with industry funding, researches low-carbon cement-making technologies.

What motivates action?

Voluntary actions appear to be driven by two primary motives: increasing competitiveness and satisfying stakeholder pressures (Boiral, 2006). Individual companies can improve competitiveness through cost-saving reductions in energy use and emissions, which can in turn reveal further operational improvements and support innovation. Anticipating future environmental regulation can also improve competitiveness (e.g. through the growing use by major corporations of an internal carbon price). Improved climate action can strengthen a company's appeal to customers or other partners, and stakeholders such as investors and insurance companies are looking increasingly at climate response as an indicator of good governance and risk management (Box 6.3). Outside the supply chain, think tanks and NGOs motivate change by translating science and policy into actionable business language and framing it within business interests.

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Box 6.3

Investors can influence corporate action on climate change

Investors are increasingly aware of – and concerned about – exposure to climate risks. Investor groups such as the United Nations (UN)-supported Principles for Responsible Investment (PRI) initiative, with nearly 1 400 signatories managing USD 59 trillion in assets, are driving action on climate change. In 2014, the PRI initiated the Montreal Carbon Pledge under which signatories commit to conduct and disclose portfolio carbon footprints annually. Beyond voluntary initiatives to track carbon footprints, policy makers can encourage other supportive actions from investors, including incorporating climate change into risk analysis, active share ownership and provision of low-carbon financing. Investors are also keen to understand the effect, if any, of corporate carbon performance on financial performance and firm value. A recent meta-analysis of over 20 corporate carbon and financial performance studies found that corporate carbon performance is on average positively related to financial performance (Busch, 2015).

How effective are voluntary actions?

Few empirical studies have analysed the effectiveness of voluntary actions at an aggregate (multi-business) level. A recent analysis of 433 companies reporting to the CDP found no statistically significant evidence linking reported carbon management practices with declines in absolute carbon emissions (Doda et al., 2015). Earlier studies investigating impacts at the sectoral level are mixed. For example, a study of retailers in the United Kingdom, the United States and Japan found that while unilateral commitments can deliver significant reductions in energy use and emissions intensity, delivering absolute emissions reductions is extremely difficult without strong incentives or regulation (Sullivan and Gouldson, 2013). More analysis in this area is required to better assess the impact of these programmes.

Evaluating the incremental impact that voluntary corporate actions have on emissions is difficult because of numerous methodological challenges (including a lack of high-quality data) and uncertainty over how to measure their effectiveness. While the number of voluntary disclosures (and thus volume of data) is increasing, disclosure programmes typically have limited quality assurance and auditing mechanisms. Results from in-depth interviews of large emitters in Canada suggests that reported emissions tend to be underestimated, and that the lack of transparency can undermine the legitimacy of studies that use secondary data on corporate GHG emissions (Talbot and Boiral, 2013). A lack of high-quality data inevitably limits the time periods studied, sample size and scope (i.e. Scope 3 emissions are not examined).

6.4 Conclusions

Various complementary measures to encourage decarbonisation actions by businesses are being actively pursued in numerous country, market and institutional contexts as part of the modern policy mix for energy sector decarbonisation. As strong action is already needed to limit temperature increase to 2°C, the even greater ambition of the Paris Agreement makes it necessary to expand the policy tool kit to increase the engagement of both private and public sector businesses in action to reduce energy sector emissions. Strengthening complementary measures that engage businesses can increase emissions mitigation by encouraging fewer high-carbon activities as well as greater investment in renewables and other low-carbon technologies.

SOEs are important to decarbonisation efforts, in particular because of their strong presence in the energy sectors of many emerging economies, where future energy demand and energy infrastructure growth are expected to be strongest. Because a relatively small number of SOEs worldwide are responsible for a significant share of global GHG emissions, opportunities for targeted leverage are great. Further exploration of options available for governments to exert public shareholder influence over SOEs will enrich future dialogue on climate change mitigation. For traditional private sector businesses, recognising that commercial and profit interests can converge with decarbonisation efforts will help to drive voluntary actions and programmes. Ultimately, the impact and influence of complementary measures (internal economic instruments, disclosure standards, self-regulation, etc.) depend on the financial incentives for action – in other words, the "business case" for decarbonisation. More research on improved specificity, meaningful incentives, proper monitoring, and suitability within the existing policy and regulatory mix could help increase the effectiveness of complementary measures.

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Chapter 7 • Enhancing energy sector resilience to climate change: Government action and mobilising investment

As temperature and atmospheric carbon dioxide (CO_2) concentrations increase, adapting to some level of climate change becomes unavoidable, irrespective of the success in meeting the ambitious "well-below-2°C" target of the Paris Agreement. This inevitable climate change poses clear challenges for the energy sector – a sector which provides the essential energy services that underpin human welfare and economic development. Improving energy sector resilience is therefore vital for businesses, households and governments. Governments have an important role to play in stimulating private sector action through policies, as well as in providing information and services to support adaptive measures and in managing their own assets. Investment in resilience-building measures is critical; the public and private sectors, often in partnership, are developing an expanding suite of instruments through which to provide financing.

7.1 Introduction: Climate change poses risks for the energy sector

Climate change poses clear challenges for the energy sector. Beyond the need to reduce emissions, the energy sector also faces increasing risks from a wide range of climate change impacts which pose a serious threat to energy security.[1] Although the energy sector already undertakes a number of measures to mitigate short-term supply risks[2] (e.g. developing emergency response systems, diversifying energy sources, and implementing energy and water efficiency measures), climate change is likely to compound these risks over both the short and long term.

Recognising the challenges present at even low levels of temperature increase, the Paris Agreement includes objectives to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change,[3] in addition to keeping temperature rise "well below 2°C".[4] Country adaptation actions will be monitored, reported and strengthened through five-year "cycles of action". This framework recognises the need for all countries to engage in adaptation and resilience-building, and encourages increasingly ambitious adaptation actions over time.

Climate change not only impacts the operation of the energy sector and its actors, but also society at large, which relies on the delivery of energy services. This includes industry, commercial operations, hospitals, schools and other social services, and individual households that rely on them. Energy has helped to fuel accelerated economic and social development around the world over the past several decades. Enhancing energy sector resilience not only protects energy companies, but also the economies and populations that rely upon the energy services they provide. Governments therefore have a compelling interest in enhancing the resilience of the energy sector.

Even if action under the Paris Agreement succeeds in limiting global temperature increase to well below 2°C, the world has already committed to a certain degree of climate change as a result of historical emissions. Indeed, with current warming having reached around 1°C from pre-industrial levels, climate change impacts are already causing disruptions to the energy sector. Enhancing the resilience (i.e. adaptive capacity) of the energy sector is needed to address the threats that climate change will continue to pose for energy service delivery to households and businesses. Improving resilience means not only increasing the ability of infrastructure and systems to withstand disruptions ("robustness"), but also recognising that some disruptions will be unavoidable and taking action to manage these disruptions, or 'weather the storm' ("resourcefulness"), as well as hastening recovery ("recovery") (Box 7.1).

This chapter begins by describing the impacts of climate change on the energy sector. It then outlines the various responses that can be taken to enhance resilience, underscoring the central role that governments play through: (i) developing policy instruments that drive energy companies to take climate change into consideration and build resilience into their assets; (ii) providing information, capacity, and emergency response and other services; and (iii) building resilience in their own (state-owned) energy assets. Enhancing resilience will require investment: the public and private sector are working, at times in partnership, to expand the array of financial instruments available to fund these investments. This is discussed in the last section.

7.2 Impacts of climate change on the energy sector

Climate change affects all components of the energy value chain: primary production; transformation; transportation, transmission, storage, and distribution; and energy demand.

1. *The IEA defines energy security as the "uninterrupted availability of energy sources at an affordable price".*
2. *Such as extreme weather events, supply or technical disruptions, and malicious cyber or terrorist attacks.*
3. *Article 7 of the Paris Agreement.*
4. *See discussion in Chapter 1.*

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Box 7.1

Action across the resilience value chain: Robustness, resourcefulness and recovery

Resilience of the energy sector refers to the capacity of the energy system and its components to cope with a hazardous event or trend, to respond in ways that maintain its essential functions, identity and structure as well as its capacity for adaptation, learning and transformation.

It encompasses the following concepts:

- *Robustness: the ability of an energy system to withstand disruptions (such as extreme weather) as well as gradual changes (e.g. sea level rise) and continue operating.*
- *Resourcefulness: the ability to effectively manage operations during disruptions.*
- *Recovery: the ability to restore operations to desired performance levels following a disruption.*

Adaptation of an energy system to climate change refers to the adjustment of all components of the energy system to actual or expected climate changes and their effects.

Sources: Adapted from IPCC (2014), Climate Change 2014: Impacts, Adaptation, and Vulnerability, and NARUC (2013), "Resilience in regulated utilities".

As a result, action to improve resilience is needed across a wide range of energy sector activities. Furthermore, the energy sector is changing, in part driven by the climate change mitigation agenda. Effective resilience action will thus need to anticipate the energy sector of the future: one in which the increased uptake of low-carbon technologies and changing demand patterns present new resilience risks and opportunities.

7.2.1 Climate change impacts on the energy value chain

A wide range of climate change impacts could affect the basic components of the energy sector: production, transformation, transportation and storage, and demand (Table 7.1). These impacts vary by region and within regions, with risks also depending on an area's vulnerability to physical exposure to hazards.[5]

Climate and weather-related changes affect the physical nature and extraction of energy resources, on which the energy system fundamentally depends. For instance, because water is an important input in some fossil fuel extraction (e.g. hydraulic fracturing), increased water stress can constrain these processes. Climate change also affects the transformation of energy resources into secondary energy carriers. These impacts are particularly important because much of the related infrastructure (e.g. power plants, refineries) is costly and long-lived, with expected lifetimes of many decades. Increased occurrence of extreme weather events, climate-related hazards (e.g. landslides, wildfires) and rising sea levels place a wide range of fossil and non-fossil fuel supply infrastructure at risk. Changes in water availability, distribution and temperature, due in part to climate change, place stress on electricity generation and other energy transformation processes.

In contrast to energy extraction and processing infrastructure, which tends to be geographically centralised, the network of infrastructure to transport energy products is diffuse and far-reaching, affecting its exposure and risk profile. The transmission, storage and distribution (TS&D) infrastructure of power systems is vulnerable to various climate-related events, such as high winds, falling trees, storm surges, floods, and increased snow and ice accumulation; these are some of the most significant threats to electricity security. In the United States, weather-related disturbances to the power sector are rising, with the annual cost to the economy estimated at between USD 18 billion and USD 70 billion (Campbell, 2012; Executive Office of the President, 2013).

The breadth of climate change impacts facing the energy sector calls for a correspondingly large range of response measures. Table 7.2 provides examples of technological and management measures that can be taken in different energy sub-sectors to adapt to climate change impacts.

Climate change affects not only energy supply, but energy demand. IEA analysis suggests, for example, that rising average temperatures will decrease global heating demand but increase cooling demand, altering seasonal demand patterns. For instance, by 2050 energy demand for space

5. Climate change risk is a function of: the potential occurrence of a hazardous event; exposure to the hazard; and vulnerability (coping capacity). As an illustration, to reduce the icing risk of wind turbines, siting wind farms in low-humidity areas in cold climates reduces exposure to physical conditions conducive to icing. Meanwhile, installing heating mechanisms within the blades reduces vulnerability of the turbines to the hazard.

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Table 7.1

Climate change affects all parts of the energy system

	Impact
Primary energy production	• Melting of permafrost and sea ice improves access to oil and gas reserves, but also compromises land stability and damages infrastructure. • Increased risk of wildfires affects oil production (e.g. Fort McMurray wildfires in Alberta, Canada). • Water scarcity poses constraints on shale gas or tight gas developments, secondary and tertiary (enhanced) oil recovery approaches, and biofuel production. • Heavy rains increase moisture content (and decrease quality) of stockpiled coal surface mines. • Drought, heavy precipitation, and reduced snowpack affect hydropower production. • Shifts and increased variability of wind speed and direction affect wind power production. • Changes in cloud cover and water vapour affect solar energy (photovoltaic [PV], concentrated solar power [CSP], solar heating).
Energy transformation	• Sea level rise and storm activity increase flood risk for coastal infrastructure (e.g. refineries, nuclear power plants). • Wind, hail and extreme precipitation increase damage to solar PV, flat plate collectors in solar thermal systems, on- and off-shore wind turbines, and hydroelectric dams. • Extreme heat reduces efficiency of solar PV cells and thermal conversion processes, and cooling efficiency in thermal power plants. • Lower reservoir levels reduce water-to-energy conversion in hydropower production. • Increased water temperatures constrains thermal power generation by reducing plant cooling efficiency and increasing cooling water demand. • Water scarcity constrains CSP and carbon capture and storage (CCS) technologies.
Transportation, transmission, storage and distribution	• Higher temperatures increase transmission losses and reduce overall transmission efficiency. • Higher temperatures reduce viscosity of transported fuels. • Extreme events (e.g. flooding, landslides), erosion and melting permafrost cause pipeline damage. • Melting sea ice opens up new shipping routes (e.g. Bering Strait and Northwest Passage). • Freeze/thaw cycles and extreme weather cause damage to paved roads; extreme precipitation increases wash-outs for unpaved roads and low-lying coastal routes.
Energy demand	• Rising air temperatures increase cooling demand (mostly electricity) in summer months and reduce heating demand (heating fuels, electricity) in winter months. • Net changes occur in energy demand, depending on geographic location and access to energy technologies such as air conditioning. • Warming trends change attractiveness of tourist destinations and tourism-related energy demand.

heating is expected to increase by only 12% from the 2010 level, compared with 28% in the absence of climate change. In this same scenario, however, global space cooling demand is projected to rise by 220%, compared with 175% (IEA, 2013). Different regions will experience different climatic changes, and different impacts on local demand. The uncertainty and variety of these impacts poses its own set of challenges for energy management and planning.

7.2.2 Enhancing resilience in the face of a changing energy sector

Not only is it necessary to make today's energy system more resilient to current climate changes, but action is needed to protect tomorrow's system against future climate change impacts – impacts that are anticipated to be larger than today's as global temperatures rise into the future. Furthermore, as the energy sector undergoes the low-carbon energy transition, new and shifting technologies

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Table 7.2

A range of adaptive measures can be taken across energy sub-sectors

Energy sub-sector	Technology and structural measures	Management and siting measures
Thermal and nuclear power	Adopt alternative cooling technologies such as closed loop and dry cooling	Site plants based on water access and away from high-risk areas Use alternative water sources, including grey water or seawater
Hydropower	Enhance reservoir capacity Improve design of spillways to manage changing water levels	Modify management procedures for water storage Site plants based on projections of hydrological conditions Enhance debris removal
Solar energy	Modify surface material for PV panels for improved light diffusion Adapt material durability to extreme wind and precipitation	Site solar PV panels based on projected changes in cloud cover and air temperature Site CSP based on water availability Adjust design of buildings with passive and active solar heating
Wind power	Alter turbine design to withstand high winds Improve material durability	Site turbines based on projected changes in wind speed and direction, and exposure to extreme weather events
Transportation, transmission and distribution (T&D)	Increase T&D line capacity and ability to withstand higher snow and ice load Modify pipeline materials to be waterproof and able to withstand freeze-thaw cycles	Place T&D lines underground Improve vegetation management around wires Site pipelines away from areas of high flood risk, extreme freeze-thaw cycles, and melting permafrost

Sources: Adapted from IPCC (2014), Climate Change 2014: Impacts, Adaptation, and Vulnerability, *and IHA (2015), "What does climate resilience mean for the hydropower sector?".*

and processes will present emerging opportunities and challenges for both supply and demand:

- Increased shares of renewable energy in the electricity mix could increase risk associated with supply intermittency by introducing variability and uncertainty of energy supply. However, distributed and diversified generation can balance supply interruptions and increase a system's ability to buffer and localise outages.
- Higher uptake of certain low-carbon technologies (e.g. CCS, CSP, geothermal energy, nuclear power) may increase water demand for energy production. Other renewable energy types, such as solar PV and wind, tend to demand less water.
- Improved demand-side management and energy efficiency may reduce exposure to supply disruptions and water constraints. However, new systems and infrastructure (e.g. storage, smart grids) may face new risks.
- Increased electrification is expected to increase electricity demand and alter demand patterns, potentially creating risks for new electricity generation and T&D infrastructure, as well as demand-side infrastructure such as vehicle charging stations and electric rail.[6]

The IEA also projects that all of the increase in energy demand over the next two decades will occur in emerging and developing countries, notably in Asia, thus shifting the geography of energy demand and related infrastructure development.[7] Moreover, improvements in energy efficiency, increased electrification, and shifts to less carbon-intensive fossil fuels will also shift demand patterns.

Both demand and supply shifts will drive changes to both the geographical distribution and the components of energy sector infrastructure. Accordingly, resilience considerations must be made on an ever-changing system. The complexity of this effort is striking, but given the centrality of energy

6. These examples also illustrate the overlap of adaptation and mitigation actions. Traditional greenhouse gas (GHG) mitigation activities, such as enhancing energy efficiency, increasing market shares of decentralised renewable energy, and deploying technologies such as energy storage and smart girds, can contribute to a more flexible, responsive, less vulnerable, and ultimately more climate-resilient energy system.

7. World Energy Outlook (2015) *New Policies Scenario to 2040.*

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in supporting economic and social development, the need is compelling.

7.3 Governments have a central role in resilience-building

Enhancing resilience to climate change impacts requires action by energy asset owners and operators, investors and insurers, to redirect investment, develop and deploy climate-resilient technologies, and incorporate future climate change impacts into business models. Private sector businesses and households are central to this effort, but the government has critical catalytic and operational functions. Key tasks for governments will be to: (i) adopt policies to catalyse private sector action; (ii) supply climate information, build capacity, and support emergency preparedness and response; and (iii) build resilience into their own energy assets. Governments also have a role in generating and mobilising finance for resilience-building activities in partnership with the private sector (Figure 7.1).

7.3.1 Catalysing private sector action through sound policies

A critical role of governments in resilience-building is to design and implement policies to drive industry, business and household investments and adaptive practices. Examples include guidelines and standards for technology adoption, operating requirements, project assessment requirements, and guidelines for climate risk assessment and disclosure. Energy regulators and commissions, as regulators of energy prices and supply, have a distinct role in setting requirements for resilience-related activities, including modalities to strengthen security of supply and the extent to which electricity rates can fund resilience-building investments.

Standards, guidelines and building codes

Governments can establish a regulatory environment conducive to resilience-building by developing guidelines and standards for infrastructure design and siting, updating building codes to account for future climatic changes, facilitating reporting of climate change risks by energy companies, and developing standards for reliability of supply for energy operators. Table 7.3 provides examples of different types of standards and guidelines that can be applied to drive various adaptive measures across the energy sector.

Building codes typically cover a range of specifications for equipment and siting, and are especially valuable in setting minimum standards for the building stock, given its costly and long-lived nature. Conventional practice is for building codes to be based on historical climate information. These codes should be regularly updated to incorporate projected changes in climate, including patterns of precipitation and extreme weather events. More stringent energy and water efficiency requirements in updated building codes support resilience efforts, as well as mitigation action.

For example, the American Society of Civil Engineers (ASCE) *Flood Resistant Design and Construction* standards define requirements for buildings that include electricity infrastructure, relating to building performance, the use of materials, and siting requirements to minimise flooding risk (FEMA, 2015). In Canada, guidelines for adapting infrastructure in the Arctic region have been developed by the Standards Council of Canada through the Northern Infrastructure Standardization Initiative. These guidelines, which apply to both new and existing infrastructure, describe standards for buildings, building foundations and drainage systems that can accommodate changing conditions, such as permafrost melt and changing snow load risk. The European Committee for Standardization

Figure 7.1

Governments have a central role in enhancing energy sector resilience

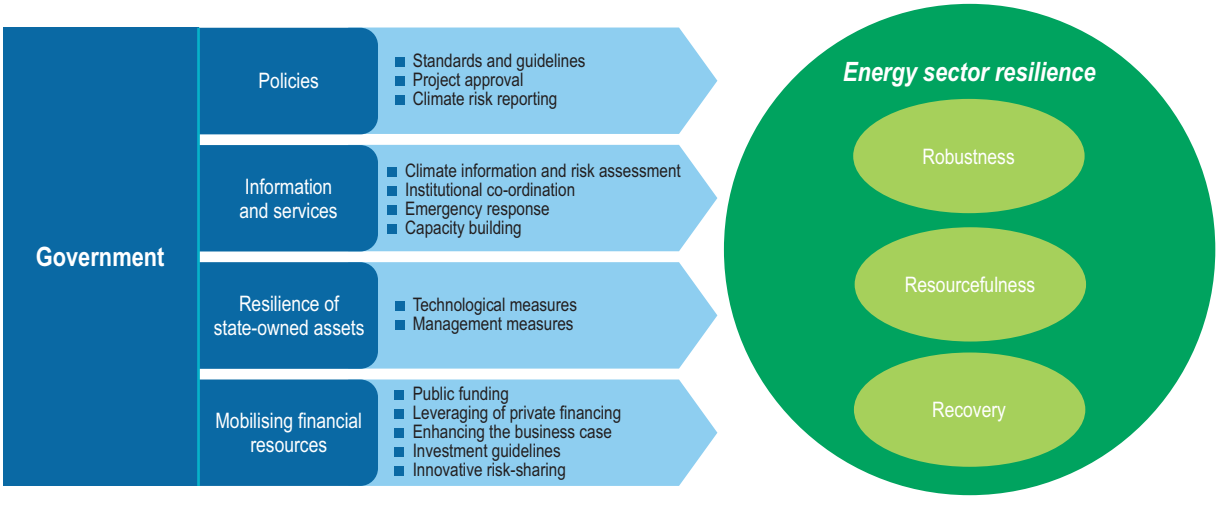

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Table 7.3

Standards and guidelines for enhancing resilience

Type	Examples
Asset hardening	• Require sturdier and more fire-resistant materials for power transmission poles and increase the minimum weight load of transmission lines.* • Adjust thermal rating and apply dynamic thermal rating systems to transmission and distribution lines.** • Adjust oil and gas pipeline durability requirements in coastal and permafrost areas. • Apply certain specific power grid technologies (such as flexible AC transmission or static VAR compensation systems) to balance voltage to better accommodate intermittent renewable power generation.
Water and energy efficiency	• Increase the stringency of water cooling standards for thermal power plants.*** • Require enhancement of wastewater reuse and reclamation for facilities in water-stressed areas extracting and processing oil and gas. • Improve energy efficiency building and equipment standards.**** • Introduce smart grid deployment and utilisation requirements (EU Directive 2009/72/EC described below).
Site design and infrastructure location	• Enhance flood risk standards for infrastructure, including minimum elevation and siting requirements for facilities and equipment (FEMA, 2015). • Require transmission and distribution wires to be buried underground. • Require use of water-resistant materials and design to facilitate escape of water.

*Notes: * A technical committee recommended increasing ice and wind loads of transmission infrastructure following the 1998 Quebec ice storm in Canada. ** Thermal rating determines the maximum voltage that can be transferred without overheating. With increasing ambient temperatures, these ratings may need to be adjusted downward. *** One example is the 2014 US EPA Cooling Water Intake Rule for Existing Power Plants. **** For example, the China Action Plan for Retrofitting and Upgrading Coal-Fired Power Plants (2014-20) imposes new minimum standards for coal generation efficiency.*

(CEN) and the European Committee for Electrotechnical Standardization (CENELEC), acting on a mandate received from the European Commission, are also working to improve standards to improve climate change resilience of infrastructure in the energy sector – one of the priority sectors identified. The Eurocodes, the European reference building codes, are undergoing a revision process which includes consideration of climate change impacts.[8]

Requiring resilience measures for project approval and risk disclosure

Governments are increasingly incorporating resilience-related requirements into project approval to encourage consideration of climate change impacts at the project development stage. The European Commission's Environmental and Impact Assessment Directive was amended in 2014 to require the consideration of climate change impacts on infrastructure projects that require an environmental impact assessment (EIA) (EC, 2014).[9] In Canada, guidelines have been issued on incorporating climate change into the federal EIA process (Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment, 2003).

To reach projects and companies beyond the scope of the environmental assessment process, governments have also adopted policies to encourage businesses to identify and address risks specific to them. In the European Union, major projects (i.e. large infrastructure projects) co-financed by the European Structural and Investment Funds are required to undertake a climate risk and vulnerability assessment, and to include appropriate adaptation measures when needed. The UK Adaptation Reporting Power asks companies, including energy generators and transporters, to report on how they predict climate change will impact them and propose ways of managing the impacts. This information is included in reports produced by the companies and are made publicly available.

8. The new codes are expected to be published by 2020.

9. An EIA is required at the European level for projects deemed to pose a "significant effect on the environment," known as Annex I projects, which encompass a range of energy infrastructure including oil refineries, thermal power stations (including nuclear), ports, hydropower dams, oil and gas extraction infrastructure, oil and gas pipelines, and CCS infrastructure.

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Role of energy regulators: Regulating prices and supply

Utility regulators and commissions play an important role in setting performance standards to ensure reliability of supply, by requiring the reporting of incidents impacting energy supply as well as developing emergency response plans with local authorities and operators. They can also determine the extent to which consumer rates can be adjusted to fund resilience-building measures. For instance, the New Jersey Board of Public Utilities approved a USD 1.2 billion programme put forth by Public Service Electric and Gas (PSE&G), the state's largest electricity and gas service provider, to enhance infrastructure resilience to severe weather damage ("Energy Strong"). The programme involves upgrading and moving substations, modernising gas mains in flood risk areas, and creating system redundancies and deploying smart grid technologies (PSE&G, 2014). These costs will be passed along to customers, although overall rates are expected to decline with the expiration of surcharges from deregulation and agreement by PSE&G to a lower return on its investments.

The Office of Gas and Electricity Markets (Ofgem) in the UK publicly reports on the climate change risks it faces and how it is managing them. The energy regulator considers the costs of resilience-building measures when determining allowed revenues by its network companies and costs to be recovered through rate adjustment. For instance, Ofgem approved a long-term work programme for electricity distribution companies to improve substation flooding resilience, which also considers future climate change.

7.3.2 Providing businesses and households with information and other services

Besides targeted policies and regulations, governments also deliver services and build capacity to support the undertaking of adaptive measures by businesses and households. Governments play an important role in supporting climate data collection and modelling efforts, undertaking risk assessments, supporting emergency preparedness and response, and improving institutional coordination.

Knowledge-building and information dissemination

It is important to base resilience-building actions on a basic understanding of climate change-induced impacts, to know what one is protecting against and preparing for. Much progress has been achieved in understanding projected climatic changes resulting from rising GHG emissions; however, considerable uncertainty remains – particularly in how certain aspects of the climate system (such as cloud cover and wind) will respond. Significant gaps also remain in understanding projected impacts at smaller geographic (local and regional) and temporal (seasonal and monthly) scales, which are especially important for energy asset planning and investment.

Governments support knowledge-building through the improved collection and dissemination of climate projections and weather data, which aid comprehension of projected climate change impacts. Climate Change Australia, a service funded by the Australian federal government and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), provides public access to a range of up-to-date technical climate change data and projections, at the national and regional levels (Australian Department of Environment and CSIRO, 2015).

Once physical impacts have been projected, they need to be translated into risks understood by energy asset managers and prioritised for action. Governments have supported engineering and economic modelling work, which helps translate biophysical impacts into quantified technological and economic impacts on the energy sector (e.g. the impact of projected air temperature rise on increased total and peak electricity demand). In the European Bank for Reconstruction and Development (EBRD) hydropower plant rehabilitation project in Tajikistan, projected river flow changes were translated into changes in hydropower plant operations and electricity output. This informed an economic analysis to determine the optimal turbine upgrade (EBRD, 2014).

Integrated risk assessments

Governments have undertaken comprehensive risk assessments at the national and regional levels, providing a fundamental basis for decision-making, as these assessments can help determine the risk exposure of proposed and existing projects, and identify priority areas for action. The UK government is required to conduct national climate change risk assessments every five years (Box 7.2). In the United States, the US Global Change Research Act of 1990 mandates that the United States Global Change Research Program (USGCRP) undertake and coordinate regular assessments of global change processes on the United States, to be published every four years in a comprehensive National Climate Assessment.

Emergency preparedness and response

Emergency preparedness and response measures are important government services which enable organised and co-ordinated preparation efforts, as well as responses following emergency events. These measures include ensuring that a robust early warning system is in place, enabling advanced preparation as early as possible, as well as prepositioning crews, equipment and backup generation. Sub-national governments play key complementary roles in emergency preparedness and response, as they are

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Box 7.2

UK Climate Change Risk Assessment

The UK Climate Change Risk Assessment was first published in 2012 and will be updated every five years, as per regulatory requirement under the UK Climate Change Act of 2008. In the first assessment, risks and opportunities were identified for eleven key sectors, including the energy sector, based on "likelihood, potential consequences and how urgently adaptation action may be needed to address them," associating each risk with low, medium, or high confidence. High-confidence risks for the energy sector included increased space cooling demand due to rising temperatures, risk of sub-station flooding, and increased losses in transmission and distribution line capacity due to line "de-rating" in response to higher temperatures (UK DEFRA, 2012).

often on the front lines of disaster impacts and act as first responders during extreme events. Regulators can also require energy operators, particularly those of critical energy infrastructure, to develop and maintain site-specific emergency preparedness and response plans.

While emergency response and relief have historically been the focus of action by governments faced with the risk of emergency events, some jurisdictions are increasingly recognising the importance of reducing exposure to hazards, rather than simply responding after an event has taken place. Japan's well-regarded approach to disaster risk management encompasses widespread public education, sophisticated early warning systems and strict building codes, which help reduce the exposure of people and assets. The US Federal Emergency Management Agency (FEMA) requires the development of "hazard mitigation plans" by sub-national governments as a condition for receiving non-emergency disaster assistance, to "break the cycle of disaster damage, reconstruction, and repeated damage" of infrastructure (FEMA, 2016).

Improving cross-agency and governmental coordination

An important barrier to integrated resilience planning and action is the lack of coordination among stakeholders.[10] Building energy sector resilience crosses the boundaries of traditional government departments, and thus presents a clear opportunity for governments to enhance internal coordination. The formation of interdepartmental committees and working groups can bring together often disparate government players to share information and reduce duplication. The importance of coordination between national and sub-national levels of government is evidenced by the coordinated response to Hurricane Sandy in 2012 by the US federal entity FEMA and state and local authorities, which facilitated access to federal financial resources and communication among all government levels.

Governments also bring together private and public sector stakeholders. For instance, effective energy facility and design standards are supported by the coordination of governments, regulators, operators and technical experts. The US Department of Energy (DOE) Partnership for Energy Sector Climate Resilience brings together energy companies (electric utilities as a first step) and the DOE to address knowledge and capacity gaps through sharing of best practices, data and decision-making tools (US DOE, 2015c). Canada's Adaptation Platform is another example of a government-led initiative to enhance inter-sectoral collaboration in building climate change adaptation (Box 7.3).

7.3.3 Building resilience of state-owned assets

In most economies, governments own and manage a wide array of energy assets (see Chapter 6). Indeed, the IEA estimates that state-owned enterprises, such as electric utilities and fossil fuel companies, own almost half of global power generation infrastructure and more than 70% of global oil and gas reserves, in addition to other electricity generation, transmission and distribution infrastructure, fossil fuel extraction infrastructure, and fuel delivery systems. This represents a substantial opportunity for governments to enhance the resilience of a major portion of global energy delivery assets. To do this, governments will need to implement a range of technological and siting measures to build resilience to climate change impacts across various energy sub-sectors (Table 7.2).[11]

Technological and structural changes to harden energy infrastructure to climate change impacts include fortifying protection of coastal and off-shore infrastructure against flooding and sea level rise, and designing wind turbines to better manage high wind speeds. Improving the energy

10. Typically, energy departments oversee energy and natural resource planning; climate data and climate change policies are the responsibility of environment departments. Meanwhile, decisions related to public energy infrastructure may be made in public works departments, public utilities, or security departments (for large-scale "critical" infrastructure), while land-use and zoning decisions on energy projects are made by planning departments, including at the sub-national level.

11. These measures are by no means exclusive to state-owned assets. Private energy companies are also widely adopting these adaptive practices.

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Box 7.3

Canada's Adaptation Platform

Canada's Climate Change Adaptation Platform was created with the primary objective of promoting collaboration among a range of stakeholders who play a role in enhancing climate resilience in Canada. Working groups comprised of public and private stakeholders, focused on energy and other themes, report to a co-ordinating plenary panel of senior officials from federal and provincial governments, and representatives from professional and industry associations. By bringing together participants from different sectors, jurisdictions and regions, information and resources are shared so that cross-jurisdictional and multi-sectoral issues can be more effectively addressed.

The Energy Working Group is comprised of representatives from relevant federal government departments, provincial and territorial governments, industry associations and electric utilities, professional associations, and research institutions. Recent projects of the Energy Working Group include conducting vulnerability assessments of infrastructure; undertaking studies on the impacts of climate change on future energy demand, and policy drivers and barriers to adaptation; developing tools to support decision-making; and compiling case studies on best practices.

and water efficiency of energy processes is also critical. Implementation of alternative cooling technologies or grey water recycling in thermal power plants, or re-use of fracturing fluids in gas extraction, are already being implemented (IEA, 2015b; US DOE, 2013a; 2015a). For example, Eskom, South Africa's state-owned electric utility, has implemented dry-cooling technology across its power generation fleet to address the challenge of water scarcity. It operates the world's largest direct and indirect dry-cooling power plants and uses seawater for cooling at its nuclear power plant (Eskom, 2016).

Governments can also implement siting and management changes, such as siting coastal infrastructure away from high flood risk areas, locating hydropower plants based on changing water availability, and siting off-shore wind turbines in consideration of sea level rise. The US Federal Flood Risk Management Standard 2015 requires federal agencies to establish a flood hazard area based on the latest available climate science, in any projects involving federal funding or land. This standard therefore applies to federal assets, as well as to a wider scope of federally supported private infrastructure.

Governments are also involved in demonstration projects, such as using constructed wetlands to enhance thermoelectric power plant cooling and mitigate surface water demand (US DOE, 2013b). System-wide measures such as increased distributed generation and implementation of smart grid technologies can improve electricity system responsiveness to changes in supply and demand, and improve predictive analysis to quickly identify outages and prioritise service restoration efforts. Hydro-Quebec, the public electric utility in Quebec, Canada, is undertaking a range of research, development and demonstration (RD&D) activities for smart grid technologies, in part to enhance system reliability in the face of eventual weather and other disruptive events.

The public sector also owns a variety of major sources of energy demand, including transit systems, schools, hospitals, other public buildings, and police and military agencies. Government action to improve the resilience of the energy sector can also involve resilience investments for these energy consumers.

7.3.4 Mobilising financial resources for resilience: An active role for private and public actors

A commonly acknowledged gap in implementing resilience-building measures is the lack of financial incentives to do so. The business case for resilience-building remains weak for many projects, resulting in under-investment; both governments and the private sector have complementary roles to play in addressing this challenge. Private sector investment in resilience can be accelerated by stronger incorporation of climate change considerations into investment decisions and business practices. Governments provide direct financial support for resilience-building through grants and loans, but also develop financial guidelines and support the development of financial instruments that leverage private investment and distribute risk.

More broadly, governments also have an important role in developing the policy framework to drive financial investment in resilience: a supportive financial policy environment characterised by sound, robust and stable business regulations for both the energy and financial sectors, and sound corporate governance. Without a solid underlying framework, which includes appropriate pricing of resources such as water and energy, investment may be misdirected.

Private sector funding

Allocating internally generated resources is the principal way in which the private sector finances operations

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and investments; policy, pricing and other incentives to encourage greater allocation of these funds to resilience-building activities can support increased investment (for example, see discussion in Section 7.3.1 on government policy to catalyse action). As the prospect of business losses from climate events increases, greater private sector investment in resilience activities will likely follow.

Private sector bonds are a mechanism for generating new streams of revenue for resilience-building purposes, as well as for mitigation measures. Globally, the green bond market has grown rapidly and reached its largest size yet in 2015 (USD 42 billion), with further expansion expected in 2016 (Climate Bonds Initiative, 2016). Although the funds have primarily financed mitigation actions so far, resilience activities have also benefited. There is great potential for further growth, as green bonds still comprise only a small fraction of the global bond market, currently estimated at USD 100 trillion (UN Secretary-General, 2015).

Aside from bonds, institutional investors such as pension funds and insurance companies can be an important source of private capital for resilience investments, and are well suited to undertake infrastructure investments that provide long-term, stable growth. Institutional investors have begun actively pursuing "low-carbon" portfolios, and the opportunity exists to increase their spending thereunder for resilience-building investments.

Public-private partnerships (PPPs) offer the benefit of sharing project risk between the public and private sectors. Engaging the private sector can provide market expertise and funding streams otherwise inaccessible to governments and public sector institutions. The West Coast Infrastructure Exchange (WCX) is an interesting PPP model which aims to build climate resilience into its investment decisions. It works to strengthen private financing of public infrastructure projects across several western US and Canadian jurisdictions[12] by sharing resources and expertise, and pooling projects to achieve sufficient scale to attract institutional investors.

Public finance sources

Governments already invest substantially in public infrastructure; climate change requires additional funding for further hardening and upgrades. For instance, the Connecting Europe Facility (CEF), which supports the development of trans-European energy networks, estimates that Europe's energy transmission infrastructure requires investments on the scale of EUR 140 billion in electricity and EUR 70 billion in gas to meet a range of needs, including security of supply. The CEF process requires that projects demonstrate their resilience to climate change impacts (EC, 2016).

Several US states have developed "green banks" that use public funds to leverage private capital to finance clean energy (i.e. renewable energy, energy efficiency, and alternative fuel vehicles and infrastructure) with the co-benefit of enhanced resilience. Green banks can reduce the market's reliance on grants, rebates and other subsidies, and facilitate more innovative financing of projects including leveraging of private finance. These banks typically pursue emissions mitigation objectives, but could also finance investments that build resilience.

The New Jersey Energy Resilience Bank is the first of these public infrastructure green banks in the United States to have a specific and explicit energy resilience mandate (Box 7.4). It was created in the aftermath of Hurricane Sandy to strengthen the resilience of energy infrastructure to extreme weather events. In contrast to other institutions that frame their activities principally in terms of mitigation, the New Jersey Resilience Bank positions investments primarily in terms of their support for resilience. There is, in practice, overlap in eligible activities among all these banks, as many actions support both resilience and GHG reduction (for example, investments in decentralised renewables generation, energy efficiency and energy storage).

In the State of Massachusetts, resilience funding was mobilised through payments made by electricity suppliers that do not comply with the state's renewable

Box 7.4

New Jersey Energy Resilience Bank

The New Jersey Board of Public Utilities (NJ BPU) and Economic Development Authority (EDA) have created a first-of-its-kind green bank with a specific focus on energy sector resilience. USD 200 million in federal disaster aid will be directed to provide low-interest loans and grants for both new distributed energy systems and retrofitting existing ones at public, non-profit, or small business facilities deemed "critical." Eligible funding includes core equipment, islanding capabilities and interconnection. Hardening and flood-proofing measures such as raising the elevation of equipment are also eligible. Prioritisation of distributed generation, such as microgrids and energy storage, underscores the clear link between measures to build resilience in the energy sector and the need to reduce its GHG emissions (NJ BPU, 2014).

12. WCX involves the states of California, Oregon and Washington, and the Canadian province of British Columbia.

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energy portfolio standard and thus must pay Alternative Compliance Payments (ACPs). USD 40 million of ACP funds have been directed towards the Community Clean Energy Resiliency Initiative, which provides grants and technical assistance to support clean energy technologies to improve resilience at critical facilities (Commonwealth of Massachusetts, 2016). The Gulf of Mexico Energy Security Act (2006) allocates offshore oil and gas royalties to Gulf States for "coastal protection, including restoration, hurricane protection, and infrastructure directly affected by coastal wetland losses", where energy infrastructure is vulnerable to flooding and erosion.

Enhancing project bankability

Strong financial benefits enhance access to capital flows. For resilience investments, however, the benefits of investing can be difficult to quantify as they include avoided losses and impacts that do not occur. Strengthening methodologies to value these avoided losses can enhance the bankability of these projects. In addition, benefits extend beyond the project or company level, for example health, socio-economic and national security co-benefits, including avoided loss of mobile communication systems, water and sewage treatment, and critical health and emergency services. Governments, insurers and project proponents are recognising the need to consider these wider benefits in project assessment (Table 7.4). Better identifying players who stand to benefit (such as utilities that avoid damage costs, and residential consumers and businesses which avoid losses due to outages) can provide a clearer picture of how the costs of managing risks can be distributed and can render resilience investments more financially attractive.

In the project cost-benefit analysis undertaken by the New Jersey Energy Resilience Bank, evaluators look beyond energy cost savings to consider public safety benefits, avoided revenue losses, and provision of emergency shelter for buildings that retain electricity access (NJ BPU, 2014). The International Hydropower Association (IHA) identifies benefits (referred to as "services") of improving hydropower resilience as including flood protection and a more secure water supply for other sectors, while recognising that "private sector developers often receive no remuneration for such services" (IHA, 2015).

Bankability can also be improved through direct financial support mechanisms. For example, the US Department of Energy Loan Guarantee Program provides loan guarantees for the deployment of innovative clean energy technologies, including projects that improve energy reliability (US DOE, 2015b).

Multilateral development banks

Multilateral development banks (MDBs) and other multilateral financial mechanisms are major sources of financing for climate resilience and adaptation. In 2015 alone, for instance, MDBs committed USD 5 billion for climate adaptation projects (ADB et al., 2016). There are also specialised multilateral financial mechanisms, such as the Green Climate Fund (GCF) and the Climate Investment Funds (CIF), that channel and leverage climate-related financial support and investment to developing and emerging economies. As of mid-2016, over USD 10 billion had been pledged to the GCF (currently the largest), 50% of which is allocated to adaptation, and USD 800 million has been pledged for the CIF Pilot Program for Climate Resilience (CIF, 2014; GCF, 2015).[13]

MDBs also encourage resilience assessments and investments by their prospective borrowers. Project design guidelines have been developed by these banks to promote the development of climate-resilient projects. For instance, the Asian Development Bank (ADB) has released step-by-step guidelines for project sponsors to incorporate climate resilience into electricity and other energy infrastructure

Table 7.4

Direct and indirect benefits of resilience investments that can enhance financial attractiveness of projects

Direct benefits	Indirect benefits
• Avoided cost of infrastructure loss and damage	• Avoided loss of mobile communication and alert systems
• Avoided lost revenue for energy suppliers, including costs of restarting operations	• Avoided loss of critical health and public safety services, including water treatment and emergency response
• Avoided business interruptions due to loss of electricity and fuel supply	• Enhanced property value
	• Poverty reduction and enhanced social inclusion
	• Enhanced national security

Sources: Adapted from EPA (2016), "Financing resilient and sustainable water infrastructure"; NJ BPU (2014), "NJ Energy Resilience Bank now accepting applications"; and Committee on Increasing National Resilience to Hazards and Disasters (2012), Disaster Resilience: a National Imperative.

13. As of July 2016, the GCF had approved its 17 projects, including climate-resilient infrastructure mainstreaming in Bangladesh, improving climate information and early warning systems in Malawi, and enhancing hydro-meteorological services in Africa.

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projects; climate change and disaster risk management is an area of strategic priority for the bank. Furthermore, four of the major multilateral development banks – the European Bank for Reconstruction and Development (EBRD), the World Bank, ADB and the African Development Bank (AfDB) – have developed screening tools to evaluate potential projects for their vulnerability to climate change.

Insurance and risk-sharing models

As the frequency and severity of extreme events and other climate change impacts rise, there is an increasing opportunity – and need – for the insurance industry to create risk-sharing models better tailored to the changing risk landscape. Although larger energy companies may self-insure, meaning they draw upon their own resources during times of need, businesses with limited financial resources (including small- to medium-sized energy companies and those in lesser developed countries) can benefit from third-party insurance. The insurance sector thus has an important role to play in managing climate risks and in encouraging resilience investment, notably by understanding emerging risks, discouraging risky behaviour through premiums, and designing innovative insurance tools that spread the risk and its associated financial cost and impact. These innovative tools include catastrophe bonds and insurance for renewables generators covering damage from weather events (Box 7.5). Governments have a role in working with the insurance industry to develop innovative insurance models and products, and also in applying them within the realm of publicly funded insurance programmes.

7.4 Conclusion

Climate change is creating a dual challenge for the energy sector, not only to decarbonise but also to adapt to the physical impacts of a changing climate. The importance of adaptation and resilience-building is reflected in the COP21 Paris Agreement, which has made adapting to climate change a priority on par with mitigating GHG emissions. Rising temperatures, increasing water constraints, and more frequent and severe extreme weather events are already threatening energy security around the world. All components of the energy value chain – from extraction, to transformation, to energy demand – face risks from climate impacts.

In developing resilience plans, it is critical to recognise the dynamic nature of the energy sector and to adjust resilience-building policies and measures to a decarbonising energy system – one that will look different in the future than it does today. Win-win mitigation-adaptation solutions can be generated through actions that both reduce emissions and enhance resilience: the challenge is to identify and exploit such opportunities. Traditional emissions-mitigating activities, including deploying distributed renewable energy technologies and improving the efficiency of energy use,

Box 7.5

Innovative insurance products to address resilience risks

The insurance industry has been at the forefront of developing innovative risk-sharing models in response to increasing extreme weather events and related losses.

Catastrophe bonds ("cat bonds"), a type of insurance-linked financial instrument, spread the risk of extreme events to broader society. Investors who hold these bonds are paid a return in the absence of a specified event taking place. If the risk event does occur, investors lose their principal, which is used to pay claims. Cat bonds are often indemnity-triggered, meaning that pay-outs are based on exceedance of actual incurred losses as opposed to the simple physical occurrence of the event. Currently, the large majority of cat bonds cover US hurricane risk (NAIC, 2016). These bonds have historically constituted a small share of the bond market, but have grown rapidly in recent years.

Insurance products targeting weather impacts on renewable energy and energy efficiency technologies specifically are emerging. For instance, Munich Re's Solar Shortfall insurance covers non-physical damage such as lower-than-normal solar radiation. Other products cover physical damages from weather events (such as floods and hail) suffered during the construction and operation of renewable energy projects (Munich Re, 2015).

Index-based insurance, in contrast to indemnity-triggered, has the benefit of not requiring proof of damage; rather, a pay-out is simply made when certain pre-determined thresholds are surpassed. Allianz Risk Transfer insurance offers index-based coverage of weather-related changes in supply (such as changes in wind or water flow) or demand (due to mild winters or cool summers), which are paid out based on weather indices such as levels of wind or precipitation (Allianz, 2015). Outside the energy sector, Sompo Japan Nipponkoa Group offers a climate change index insurance product for small-scale farmers in rural Southeast Asia. Farmers who purchase coverage are compensated without the need for a damage assessment if weather indices such as temperature and rainfall exceed certain thresholds.

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can also reduce exposure to supply interruptions and other climate impacts.

Governments have an important role to play in enhancing energy sector resilience: as regulators, long-term planners, public service providers and asset owners. Governments can shape the regulatory and fiscal environment to drive investment and actions in resilience-building; provide services and information to businesses to integrate climate change considerations into planning and operations; and implement adaptive practices in the energy assets they own and manage. Lastly, both the public and private sectors have distinct yet complementary functions in funding resilience investments.

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Chapter 8 • Tracking tools to support energy sector transformation

The radical transformation of energy systems accelerated by the Paris Agreement requires new approaches to energy metrics and indicators to help countries and others understand whether current actions are consistent with short- and long-term national and global goals, including keeping temperature rise well below 2 °C. Aligning measurement metrics and tools with domestic policy priorities supports sound policy development and implementation, and the right metrics can inherently promote transformation of the energy sector. As the transparency arrangements established under the Paris Agreement are unlikely to provide comprehensive data on energy system transformation, additional metrics could complement the United Nations Framework Convention on Climate Change (UNFCCC) process and help guide policy makers and others onto a sound low-carbon pathway.

8.1 Introduction: A new context for energy metrics

As described in Chapter 1, the Paris Agreement marks a turning point in global climate efforts with its aim to collectively reach a global peaking of greenhouse gas (GHG) emissions as soon as possible, and undertake rapid reductions thereafter. The energy sector currently generates two-thirds of total anthropogenic GHG emissions, so in most scenarios of deep emission reductions, the energy sector plays a leading role. The International Energy Agency (IEA) low-emissions scenarios are no exception, with CO_2 emissions across the global energy sector falling by more than half from over 32 gigatonnes (Gt) to less than 15 Gt by 2050 in the IEA 2 °C Scenario (2DS), and to only 1.4 Gt for the electricity sub-sector.

As part of the low-carbon transition of global and national energy systems, a robust tracking and reporting framework will give national policy makers the information needed to establish energy sector investment and operation policies. Comprehensive tracking and reporting will also encourage progress by providing confidence that all countries are acting, and will send a clear signal to the private sector that governments are serious about a rapid transition to clean energy.

8.2 What was agreed in Paris on tracking and metrics

The Paris Agreement determined that a common framework will be developed to track progress toward, and achievement of, countries' nationally determined contributions (NDCs), with built-in flexibility for Parties' different capacities. It also establishes a five-yearly cycle of communicating these contributions, and a periodic collective "global stocktake" of progress toward the goals of the Agreement (Box 8.1), including the long-term goals for the second half of this century. The Agreement also encourages countries to develop long-term low-emissions development strategies to guide domestic policy-making. Each of these processes would be strengthened by the use of energy metrics to provide a clear picture of the present state of energy systems nationally and globally, and where they are headed based on current policies and market conditions.

8.2.1 Energy and the NDCs

All Parties to the new agreement are individually required to submit NDCs every five years to reduce GHG emissions, with each successive NDC progressing beyond the previous one. As of 1 September 2016, 162 intended NDCs[2] had been submitted, covering 189 countries.[3] As NDCs are fully "nationally determined", little guidance was given as to the content of these submissions. For developing countries, the Paris Agreement is the first international climate agreement with a binding obligation to set mitigation goals, so the formulation of the first round of NDCs was a learning experience for many.

What the NDCs say about energy

Most of the intended NDCs are framed as goals for GHG levels, either as absolute levels, reductions compared with a business-as-usual (BAU) baseline, or as reductions in emissions per unit of gross domestic product (GDP). However, 35 countries[4] set goals framed in terms of energy metrics, such as The People's Republic of China

1. Developed countries will continue to submit emissions inventories annually.

2. Intended NDCs (INDCs) become NDCs when countries ratify or accede to the Paris Agreement.

3. The EU NDC covers its 28 member states.

4. Antigua and Barbuda, Bahamas, Belize, Brunei, Bolivia, Cabo Verde, China, Ecuador, El Salvador, Fiji, Guinea, Guinea Bissau, Guyana, India, Jordan, Lao PDR, Lebanon, Liberia, Malawi, Mongolia, Myanmar, Nepal, Niue, Palau, Panama, Papua New Guinea, Samoa, Sudan, Suriname, Swaziland, Tonga, Uganda, United Arab Emirates, Uruguay and Vanuatu. Developed countries all submitted NDC goals framed in terms of GHG levels.

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Box 8.1

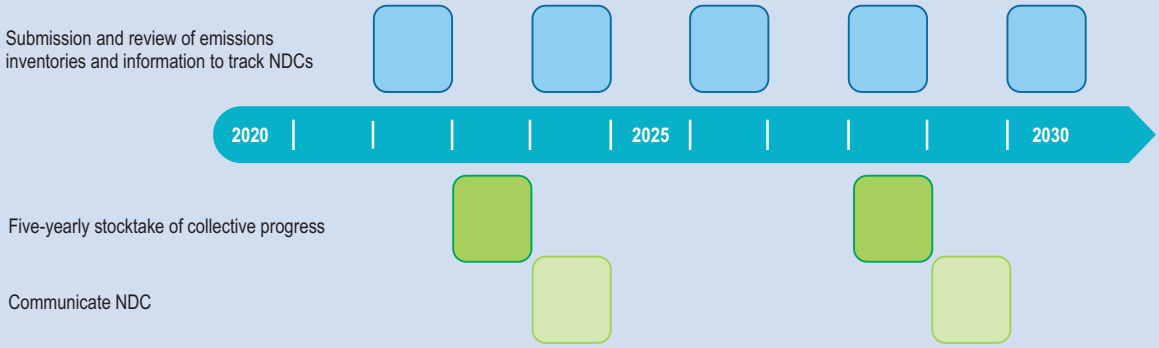
Scaling up ambition: Five-yearly NDC cycles under the Paris Agreement

The Paris Agreement is based on bottom-up submission and implementation of nationally determined contributions (NDCs). While they are a very significant step forward, IEA analysis has found that the path set by the initial round of NDCs would be consistent with average global temperature increase of around 2.7°C by 2100 and rising thereafter, which falls short of the goal to keep global temperature rise well below 2°C (IEA, 2015a).

To encourage more ambitious commitment over time towards this global long-term goal, cycles of NDC submission, review and stocktaking have been built into the process (Figure 8.1). Biennial reporting of emissions[1] and information on progress toward the NDC is coupled with a five-yearly stocktake of collective progress toward the global goal. This global stocktake informs countries as they make their next NDC submissions. In addition, an initial facilitative dialogue meeting is planned for 2018, which is expected to set the foundation for the five-year stocktake cycle that formally starts in 2023.

Figure 8.1

Paris Agreement cycle of transparency: Reporting, collective stocktake and NDC-setting



(hereafter "China") target of a 20% non-fossil fuel share in primary energy consumption by 2030, and India's goal to achieve about 40% cumulative electric power installed capacity from non-fossil fuel energy resources by 2030 (Table 8.1). All 35 of these energy NDCs set targets for renewable energy or clean energy supply, while 15 also set energy efficiency or energy demand targets. In addition, 12 countries[5] did not set specific energy-framed targets, but submitted sets of clean-energy policies or projects they intend to implement as their NDCs.

The Paris Agreement also creates an obligation for Parties to "pursue domestic mitigation measures, with the aim of achieving the objectives of" NDCs. The vast majority of Parties see energy sector actions as pivotal to delivering on their NDCs: a key-word search of the NDCs shows that 140 countries mention renewable energy, and 143 energy efficiency.

8.2.2 Transparency framework of the Paris Agreement

The Paris Agreement establishes a transparency (i.e. measurement, reporting and review) framework to improve understanding of countries' climate change actions. At least every two years, all Parties will submit national GHG inventory reports, as well as information necessary to track progress in implementing and achieving their NDCs.[6] These biennial submissions will be subject to technical expert review, as well as a facilitative consideration process by other countries. Common guidance will be developed on how to account for NDCs. Previous UNFCCC experience in tracking progress toward and accounting for mitigation commitments has largely focused on absolute GHG targets, such as the multi-year carbon budgets set for developed countries under the Kyoto Protocol. The wide variety of NDC types therefore poses a significant challenge in defining what information should be

5. Bahrain, Benin, Cuba, Egypt, Gambia, Kuwait, Mozambique, Nauru, Qatar, Saudi Arabia, Somalia and South Sudan.

6. Developed countries currently submit national inventories annually, and will continue to do so. Flexibility will be provided to recognise the needs of least-developed countries and small island developing states.

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Table 8.1

Different types of energy-framed NDCs

Country	GHG	Renewable energy or non-fossil supply	Energy efficiency
China	60% to 65% reduction in CO_2 emissions per unit of GDP; peak CO_2 emissions around 2030.	Increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030.	
Fiji		Renewable energy share in electricity generation to approach 100% by 2030, from around 60% in 2013.	Indicative reduction of 10% CO_2 emissions from energy efficiency improvements economy-wide.
India	Reduce the emissions intensity of GDP by 33% to 35% by 2030 from 2005 level.	Achieve about 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of technology transfer and low-cost international finance, including from the Green Climate Fund (GCF).	
Lebanon	15% reduction compared with business-as-usual scenario in 2030.	15% (or 20% conditional on support) of power and heat demand in 2030 to be generated by renewable energy sources.	3% (or 10% conditional on support) reduction in power demand through energy-efficiency measures in 2030, compared with demand under the business-as-usual scenario.
United Arab Emirates		Increase contribution of clean energy in total energy mix from 0.2% in 2014 to 24% by 2021.	

Source: UNFCCC INDC Portal, http://unfccc.int/focus/indc_portal/items/8766.php.

tracked in the case of each NDC type, and how it will be accounted for.

As part of the UNFCCC post-Paris work programme, it will need to be decided whether to develop common guidance for communicating, tracking and accounting for low-carbon energy and energy efficiency goals, or whether to treat these on an ad-hoc basis. As the examples in Table 8.1 demonstrate, the lack of guidance for submission of NDCs has already led to a wide spectrum of target formulations, with some expressed as a share of generation and others as capacity levels, some as renewable energy (itself with varying definitions) and some as non-fossil fuel shares. To track NDC progress and achievement, at minimum Parties will need to further clarify and define their targets (e.g. the precise definition of renewable energy or fossil-fuel share), as well as specify what data sources and statistical methodologies will be used to track progress, including base year/level information. Significant differences can arise: for example, different statistical approaches can be used to convert renewable and nuclear power generation to a corresponding primary energy share. How and when further information is to be reported will need to be agreed as part of the post-Paris UNFCCC work programmes on NDCs and transparency.

Given the various ways of framing energy NDCs, it will likely be impractical to develop detailed reporting and accounting guidance for each type, so any guidance may remain at a general level. For future rounds of NDCs, however (e.g. for the 2025-30 NDCs to be communicated by 2020), Parties could agree to narrow the range of options for energy targets. For example, Parties could be requested to express renewable energy targets as shares of final energy demand, with a common definition of renewable energy adopted across all countries. Similarly, a common definition for "clean energy" would assist in understanding targets of this type. Commonly expressed targets would enable development of common guidance for reporting, review and accounting that would significantly improve the clarity and comparability of energy-framed NDCs.

The further obligation for Parties to "pursue domestic mitigation measures, with the aim of achieving the objectives of" NDCs may prompt the transparency framework to also serve as a forum for countries to report on policies implemented, and on the impact of these policies on GHG emission levels. With over 140 countries having signalled their intention to implement energy policies toward achievement of their NDCs, if the Paris Agreement's transparency framework were to cover reporting of policy implementation, it would

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be valuable to develop guidelines for countries to report on energy policies and their GHG impacts.

8.2.3. The "global stocktakes" of progress under the Paris Agreement

The third element of the COP21 decisions relevant to tracking energy system transformation is the establishment of five-yearly reviews of collective progress. Here the mandate is much wider, including a focus not only on whether the short-term actions through the NDCs are being delivered, but whether countries are collectively on track to achieve the Agreement's purpose and objectives, including the long-term goal of keeping temperature rise well below 2° C. A work programme has been established to develop procedures for how the global stocktake will be conducted, and to identify the relevant information sources, including (but not limited to):

- The overall effect of the NDCs communicated by Parties.
- The provision of support (financing, capacity-building and technology transfer).
- The latest reports of the Intergovernmental Panel on Climate Change (IPCC).

In the first round of NDCs, most countries appear to have based their actions and targets on a short- to medium-term assessment of abatement opportunities, with only 21 countries making reference to a domestic or global longer-term goal or long-term vision (World Resources Institute, 2015). This suggests that the first round of NDCs may well omit some critical immediate actions needed for consistency with the longer-term goals of the Agreement. For example, investments made today in long-lived infrastructure (such as low-efficiency buildings) may have only marginal impact on GHG emissions in the short term (measured under the NDCs), but are drivers of emissions in the long term. The emissions that are consequently "locked in" by these investments make achieving later emission goals significantly more challenging and costly. Information gathered through the transparency framework on emissions and NDC implementation is therefore unlikely to provide the global stocktake with a complete picture of energy sector transformation. Aggregating the effect of NDCs can provide a snapshot of current emission levels and past success in policy implementation, but it will not give a clear indication of where emissions are headed in the future or whether the policy mix is complete.

As a strategic process designed to inform the next round of NDCs, the global stocktake will also benefit from a richer set of indicators to complement the outputs of the transparency framework, including forward-looking indicators capturing patterns of investment in long-lived energy infrastructure. Further, the ease of this energy sector transformation will hinge on how rapidly progress is made in bringing down the cost and improving performance of key low-carbon technologies. The IEA therefore views national-level tracking of key energy sector indicators (including patterns of long-lived energy infrastructure), and tracking progress in technology investment, research, development, demonstration and deployment (RDD&D), as key additional inputs to the stocktake process (IEA, 2015a; 2015b). As these elements fall outside the NDC tracking that will be undertaken through the Paris Agreement transparency framework, the global stocktake should allow for submissions from outside organisations. The IEA would be ideally placed to provide additional information through this mechanism.

8.2.4 National low-emission development strategies

One further provision in the Paris Agreement addresses long-term energy system transformation, the agreement that "all Parties should strive to formulate and communicate long-term low GHG emission development strategies", and a decision inviting strategies to be submitted by 2020. There is no work programme set up under the UNFCCC for this purpose, nor is any further guidance provided: the low-emission development strategies (LEDS) are to be developed by countries, then submitted to the UNFCCC.

Developing national LEDS will clarify what an energy sector pathway consistent with limiting temperature rise to well below 2° C looks like in each country's context. LEDS should also enable actions submitted in future NDCs to be better aligned with long-term goals, and allow countries to place greater focus on measures that do not produce immediate, short-term emission reductions.

There is currently no work programme arising from the Paris Agreement for the design of LEDS, so there is a risk that countries will not give priority to this critical process. Organisations such as the IEA have a key role to play in LEDS design, so that they are transparent, robust and coherent, and disaggregated to a level that is meaningful for national policy makers. The same energy and technology indicators which are relevant at a high level for global stocktaking will also be useful to countries preparing LEDS at the national level. As part of developing their national LEDS, policy makers should build capacity to collect the more detailed sectoral and demand-side data that will be necessary to track the delivery of their LEDS.

8.3 Indicators to track energy sector transformation

8.3.1 Why the choice of energy metrics matters

The choice of metrics used to track and drive energy sector transformation matters a great deal (IEA, 2014; 2015a; 2015b). The metrics used to express goals can themselves

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influence what policies countries choose to adopt, and how ambitiously they apply them. Compared with GHG measures, energy sector metrics can link more directly to policy influences, as it is easier for policy makers to understand how to deliver energy targets. Specific energy goals can also better capture the multiple benefits of low-carbon technologies at the local level, where the primary purpose of energy policies is often not GHG emission reductions. This can facilitate public and political support for the roll-out of these solutions. As such, the right choice of metrics can help to guide countries onto the right path and to take sound action. Metrics are not merely useful in helping to monitor what has happened after the fact, but also in influencing future decisions for action.

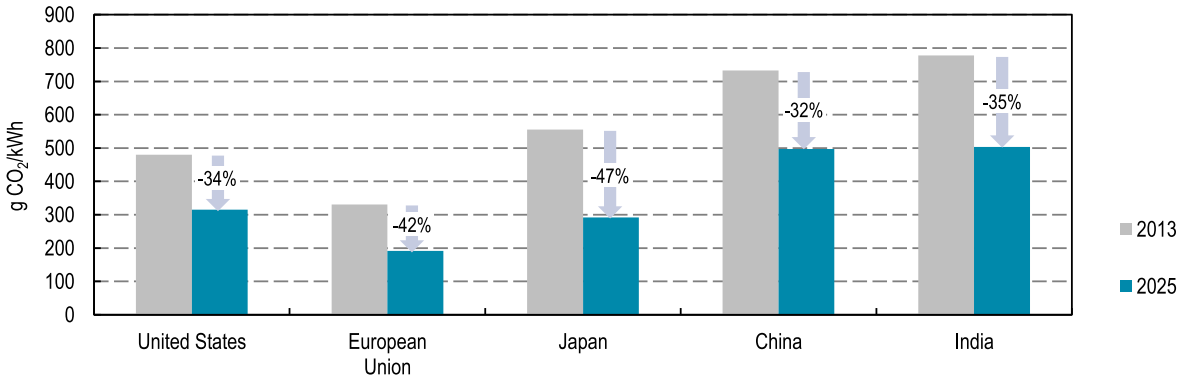
Understanding and accurately tracking all countries' actions is also critical to building the mutual trust the Paris Agreement relies on. Tracking GHG levels is currently undertaken through the UNFCCC process, and will form the basis of the Paris Agreement's transparency provisions. This information is critical, but GHG levels depend on many factors exogenous to energy systems, including economic conditions and weather, so a change in annual emissions does not necessarily guarantee that countries are taking action to transform their energy systems. Tracking energy metrics will give greater insight into whether countries are individually and collectively doing this.

The use of alternative metrics (e.g. increasing the clean energy share instead of decreasing GHG emissions) could also positively reframe the challenge of energy transformation, changing the discussion from one of reducing emissions (which could have the negative association of limiting economic growth) to a positive one of expanding low-carbon energy supply. Using energy metrics could also highlight commonalities rather than differences among countries. For example, the IEA Bridge Scenario adds a set of five measures,[7] beyond the current intended NDCs, to cause peaking of global GHG emissions around 2020 with no impact on GDP. The potential for major developed and developing countries to reduce the carbon dioxide (CO_2) emissions intensity of electricity generation (i.e. emissions per unit of electricity generated) by 2025 under this scenario is not only great but also cost-effective (Figure 8.2). Framing the challenge as a reduction in emissions intensity of power generation, instead of focusing solely on total economy-wide GHG emissions, highlights the potential (and significant need) for common action across countries. Rapid progress in reducing electricity sector emissions is particularly important given the great role it plays as an energy carrier for transportation and heating in low-carbon scenarios.

Energy metrics can also play the important role of highlighting those short-term actions that are needed to underpin longer-term low-carbon energy system transformation, but that do not necessarily reduce emissions significantly in the short term; that is, metrics can elucidate the essential *drivers* as well as the *outcomes* of energy sector change. Maximum action is clearly needed to reduce emissions in the short term, and cost-effective options such as the IEA Bridge Scenario exist to scale up ambition (IEA, 2015a). However, some elements of an optimal set of policies employed to meet a short-term emissions reduction goal could differ from those that would be introduced for a cost-optimal transition over a longer time frame (IEA, 2015b; Fay et al., 2015). Given the long operating lifetime of many energy sector assets, the deep emission reductions required by 2050 already fall within the lifetime

Figure 8.2

CO_2 emissions intensity of electricity generation by selected region in the Bridge Scenario



Note: gCO_2/kWh = gramme of carbon dioxide per kilowatt hour.

Source: IEA (2015a), Energy and Climate Change: World Energy Outlook Special Report.

7. Increasing energy efficiency, boosting renewable electricity generation, phasing out inefficient coal generation, removing fossil fuel subsidies, and reducing methane loss in oil and gas production.

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of many new energy infrastructure investments. The short-term policies implemented therefore need to be examined with an eye to the longer term, to ensure that short-sighted investment does not lock in infrastructure choices that will be costly to undo. For example, some investment in natural gas infrastructure can play a part in the transition to low-carbon energy systems, but over-investment in natural gas in the short term could lead to lock-in of higher-emissions infrastructure that is incompatible with keeping temperature rise well below 2° C.

8.3.2 Developing strong metrics to drive sound energy system transformation

New efforts to develop the right metrics

Efforts to develop metrics that align today's energy investments with long-term climate goals are beginning. The UNFCCC Green Climate Fund, the Nationally Appropriate Mitigation Actions (NAMA) Facility (set up by Germany and the United Kingdom), and the World Bank Transformative Carbon Asset Facility are three major investment funds that have explicit mandates to support "transformational" change. IEA analysis of long-term low-carbon pathways (IEA, 2015c), as well as that of other organisations such as the Deep Decarbonisation Pathways Project (DDPP, 2015), finds that these pathways feature the common elements of energy efficiency improvement, reduced emissions intensity of power generation and electrification of energy systems, and recommends focus on these areas. The 2° Investing Initiative (2°ii, 2015), among others, is developing methodologies to align investment portfolios with climate objectives. The Carbon Transparency Initiative projects future emissions and other outcome metrics from sector-based activity and intensity driver metrics (Climateworks, 2015), and the recently launched Initiative for Climate Action Transparency intends to measure impacts for transformational change of climate policies and actions (ICAT, 2016).

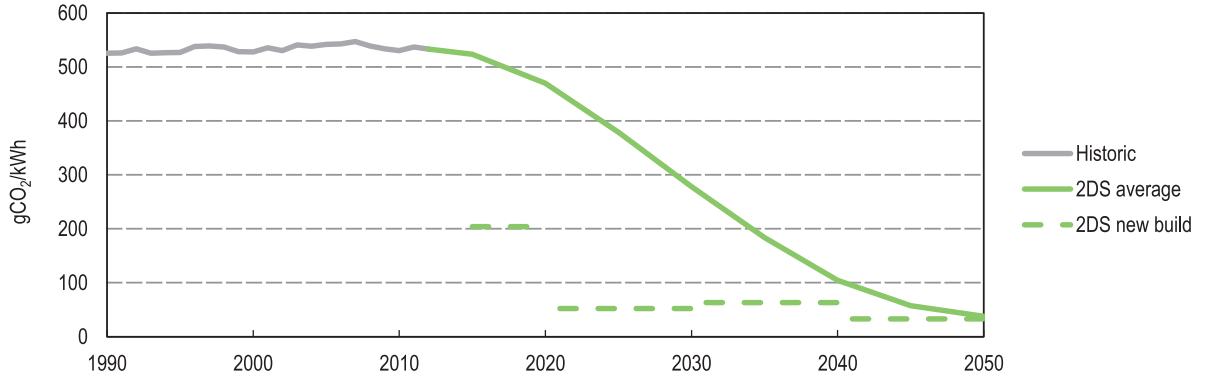
Possible metrics for the energy sector

As an illustration of this concept, in the 2DS, a scenario consistent with limiting temperature rise to 2° C, CO_2 intensity of electricity generation falls dramatically by 2050 (Figure 8.3, solid lines). As a first step along this pathway, to 2025 there is a 28% drop globally compared with 2010 levels. While this result may seem challenging in and of itself, examining an alternative metric – the CO_2 intensity of new-build electricity generating plants (Figure 8.3, dashed lines) – gives an even clearer picture of the actions required. To achieve the sharp decline in CO_2 intensity of the 2DS, the average CO_2 intensity of new generation must be only 10% of historical levels after 2020. The average CO_2 intensity is an example of an *outcome* metric, while the new-build intensity is a *driver* metric. Tracking of both types of indicators is needed for an understanding of both current status and future trends.

An important driver metric is relative investment activity in fossil and non-fossil power generation and industrial capacity. The IEA *World Energy Investment report* (IEA, 2016a) tracks energy sector investment as a leading indicator of transition, and estimates and tracks the emissions intensity of new capacity. The investment analysis goes beyond counting the value of capacity realised in a given year, however, by looking at financing activity in projects just commencing construction – a better forward-looking indicator for projects with long lead times (nuclear, concentrated solar power [CSP], coal). The report finds, for example, that investment in renewables and low-carbon electricity in 2015, at USD 310 billion, bought more low-carbon power than in any previous year. Factoring in what was spent on fossil fuel-based power, the result is a reduced emissions intensity of new power generation over the last decade, at 420 kilogrammes of carbon dioxide per megawatt hour ($kgCO_2$/MWh) in 2015.

Figure 8.3

Average and new-build CO_2 emissions intensity of electricity generation in the 2DS



Source: IEA (2015c), Energy Technology Perspectives 2015.

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For an integrated view of progress and trends across the energy sector, a small number of high-level energy indicators can be used. These indicators provide not only a snapshot of progress, but a common basis for understanding differences in progress among countries. The fundamental challenges in the energy sector are to improve the efficiency of energy use and to reduce the carbon intensity of the energy supply; it is therefore essential to track energy sector carbon intensity (ESCI) – which, as discussed in Chapter 1, remains stubbornly unchanging – and the energy intensity of GDP.

However, broader indicators are needed to understand energy sector evolution and formulate sound policy. Table 8.2 shows one set of potential indicators covering

Table 8.2

Example set of high-level metrics to track energy sector transition

Sector	Metric	Unit
Aggregate energy sector	• Carbon intensity of primary energy supply	• tCO_2/toe
	• Energy intensity of GDP	• toe/USD
	• New investment in low- and high-carbon energy supply and energy efficiency	• USD
	• Share of renewables in final energy demand	• %
	• Population and share of population without access to electricity and/or reliance on traditional biomass for cooking	• million, %
	• Fossil fuel subsidies	• USD, % of GDP
	• Percentage of energy sector emissions covered by carbon pricing	• %
	• Public and private investment in low-carbon energy RDD&D	• USD, % of GDP
	• Percentage of total RDD&D investment in low-carbon energy	• %
	• Energy demand per economic sector	• TWh, %
Power	• CO_2 emissions per unit of electricity (fleet and new additions)	• gCO_2/kWh
	• Average efficiency of all fossil-fuel plants	• %
	• Share of low-carbon generation in new additions*	• %
Transport	• New passenger cars: CO_2 emissions per vehicle-kilometre	• gCO_2/vkm
	• Road freight vehicles: CO_2 emissions per tonne-kilometre	• gCO_2/tkm
	• Carbon intensity of total transport fuel demand	• tCO_2/toe
	• Aviation emissions	• gCO_2/pkm
	• Shipping emissions	• gCO_2/tkm
Buildings	• Residential: energy demand per dwelling (stock and new build)	• kWh/dwelling
	• Services: energy demand per square metre of floor space (stock and new build)	• kWh/m^2
	• Retrofit rate for existing buildings	• %/year
Industry	• CO_2 emissions per unit of value added	• tCO_2/USD
	• CO_2 emissions intensity of energy-intensive production (fleet average and new build)	• tCO_2/tonne of product
Fossil-fuel systems	• Share of natural gas vented or lost out of total gas production	• %
	• GHG emissions from fugitive emissions, gas venting, flaring and losses per unit of energy extracted	• tCO_2-eq/toe

**Includes renewables, nuclear and plants incorporating carbon capture and storage (CCS). For CCS, the relevant measure is only the portion which is captured.*

Notes: toe = tonnes of oil-equivalent; gCO_2/kWh = grammes of carbon dioxide per kilowatt hour; vkm = vehicle-kilometre; tkm = tonne-kilometre; pkm = passenger-kilometre; tCO_2-eq/toe = tonnes of carbon dioxide-equivalent per tonne of oil-equivalent.

Source: Based on IEA (2015a), Energy and Climate Change: World Energy Outlook Special Report.

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energy supply and demand, and measuring the overall state of the energy system (*outcome* metrics) as well as underlying *drivers* of change.

Tracking a small set of high-level indicators of this type offers the potential to understand how individual countries are progressing in energy system transformation, so that national policy makers can not only understand their own progress, but can compare with other countries to discover opportunities for further action. Energy targets – and the indicators associated with them – contribute to achieving wider sectoral or economy-wide GHG emissions targets, so actions taken to meet the energy targets will also support GHG goals.

8.3.3 Strong metrics are built on strong data

Significant data gaps currently exist both in developed and developing countries for some of these energy indicators. Data to construct a detailed set of energy demand indicators (such as energy use per building floor area) are collected by the IEA for its member countries, but not systematically for developing countries. Data on clean energy research, development and demonstration (RD&D) investment is patchy, particularly with regard to private investment and investment in developing countries. Fortunately, a number of processes are under way that will fill some of these gaps. For example, the tracking framework being developed for the UN Sustainable Development Goals will cover energy access issues, and the Mission Innovation technology collaboration launched at COP21 aims to track RD&D investment – in both cases, IEA methodologies and templates could be used to align data. To fill any remaining data gaps, the IEA could work with partner organisations to develop methodologies and establish sound systems for data collection and reporting, as it already does in other areas of energy statistics. Capacity for energy data collection needs to be strengthened in many developing countries, particularly in relation to demand-side and sectoral indicators. Given the impact of cities on future carbon trajectories, data at the urban scale should also be a priority.

To track a set of high-level indicators such as those in Table 8.2 at the country level, significant gaps in data will need to be overcome. Various ongoing efforts can be expanded to build a more robust database:

- The IEA collects and publishes global data for basic energy statistics and further energy demand-side and energy-use data for its member countries, providing a strong foundation on which robust metrics could be developed. However, consistent and comprehensive data for other countries is more limited. Capacity for energy data collection in many developing countries needs to be built, for basic energy statistics as well as the more detailed demand-side and sectoral indicators. The IEA conducts regular training in energy statistics for developing countries.

- Developing a globally consistent database of energy transition indicators would be a huge undertaking, but the IEA has already begun to track some metrics systematically, such as new investment indicators through the annual *World Energy Investment report* (IEA, 2016a) and *Tracking Clean Energy Progress* (IEA, 2016b). Through in-depth reviews of countries' energy policies, the IEA is also asking its member countries to consider how they will track their own domestic energy transformation.

- A key to implementing better energy indicators would be to bring together and build upon existing processes such as the energy indicators within the UN Sustainable Development Goals and Sustainable Energy for All initiative, the Major Economies Forum, the G20, and the Mission Innovation programme to increase public RD&D which was launched at COP21. IEA methodologies and templates can form the basis for this alignment.

8.3.4 Adjustments to the UNFCCC processes can help

The UNFCCC process provides a strong foundation for metrics and data collection, but it could also be developed further in ways that support energy sector tracking, addressing the three key dimensions of: choosing the right metrics to help guide the transition; putting tracking frameworks in place; and collecting the data. Specific actions that could be taken through the UNFCCC process include:

- Establishing procedures for tracking progress toward energy NDCs, and for assessing the impact on GHG emissions. For future rounds of NDCs, common information and/or a format for energy NDC submissions would enable easier tracking and comparability. Such guidance could also be applied when countries report on energy policies implemented toward delivery of GHG NDCs.

- Encouraging policy makers to build capacity to collect the detailed sectoral and demand-side data necessary to develop their LEDS, and to track progress toward achieving them.

- Highlighting the status of energy system transformation in the five-yearly UNFCCC stocktaking, to evoke the underlying drivers of future emissions. Investment patterns and RD&D levels will be important elements of this. As there is no clear mandate in the Paris Agreement for this information to be tracked within the UNFCCC processes, allowing input from expert organisations such as the IEA is important.

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Box 8.2

The value of disaggregated data and indicators for national policymaking

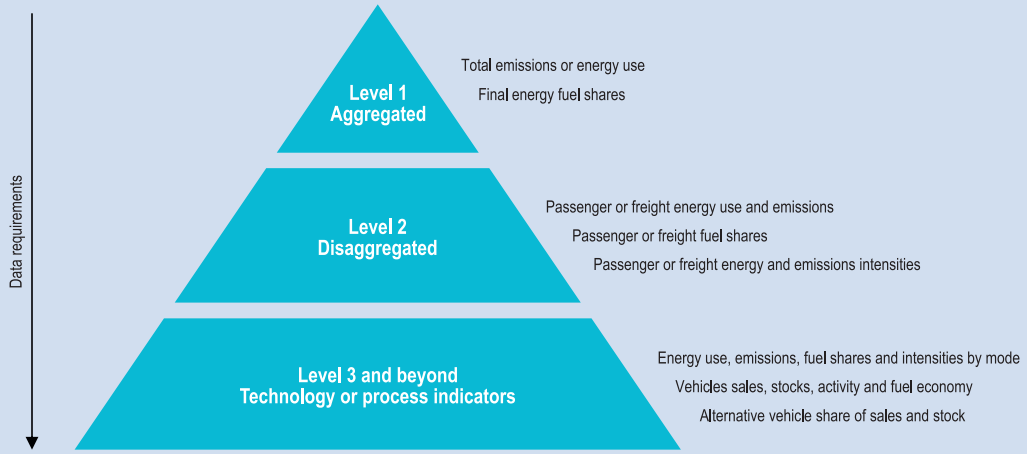
The Paris Agreement is based on bottom-up submission and implementation of NDCs. While they are a very significant step forward, IEA analysis has found that the path set by the initial round of NDCs would be consistent with average global temperature increase of around 2.7°C by 2100, falling short of the goal to keep global temperature rise well below 2°C (IEA, 2015a).

In addition to using high-level metrics, the IEA recommends that countries build capacity to collect detailed sectoral and sub-sectoral data, with the precise set of detailed metrics tailored to fit national targets and objectives. This disaggregation would facilitate understanding of changes within the energy system to better inform policymaking. Disaggregation of data is particularly helpful in understanding trends in energy demand, as changes in energy consumption can be affected by economic activity levels, economic structure, and energy efficiency gains. To disentangle the causes of overall energy demand shifts (and hence to tailor the energy efficiency policy mix) requires these more detailed indicators.

As an example, Figure 8.4 shows possible disaggregated indicators for the transport sector. High-level indicators can give a picture of total emissions and energy use within the sector, but to understand what gives rise to these requires further breakdown, for example between passenger and freight modes, and information on performance improvements within road and rail transport, public transportation and aviation. Finally, indicators of new investment in the sector (e.g. the share of alternative vehicle sales) can be tracked as a driver metric that will indicate future direction over the lifetime of these assets. A similar breakdown can be undertaken for each energy sub-sector.

Figure 8.4

Disaggregated data: Example of metrics to track progress in transport



Source: IEA (2015c). Energy Technology Perspectives 2015.

8.4. Conclusion: A strengthened tracking framework can support more effective energy sector change

With the Paris Agreement in place, the challenge for countries now is implementation. As described above, the UNFCCC process can offer assistance across the three dimensions of choosing the right metrics, establishing tracking frameworks (both within and alongside the UNFCCC) and collecting data, and the IEA and other specialised agencies can provide support.

To strengthen the tracking framework and related energy sector metrics and data, policy makers at the national level should consider what metrics are needed within their own countries to capture progress in long-term energy sector transformation, complementary to the GHG emissions figures reported to the UNFCCC. These should include both *outcome* and *driver* metrics, so that countries gain an understanding of both the current status and future direction of their energy transition. An example of an outcome metric is the carbon intensity of transport demand, while a driver metric would be the vehicle fuel economy of new car sales. A set of high-

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level energy indicators for each country, following a consistent methodology applied globally, would not only be useful for countries to assess their own low-emissions development pathways, but would also reveal the speed and direction of transition globally.

Not only will the right metrics, supported by robust data, enhance the credibility of the tracking framework: they can also promote action to support sound low-carbon energy sector transition and make the goal of reducing emissions to limit temperature increase to well below 2°C more achievable.

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Chapter 9 • Energy and emissions data

Tracking progress in the transition to low-carbon energy systems, including action taken through countries' nationally determined contributions (NDCs), is necessary to focus attention on the steps needed to achieve both short- and long-term climate goals. As targets become increasingly challenging to meet, measuring and tracking progress become all the more important. United Nations (UN) climate agreements have so far focused tracking efforts on greenhouse gas (GHG) emissions information. While vitally important, tracking GHG targets alone cannot reveal whether changes are occurring rapidly enough in the underlying energy infrastructure. Chapter 8 discusses a wider suite of energy metrics (e.g. renewable energy deployment, energy efficiency improvements and low-carbon investments) that could be used to inform both the international process and the development of national climate action plans. This chapter presents a selection of these metrics for the ten global regions and the aggregate world region.

9.1 Introduction

This chapter presents some of the latest International Energy Agency (IEA) data on GHG emissions and energy metrics that could be helpful in tracking progress towards deep decarbonisation in the energy sector. As discussed in Chapter 8 and in other IEA publications (IEA, 2014; 2015a), the metrics used to track energy sector decarbonisation play an important role in framing policy decisions. Timely, accurate and credible GHG emissions data provide an essential benchmark of progress, but reveal only part of the picture. Non-GHG energy sector metrics can provide greater insight into underlying changes to the energy sector and drivers of future emission trends, and aid in tracking efforts of countries and their contributions toward global climate targets. Tracking measurements such as energy intensity and efficiency can also help to reframe policy objectives, while delivering multiple and potentially more tangible benefits including reduced energy costs and enhanced energy independence.

This chapter first presents interregional comparisons on several key indicators, and then provides an in-depth analysis of each of the global regions to provide further insight into regional energy and emissions trends and their drivers. The chapter presents both historical data (1990-2014) and model results for 2025 and 2050 from the 2°C Scenario (2DS) of the IEA *Energy Technology Perspectives* (*ETP*) 2016 model (IEA, 2016a) to show where we are, how we got here, and where need to be. A complete description of the indicators is available in the Appendix (Section 9.4).

9.2 Interregional comparisons on key indicators

Interregional comparisons on key emissions and energy indicators can help to show how the energy trajectories and current situations of specific regions compare and contrast. This section compares select regions on four key metrics from 1990 to 2014:

- **Carbon dioxide (CO_2) emissions** from fuel combustion[1] (Figure 9.1);
- **Carbon intensity of energy supply (CO_2/TPES):** CO_2 emissions per unit of total primary energy supply (TPES), also referred to as the Energy Sector Carbon Intensity Index (ESCII) (Figure 9.2);
- **CO_2 emissions per capita** (Figure 9.3);
- **Energy intensity (TPES/GDP):** TPES per unit of gross domestic product (GDP) (in 2014 USD purchasing power parity [PPP]) (Figure 9.4).

1. Including international marine and aviation bunkers but excluding process emissions.

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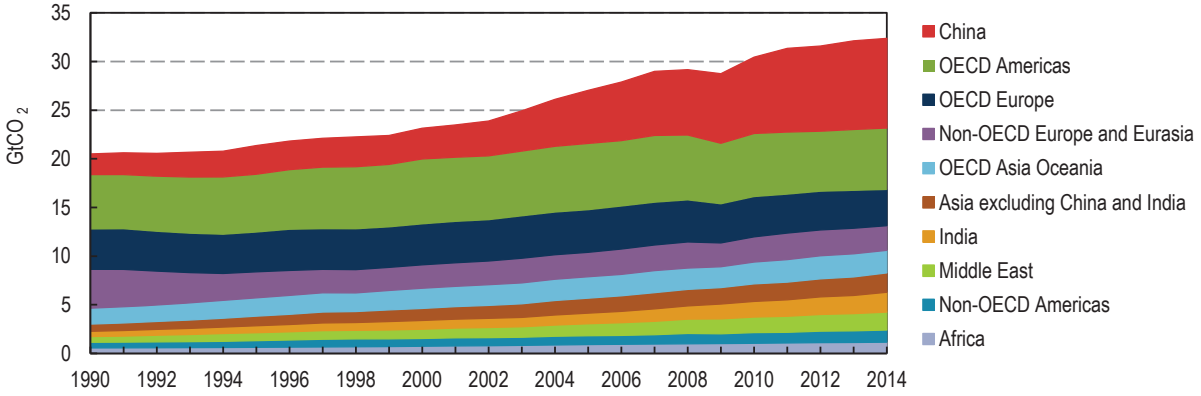
Figure 9.1

CO_2 emissions: Contributions over time



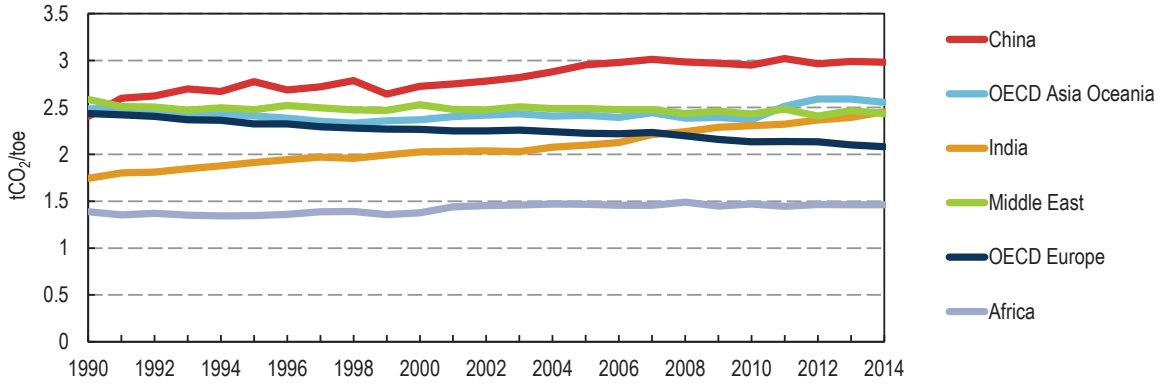
Note: $GtCO_2$ = gigatonnes of carbon dioxide. Regions ordered based on 2014 CO_2 emissions from fuel combustion.

- In 2014, global energy-related CO_2 emissions rose to their highest-ever levels, with CO_2 emissions of non-Organisation for Economic Co-operation and Development (OECD) regions accounting for the majority of global emissions (62%) and The People's Republic of China (hereafter "China") alone representing 28.5%. In 1990, OECD regions produced 55% of global CO_2 emissions, but since 2005, non-OECD regions have produced the majority of global emissions.

- Only two regions have reduced their CO_2 emissions from 1990 to 2014: non-OECD Europe and Eurasia (37% decrease or 1.5 gigatonnes [Gt]) and OECD Europe (10% decrease or 0.4 Gt). Since 1990, China has experienced the greatest increase in emissions (7.1 Gt or 334%) followed by India (1.5 Gt or 280%).

Figure 9.2

Carbon intensity of energy supply (ESCII)



Note: tCO_2/toe = tonnes of carbon dioxide per tonne of oil-equivalent.

- In 2014, India's carbon intensity of energy supply surpassed that of the Middle East for the first time. In 1990, India's ESCII was one-third lower than that of the Middle East.

- Since 1990, four world regions (not all shown) have experienced ESCII improvements: OECD Europe, non-OECD Europe and Eurasia, the Middle East, and OECD Americas. OECD Asia Oceania experienced a slight decline in carbon intensity of energy supply up to 2011, at which point it rose significantly due to the shutdown of substantial nuclear generation in Japan.

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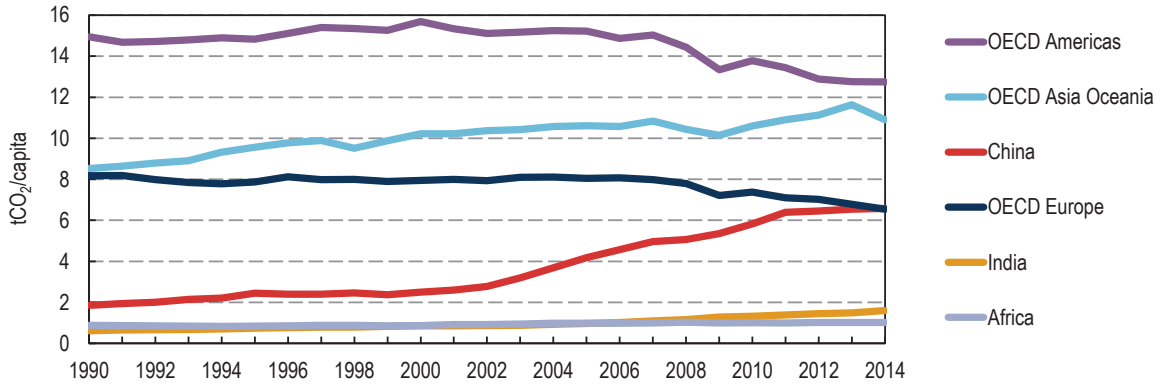
Figure 9.3

CO_2 emissions per capita

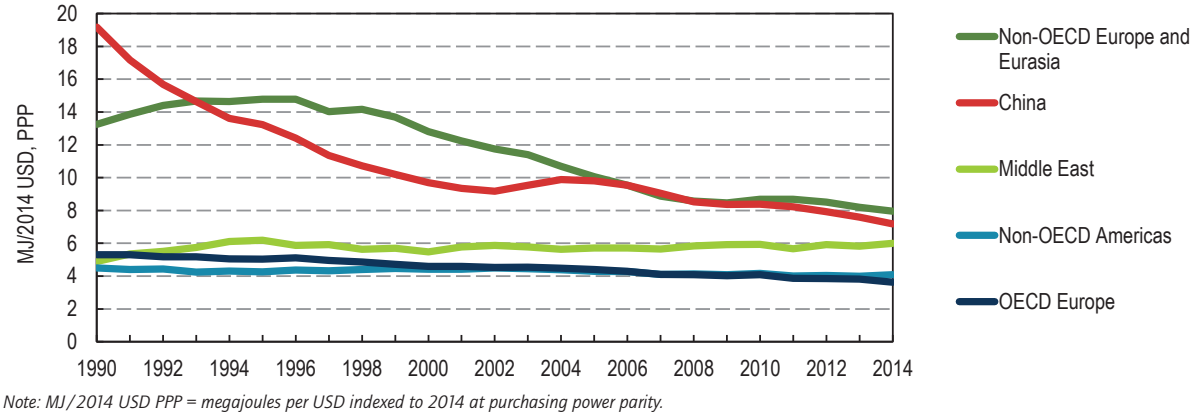


- CO_2 emissions per capita of China and OECD Europe converged for the first time in 2014. Per capita emissions in Europe have fallen by 20% since 1990, while China's have increased by over 250% over the same period.

- Despite decreasing by 15% since 1990, OECD Americas continues to have the highest CO_2/capita of all regions (13 tCO_2/capita), almost three times higher than the global average (4.5 tCO_2/capita). Africa's per-capita emissions remain the lowest at just 1.0 tCO_2/capita.

Figure 9.4

Energy intensity (TPES/GDP)



Note: MJ/2014 USD PPP = megajoules per USD indexed to 2014 at purchasing power parity.

- At the global level, energy intensity has declined every year since 1990 with the exception of 2010.

- China's energy intensity has decreased the most of all regions since 1990. The Middle East was the only region to increase its energy intensity during this period, although the level has remained relatively constant since the mid-1990s.

- In 2007, OECD Europe surpassed non-OECD Americas to become the least energy-intensive region. In 2014, non-OECD Europe and Eurasia was the world's most energy-intensive region.

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9.3 Regional data and indicators

To enable an in-depth look at trends at the regional level, this section presents key energy and emissions data and indicators from 1990 to 2014, as well as modelling results for 2025 and 2050 from the 2°C Scenario (2DS) of *ETP 2016* (IEA, 2016a).

Key indicators are presented in three graphs for the aggregate world region and each of the ten global regions:

- The first graph on each page shows **CO_2 emissions by fuel and by sector in 2014.**[2]
- The second graph charts four key indicators from 1990 to 2014, indexed to 1990 levels, as well as 2025 and 2050 results from the *ETP 2016* 2DS:
  - **CO_2 emissions** from fuel combustion[3]
  - **Carbon intensity of energy supply (CO_2/TPES)**, also referred to as ESCII
  - **Energy intensity (TPES/GDP)**
  - **GDP per capita.**
- The third graph charts key indicators for the electricity sector from 1990 to 2014, as well as 2025 and 2050 results from the *ETP 2016* 2DS:
  - **CO_2 intensity of electricity** (left axis, indexed to 1990)
  - **Share of low-carbon[4] generation in the electricity mix** (left axis, %)
  - **Net additions of low-carbon power** (right axis, gigawatts [GW] per year), comprised of **net additions of renewable power capacity** and **net additions of nuclear and carbon capture and storage (CCS) power capacity.**

2. International aviation and marine bunkers are only included in the World figures.

3. Includes international marine and aviation bunkers but excludes process emissions.

4. Low-carbon comprises renewable sources (bioenergy, hydropower including pumped storage, onshore and offshore wind, solar photovoltaic [PV], concentrating solar power [CSP], geothermal, and ocean technologies) plus nuclear and carbon capture and storage (CCS) sources.

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World

Global energy-related CO_2 emissions reached 32.4 Gt in 2014, while energy intensity declined to its lowest-ever level in 2014, 30% below 1990 levels.

Figure 9.5

CO_2 emissions by fuel and sector, 2014

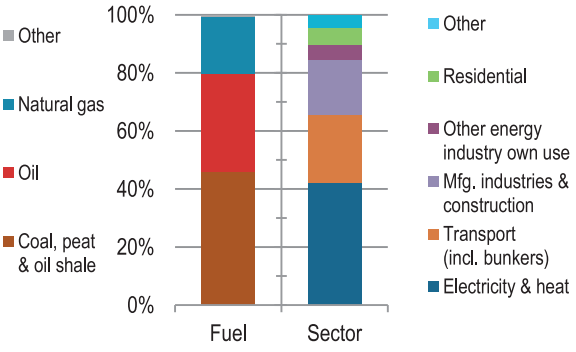


Figure 9.6

Energy sector-wide metrics

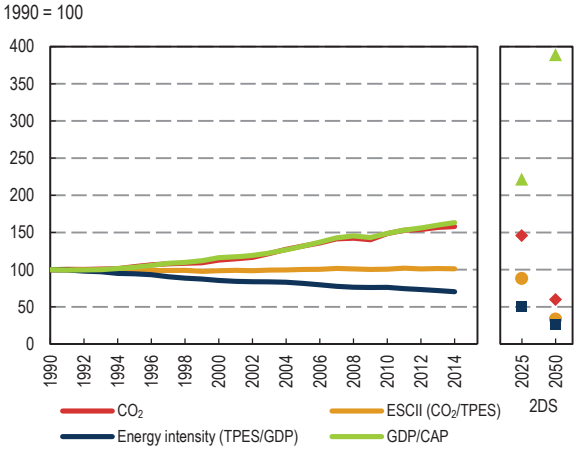
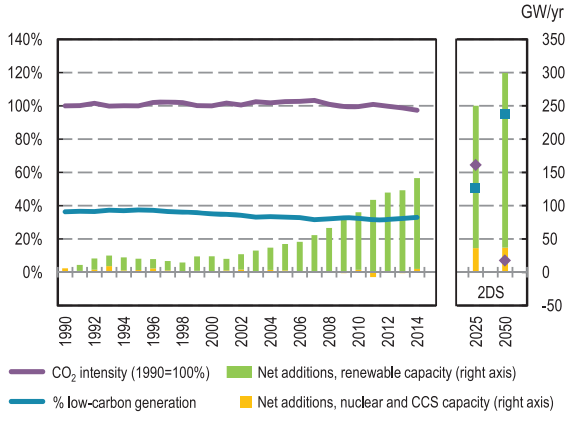


Figure 9.7

Electricity sub-sector metrics



Where we are and how we got here

- Global energy-related CO_2 emissions rose to their highest-ever levels in 2014, 58% above 1990 levels. Coal remained the largest contributor to emissions by fuel (46%), while electricity and heat accounted for the largest sectoral share (42%). International aviation and marine bunkers accounted for 1.1 Gt (3.5%).
- The carbon intensity of energy supply (CO_2/TPES, or ESCII) decreased slightly in 2014. Overall decarbonisation of the global energy supply since 1990 has been negligible.
- On a positive note, energy use continued to decouple from economic growth, with energy intensity of economic output (TPES/GDP) declining to its lowest-ever level in 2014, 30% below 1990 levels.
- In 2014, the average emissions intensity of power generation reached its lowest level since 1990 (519 grammes per kilowatt hour [g/kWh]). Power sector carbon intensity has declined only 3% since 1990, although the expansion of renewables has helped drive more steady improvements in power sector carbon intensity over the last several years.
- In 2014, net additions of renewable capacity reached an historic high, despite the prices of oil and other fossil fuels falling sharply in many parts of the world. Countries including India and Indonesia used this opportunity to move ahead with the phase-out of fossil fuel subsidies.

Where we need to be

- In the 2DS, a reduction in carbon intensity of the energy supply (ESCII) overcomes the stagnation in progress over the past several decades to reach one-third of current levels by 2050.
- Carbon intensity of power generation declines to less than 10% of the 2014 level by 2050 in the 2DS, with low-carbon sources comprising 95% of the electricity generation mix. These changes help to limit CO_2 emissions growth.
- IEA analysis clearly shows that across numerous metrics, the world is not on track to limit temperature rise to 2°C.

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OECD Americas

Energy-related CO_2 emissions continued to rise in 2014, while the carbon intensity of energy supply and energy intensity of economic activity declined slightly.

Figure 9.8

CO_2 emissions by fuel and sector, 2014

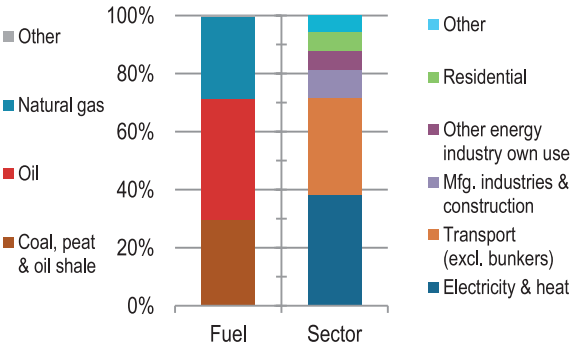


Figure 9.9

Energy sector-wide metrics

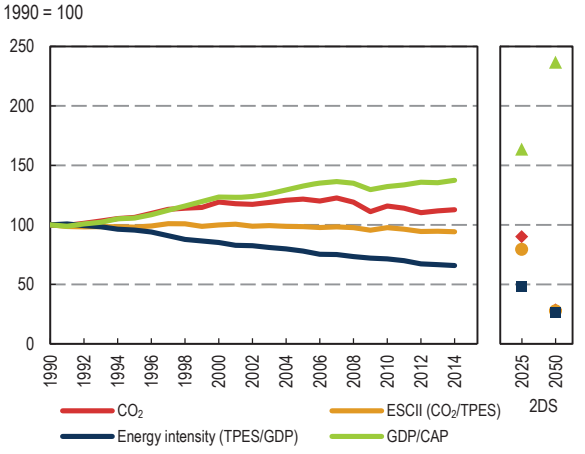
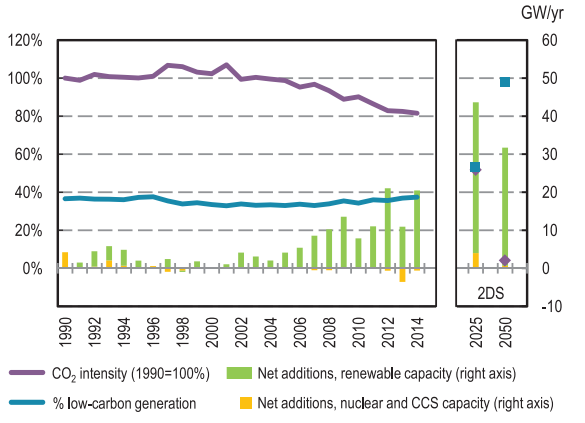


Figure 9.10

Electricity sub-sector metrics



Where we are and how we got here

- Emissions rose in 2013 and 2014, following two years of decline. Oil remained the largest source of CO_2 emissions by fuel type (41%), while the electricity and heat sector was the leading contributor by sector (38%), followed by transport (33%).
- This region also experienced a small decline in energy sector carbon intensity (CO_2/TPES). Since 1990, ESCII has declined 6% in the region.
- Energy intensity continued to decline in 2014, falling 1.1%. It has decreased by 34% since 1990.
- In the power sector, carbon intensity of generation fell slightly in 2014 to 441 g/kWh, and has declined by 18% since 1990.
- Net additions of low-carbon capacity reached an unprecedented high in 2014, up from 2013 when net additions declined from the previous year. However, the decline in 2013 reflects a substantial retirement of nuclear capacity as well as a drop in wind power additions in the United States (due to uncertainty in the prior year over the extension of the production tax credit). However, the addition of other low-carbon generation sources, notably solar power, continued to rise in 2013 and 2014.
- OECD Americas has the highest CO_2/capita emissions (12.8 tCO_2/capita) of all regions.

Where we need to be

- In the 2DS, emissions fall to one-quarter of 2014 levels by 2050, while energy intensity and carbon intensity of energy supply continue their downward trajectory. CO_2/capita falls to one-fifth of 2014 levels by 2050.
- Carbon intensity of power generation declines to about 280 g/kWh by 2025 and to near-zero by mid-century in the 2DS, driven by the phase-out of coal-fired power in Canada and the United States.

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OECD Asia Oceania

In 2014, CO_2 emissions fell for the first time since 2009, while carbon intensity of power generation experienced its largest percentage decline since 1990.

Figure 9.11

CO_2 emissions by fuel and sector, 2014

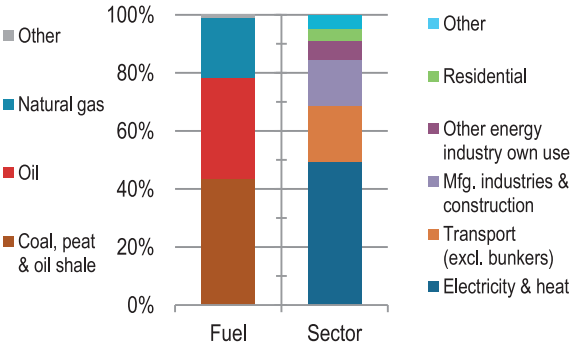


Figure 9.12

Energy sector-wide metrics

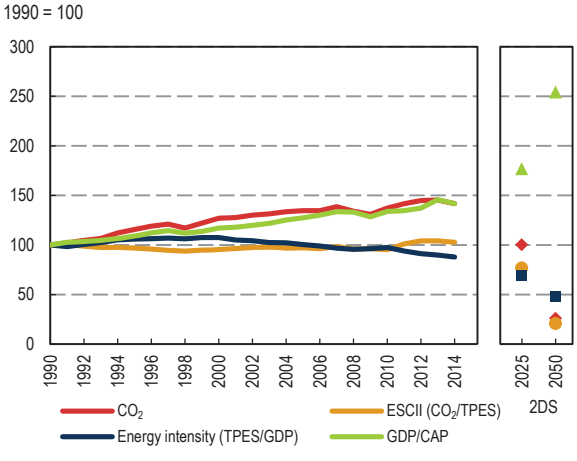
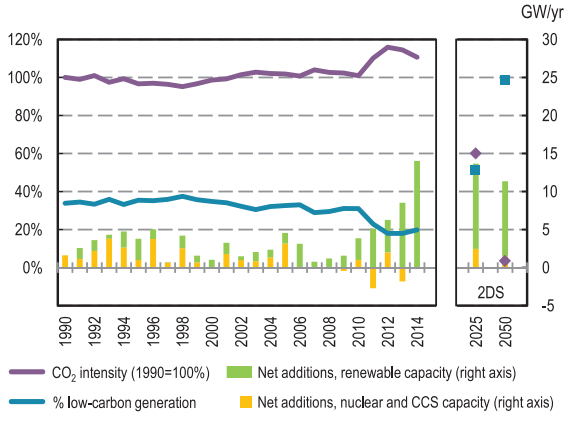


Figure 9.13

Electricity sub-sector metrics



Where we are and how we got here

- In 2014, CO_2 emissions fell for the first time since 2009, down 2.5% to 2.3 Gt, but were 41.5% above 1990 levels. The electricity and heat sector accounted for nearly half of the total emissions in this region.
- The region's largest historical rise (9%) in carbon intensity of energy supply (ESCII) occurred between 2010 and 2012 due to the substantial shutdown of nuclear power plants following Japan's Fukushima Accident. ESCII decreased 1.5% in 2014, but remained above the 1990 level.
- Energy intensity of GDP continued its decline, underway since the beginning of the 2000s, reaching its lowest level since 1990. This steady drop reflects the continued decoupling of energy use and GDP.
- In the electricity sector, carbon intensity of generation fell to 561 g/kWh in 2014, its largest percentage decline since 1990.
- In Japan, coal's share of generation stabilised in 2014 after a large increase in 2013. In both Korea and Australia, the second and third largest power producers in the region, the proportion of low-carbon sources in the power generation mix increased in 2014. In Korea, the share of coal remained unchanged, while the share of natural gas fell.
- Renewable power generation continued to rise in the region, led by gains in solar PV, followed by onshore wind and hydropower. Japan accounted for 68% of the regional increase in total renewable generation.
- In 2014, CO_2/capita in this region (11 t/capita) remained second highest in the world behind OECD Americas.

Where we need to be

- In the 2DS, the decline in energy intensity accelerates, while carbon intensity of energy supply and CO_2 emissions drop to one-fifth of 2014 levels by 2050.
- Carbon intensity of electricity drops to just 3% of 2014 levels in the 2DS by 2050, driven by a 98% share of low-carbon sources in the generation mix.

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OECD Europe

In 2014, CO_2 emissions in OECD Europe declined by the greatest percentage among the ten global regions, falling by over 4%.

Figure 9.14

CO_2 emissions by fuel and sector, 2014

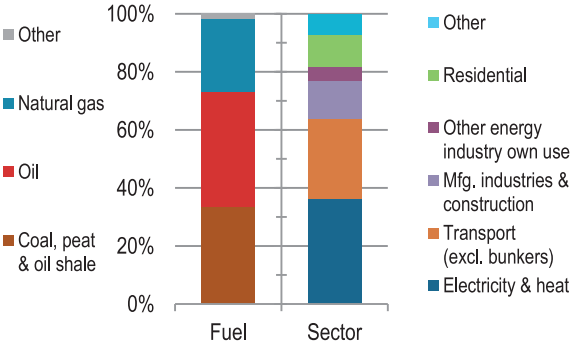


Figure 9.15

Energy sector-wide metrics

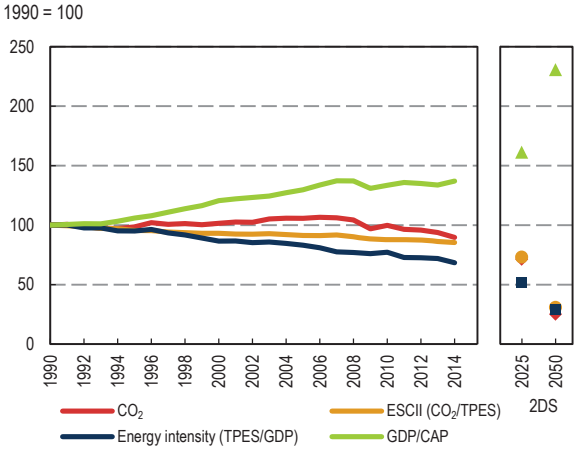
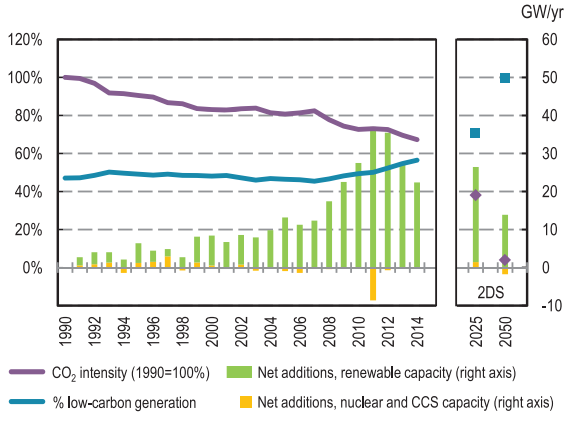


Figure 9.16

Electricity sub-sector metrics



Where we are and how we got here

- OECD Europe was one of three global regions in which total emissions declined in 2014. CO_2 emissions decreased by over 4%, driven largely by a drop in the carbon intensity of the energy supply (ESCII). Oil was the largest emissions source by fuel (40%), while electricity and heat accounted for the largest sectoral share (37%).
- Emissions fell in each of the highest emitters in the region, including declines of more than 5% in Germany, the United Kingdom, Italy and France.
- The 2014 drop in energy intensity (4.9%) was the second largest since 1990.
- Coal and oil consumption declined in 2014, due in part to increased deployment of renewable energy and a drop in overall energy demand. Since 1990, ESCII in this region has dropped by 15% – the largest decline of all regions.
- In 2014, carbon intensity of electricity declined to its lowest level since 1990. The shares of solar and wind continued to rise in 2014 while the proportion of fossil fuels in the generation mix declined.
- The share of low-carbon generation increased to 57% in 2014, although net low-carbon capacity additions continued to fall from their 2012 peak as investments in renewable energy slowed. The region's demand for power declined slightly in 2014, as a consequence of both sluggish economic growth and improvements in energy efficiency.
- The share of nuclear in the generation mix has trended downward over the past two decades, punctuated by the retirement of eight nuclear reactors in Germany in 2011.

Where we need to be

- In the 2DS, CO_2 emissions fall to 20% below 2014 levels by 2025, and to 72% below 2014 levels by 2050.
- Carbon intensity of electricity generation drops to almost half of 2014 levels by 2025 and to just 18 g/kWh by 2050 in the 2DS, as the share of low-carbon generation rises to 99% by mid-century.

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Africa

Africa has by far the world's lowest-emitting energy supply given its dependence on bioenergy, although the traditional use of solid biomass is associated with negative economic, social and environmental impacts.

Figure 9.17

CO_2 emissions by fuel and sector, 2014

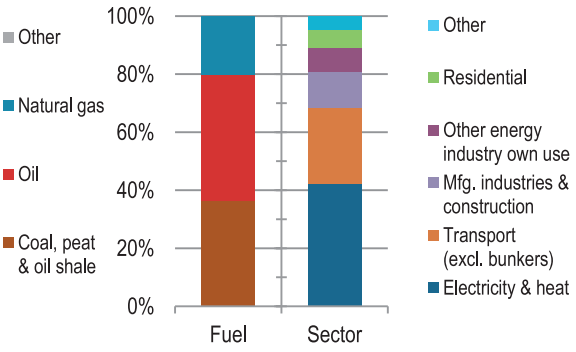


Figure 9.18

Energy sector-wide metrics

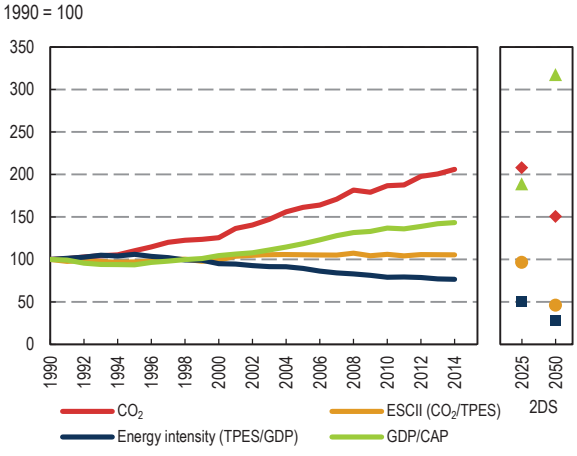
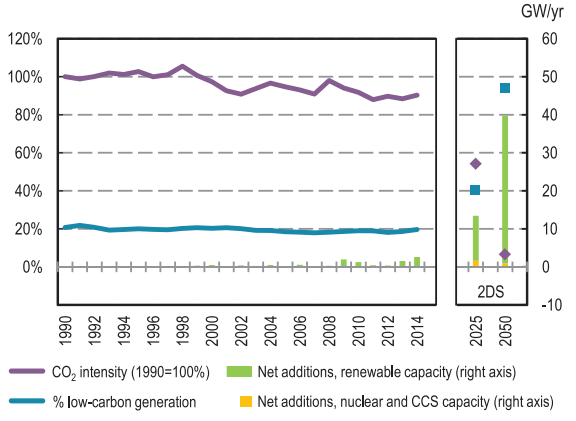


Figure 9.19

Electricity sub-sector metrics



Where we are and how we got here

- CO_2 emissions increased by almost 3% to 1.15 Gt in 2014, accounting for just 3.6% of total global emissions. Carbon intensity of energy supply (ESCII) remained stable while energy intensity continued to decline.
- Since 1990, Africa has had by far the lowest-emitting energy supply (ESCII) of all regions. However, this is largely due to its dependence on traditional biomass in the residential sector (for cooking and heating), associated with negative health and economic impacts.
- Carbon intensity of electricity generation increased to 615 g/kWh in 2014, and remains higher than the global average of 519 g/kWh. Since 1990, carbon intensity has declined by 10%, due to a decreasing share of coal in the generation mix (declining to its lowest-ever level in 2014).
- Net additions of low-carbon capacity (2.6 GW) reached by far their highest levels in 2014, led by wind and solar PV.
- Electricity access remains a substantial challenge in this region, with electricity access rates highly varied across the continent. In North Africa, 99.4% of the population had access to electricity in 2013. In Sub-Saharan Africa, access ranged from less than 3% in parts of Central Africa to 85% in South Africa, averaging 32% across the region.
- This region produces the lowest level of CO_2 emissions per capita (1.0 t/capita in 2014), less than a quarter of the global average.

Where we need to be

- In the 2DS, emissions rise modestly over the medium term and fall to three-quarters of 2014 levels by 2050. The region's share of global emissions increases from 3.5% in 2014 to 7% by 2050.
- By 2050, carbon intensity of power supply drops to 45 g/kWh under the 2DS, while net annual additions of low-carbon electricity (mostly renewables) rise substantially to 15 times the 2014 additions by mid-century.

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Non-OECD Americas

Drought conditions resulted in the continued decline of hydropower generation while the share of fossil fuels in the generation mix increased to its highest level since 1990.

Figure 9.20

CO_2 emissions by fuel and sector, 2014

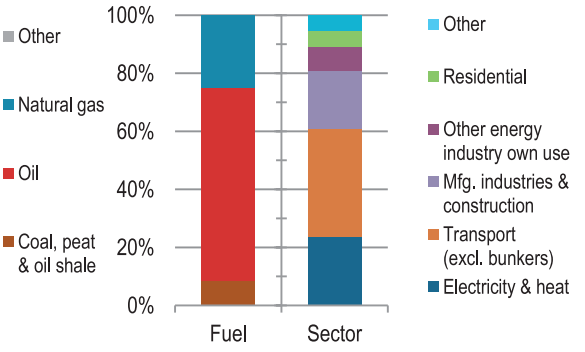


Figure 9.21

Energy sector-wide metrics

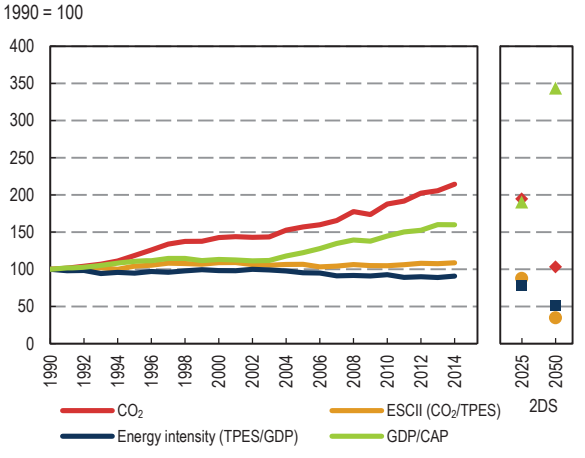
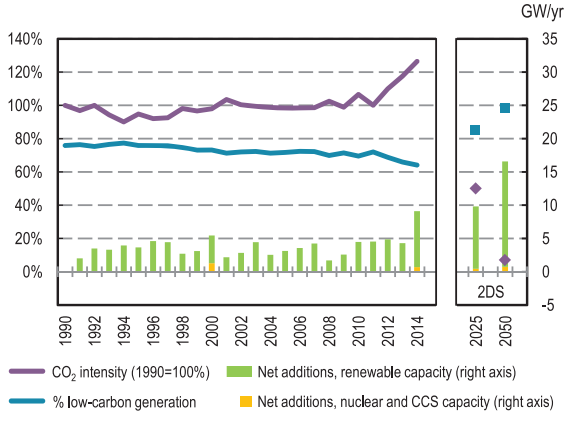


Figure 9.22

Electricity sub-sector metrics



Where we are and how we got here

- Energy-related CO_2 emissions increased by more than 4% in 2014, reaching 1.25 Gt. The region's emissions have more than doubled since 1990.
- This region has the cleanest power supply of all global regions, and consequently a relatively low sectoral share of emissions from electricity and heat. With transport contributing the highest sectoral share, oil accounted for about two-thirds of the region's CO_2 emissions.
- In 2014, carbon intensity of energy supply (ESCII) rose 1%, with the rise in primary energy supply of natural gas and oil partly offset by a rise in biofuel consumption.
- In the power sector, carbon intensity of generation rose to 230 g/kWh, its highest level since 1990, as drought conditions continued to bring down the share of hydropower to just 56%, its lowest level since 1990. Fossil fuel generation increased to its highest level since 1990 to fill supply gaps.
- Despite a decline in hydropower production, renewable generation remained stable in 2014 due to a doubling of onshore wind generation. Net additions of low-carbon generation amounted to 9.1 GW in 2014, more than double the previous year's additions.
- This region continues to have the cleanest power supply of all regions, with an emissions intensity of less than half the global average.

Where we need to be

- In the 2DS, CO_2 emissions level off and subsequently decrease to less than half of the 2014 level by 2050, while ESCII falls to less than one-third of the 2014 level by 2050.
- With the growing deployment of renewables in the 2DS, the power sector becomes nearly non-emitting in 2050, with the share of low-carbon generation increasing from 64% in 2014 to 98% by mid-century.

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Non-OECD Europe and Eurasia

Non-OECD Europe and Eurasia was one of three regions to experience an emissions decline in 2014, the others being OECD Asia Oceania and OECD Europe.

Figure 9.23

CO_2 emissions by fuel and sector, 2014

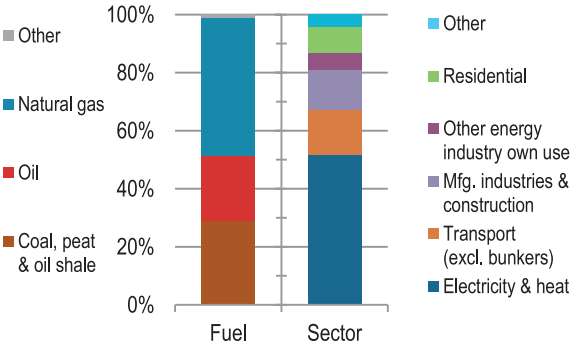


Figure 9.24

Energy sector-wide metrics

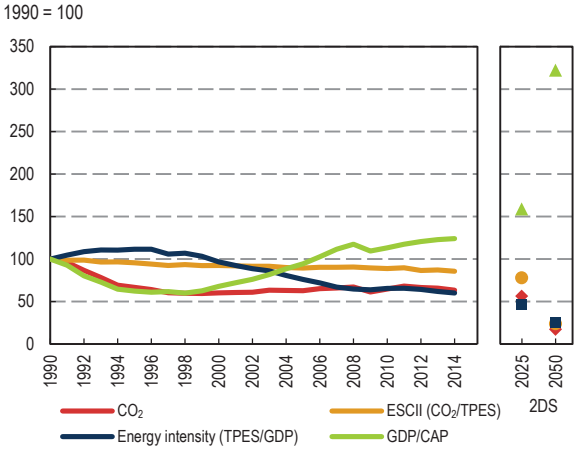
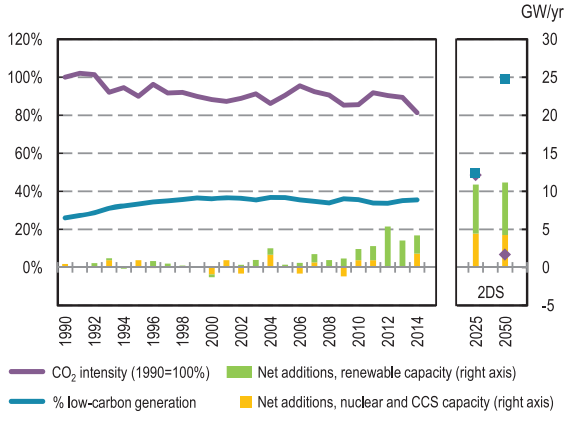


Figure 9.25

Electricity sub-sector metrics



Where we are and how we got here

- CO_2 emissions declined by 3.7% in 2014 and have fallen by 37% since 1990. Natural gas accounted for the largest share of emissions by fuel (47%), while the electricity and heat sector accounted for more than half (52%) of emissions in 2014.
- This region has the fourth highest CO_2/capita (7.4 t/capita) among all regions, slightly higher than OECD Europe (6.5 t/capita).
- After having increased slightly in 2013, the carbon intensity of energy supply (ESCII) resumed its longer-term trajectory of decline, falling 2% in 2014. Since 1990, ESCII has dropped by 14%.
- The region's energy intensity continued to decline in 2014, falling by almost 3%, but remains the highest in the world. The Russian Federation, the region's highest emitter, is also among the world's largest holders of fossil fuel resources. Its economy is highly dependent on hydrocarbons and remains comparatively energy and emissions-intensive, emitting 60% more CO_2 per unit of GDP than IEA member countries.
- Total energy supplied (TPES) to the region fell by almost 2% in 2014, the second largest regional decline after OECD Europe.
- Carbon intensity of electricity declined by 9% in 2014 as the share of low-carbon generation rose. In 2014, the region added approximately 2.4 GW of new renewable power capacity, a smaller increase than in both 2012 and 2013.

Where we need to be

- In the 2DS, CO_2 emissions decline to about one-quarter of 2014 levels by 2050. ESCII continues a downward trend, reaching almost a quarter of its 2014 level by 2050.
- In the power sector, carbon intensity falls to about 60% of the 2014 level by 2025 and to 8% of 2014 levels by 2050 under the 2DS, as low-carbon sources comprise 99% of the generation mix by mid-century.

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Middle East

All regions except the Middle East have improved their energy intensity since 1990.

Figure 9.26

CO_2 emissions by fuel and sector, 2014

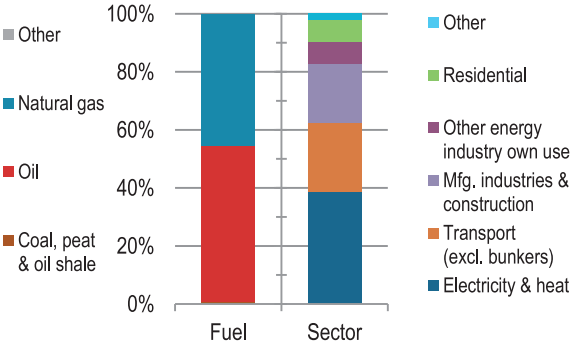


Figure 9.27

Energy sector-wide metrics

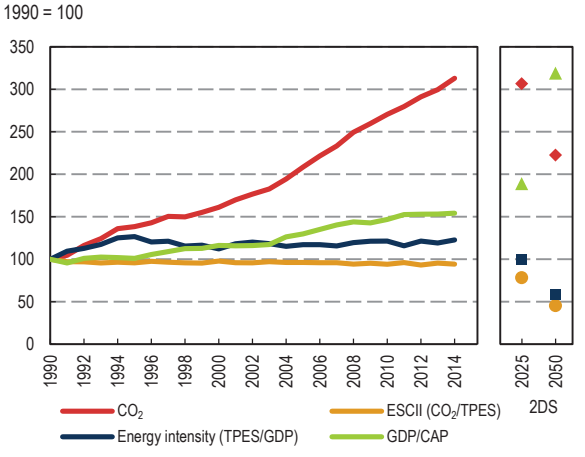
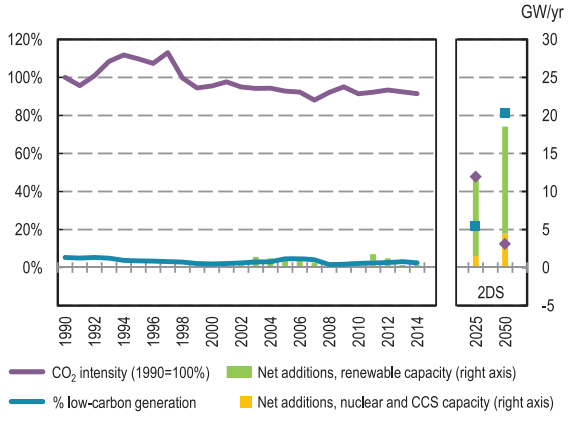


Figure 9.28

Electricity sub-sector metrics



Where we are and how we got here

- Driven by economic and population growth, emissions have risen more than three-fold in the Middle East since 1990 – the third largest increase after China and India during this period. Carbon intensity of energy supply (ESCII) has remained relatively unchanged over the past two decades.
- With a 23% increase in TPES/GDP since 1990, the Middle East is the only region not to have reduced the energy intensity of its economy over this period. This lack of decoupling between energy use and economic growth reflects the region's continued dependence on energy resource extraction for economic growth.
- GDP per capita has remained essentially flat in this region since 2011, while emissions have continued to rise. This region had the second lowest per capita GDP growth rate during this time period.
- The power sector is more fossil fuel-dependent than that of any other region, with over 97% of electricity generation derived from fossil fuels, primarily oil and gas. Net additions of renewables in 2014 amounted to only 0.34 GW.
- Although the carbon intensity of electricity generation decreased by 1% in 2014, the region's power sector remains the world's third most carbon-intensive, behind coal-heavy China and India, and over 30% more carbon-intensive than the global average.

Where we need to be

- In the 2DS, CO_2 emissions level off by 2025 and fall by nearly one-third from the 2014 level by 2050, driven by both a steep decline in energy intensity of the economy and in the carbon intensity of energy supply.
- Net low-carbon capacity additions, which have consistently been the lowest among all regions, rise dramatically by mid-century under the 2DS to 19 GW – more than 50 times the 2014 rate. Low-carbon generation accounts for over 80% of generation by 2050, compared with just 3% in 2014.

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Asia (excluding China and India)

In 2014, energy-related CO_2 emissions rose nearly 5% to its highest level in Asia (excluding China and India), while energy intensity continued to decline.

Figure 9.29

CO_2 emissions by fuel and sector, 2014

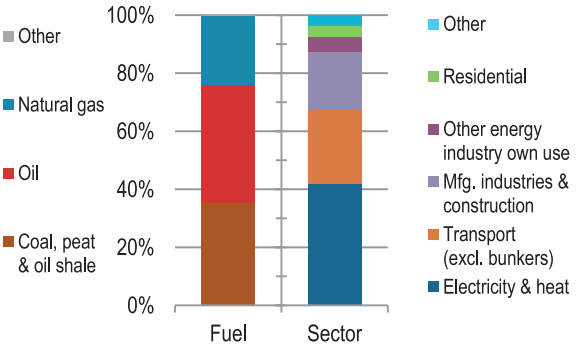


Figure 9.30

Energy sector-wide metrics

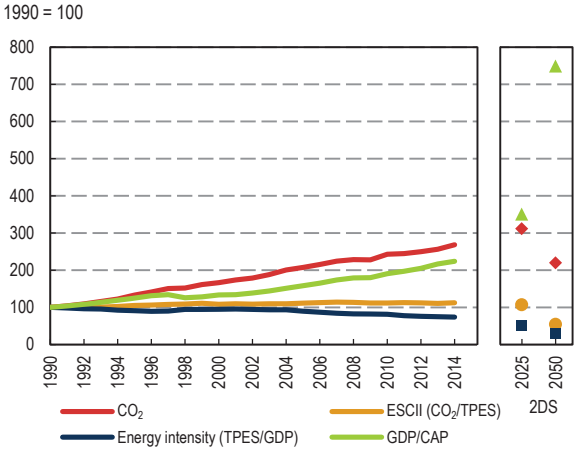
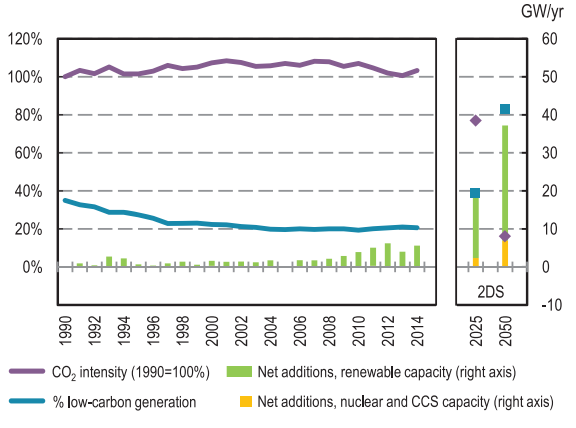


Figure 9.31

Electricity sub-sector metrics



Where we are and how we got here

- In 2014, CO_2 emissions increased 4.6% to 2.0 Gt. Oil was the leading source of emissions by fuel type, while the electricity and heat sector had the largest sectoral share (42%).
- Since 1990, CO_2 emissions have consistently increased in this region; only in 2009 with the economic recession did emissions decline (by less than 1%).
- Opposing drivers of CO_2 trends were at play in 2014, with carbon intensity of energy supply (ESCII) rising as energy intensity (TPES/GDP) fell.
- In 2014, energy intensity was the third lowest energy intensity among the world regions, declining by 1.3%. Meanwhile, GDP has more than tripled since 1990, reflecting the region's success in achieving strong economic growth without commensurate growth in energy use.
- Nonetheless, carbon emissions have been increasing due to the growing population and increasing carbon intensity of the energy supply (ESCII). ESCII has risen by 12.5% in the region since 1990, while globally ESCII has increased by just 1% over the same period.
- In 2014, net additions of low-carbon capacity increased to 5.6 GW, but the share of low-carbon generation remained constant at 21%, well below the global average of 33%.
- Following several years of decline, carbon intensity of electricity generation increased by 3% to 561 g/kWh.

Where we need to be

- In the 2DS, CO_2 emissions continue to increase over the medium term but decrease to 18% below 2014 levels by 2050. ESCII declines to less than half of 2014 levels by 2050.
- The share of low-carbon electricity generation increases substantially in the 2DS, reaching 83% of the generation mix by mid-century. Net additions of low-carbon power triple by 2025 and grow almost seven-fold by 2050.

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China

China's net additions of low-carbon power capacity accounted for almost half of the global total in 2013 and 2014.

Figure 9.32

CO_2 emissions by fuel and sector, 2014

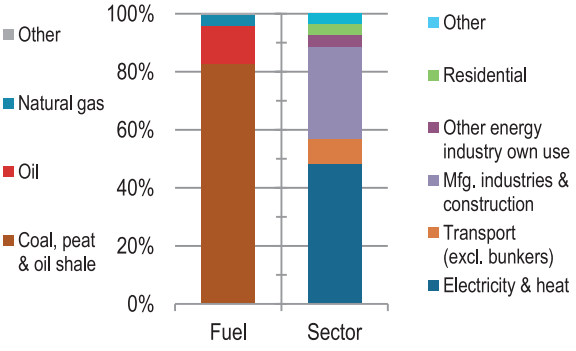


Figure 9.33

Energy sector-wide metrics

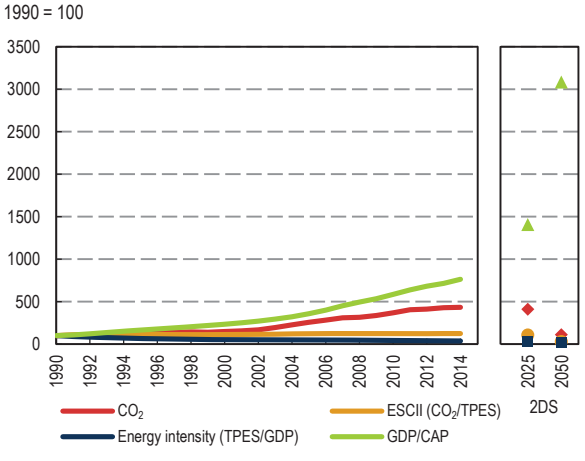
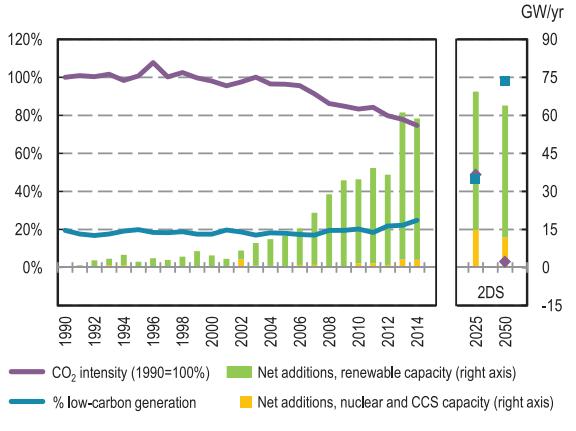


Figure 9.34

Electricity sub-sector metrics



Where we are and how we got here

- In 2014, China's energy-related CO_2 emissions rose by 1.2% to 9.2 Gt, its smallest increase since 1999. China's CO_2 emissions have more than quadrupled since 1990, the highest increase of any region. Per capita emissions in 2014 were 46% higher than the global average, though still about half those of the OECD Americas.
- With its heavy dependence on coal, China has had the most carbon-intensive energy supply among all regions for the past two decades. Since 1990, ESCII has increased by almost 25%, second only to India.
- China has experienced by far the greatest decline in energy intensity of all regions since 1990 (to 38% of its 1990 level), though it was still the second most energy-intensive economy in 2014, after non-OECD Europe and Eurasia.
- Coal has comprised around three-quarters of China's electricity generation mix since 1990. In 2014, China had one of the most coal-dependent power sectors in the world, with coal accounting for over 70% of total generation.
- Renewable energy deployment is taking place at an impressive pace in China. In 2014, China increased its renewable generation capacity by 56 GW, by far the most of any region and about 40% of the global total.
- The share of low-carbon generation increased to an all-time high of 25% in 2014, and has increased rapidly since 2011 (18% share).

Where we need to be

- In the 2DS, China's CO_2 emissions peak before 2025, falling to one-quarter of the 2014 level by 2050. Energy intensity continues to decrease, falling to one-quarter of the 2014 level by mid-century.
- Net additions of low-carbon capacity continue at an impressive pace towards 2025 and 2050 in the 2DS, as China continues to lead the world in net low-carbon additions. The share of low-carbon generation reaches 98% in 2050, up from 46% in 2025.

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India

Since 1990, India has experienced the greatest increase in carbon intensity of energy supply (ESCII) of all regions, but also the greatest decline in energy intensity.

Figure 9.35

CO_2 emissions by fuel and sector, 2014

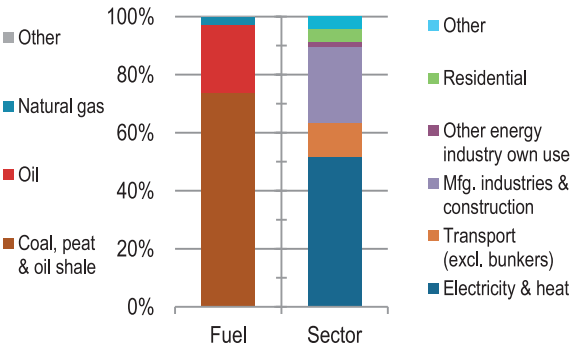


Figure 9.36

Energy sector-wide metrics

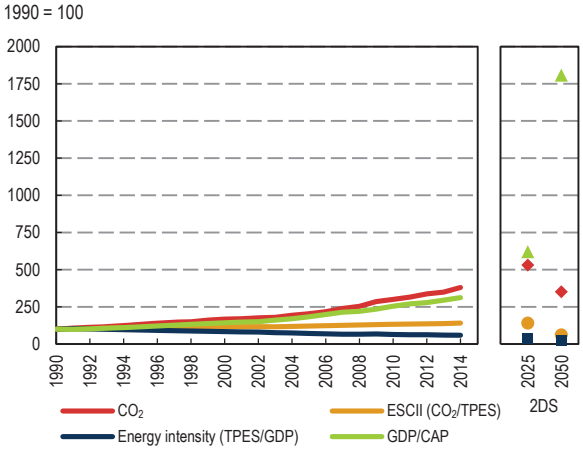
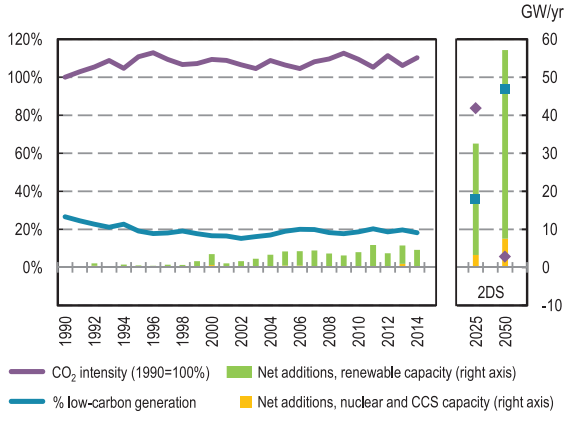


Figure 9.37

Electricity sub-sector metrics



Where we are and how we got here

- In 2014, India's energy-related CO_2 emissions increased 9% to over 2 Gt. It is the third highest-emitting country in the world after China and the United States. Coal is by far the largest CO_2 emissions source by fuel (74%); only 2.8% of emissions are from natural gas.
- Since 1990, CO_2 emissions have almost quadrupled – the highest growth rate of any region except China. Meanwhile, per capita emissions (1.6 t/capita) are the world's second lowest.
- Among the global regions, India has experienced the greatest increase in ESCII since 1990 (41%), driven by an increasing share of coal in India's primary energy supply.
- India's energy demand is rising rapidly, although not as quickly as GDP, indicating a decoupling of energy use and economic growth. Since 1990, energy intensity has declined by over 40%.
- Energy access remains a substantial challenge in India. Progress has been made in expanding electricity access, however, with low-cost coal used to fuel rapidly growing electricity demand. In absolute terms, five times more coal was used for electricity generation in 2014 than in 1990.
- Although low-carbon electricity generation has almost tripled since 1990, its total share in the generation mix has in fact declined from 27% to 18%. Carbon intensity of electricity generation has increased by 10% over this period, to 813 g/kWh in 2014 – highest among the global regions.

Where we need to be

- In the 2DS, India maintains its rate of decoupling economic growth from energy use. Emissions continue to rise in the short to medium term, then decline to the 2013 level by 2050.
- The share of low-carbon generation rises substantially in the 2DS, reaching 94% by mid-century. Net renewable additions in 2050 are second only to China, while India leads the world in net additions of CCS and nuclear.

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9.4 Appendix

Interregional comparisons

Interregional comparisons on key emissions and energy indicators can help to show how the energy trajectories and current situations of specific regions compare and contrast. The focal metric "CO_2 emissions from fuel combustion" is used to track progress towards national and aggregate global climate goals, and can be decomposed into the product of four factors (i.e. Kaya decomposition): CO_2/TPES or ESCII, TPES/GDP, GDP per capita, and population. Two of these indicators – ESCII and TPES/GDP – are compared, along with a population-based metric (CO_2 emissions per capita):

- **CO_2 emissions** from fuel combustion, including international marine and aviation bunkers but excluding process emissions.
- **Carbon intensity of energy supply (CO_2/TPES)**: calculated as CO_2 emissions per unit of TPES, also referred to as the ESCII. GHG metrics that go beyond total GHG emissions, such as the ESCII, can reveal underlying causes of GHG emission changes and where action is needed (IEA, 2014). For example, world ESCII has remained largely unchanged in the last 40 years as increases in clean energy have been matched by increased coal use. As energy demand has risen, so have energy sector emissions. In other words, tracking ESCII shows that the clean energy supply has not kept up with rapid growth, and a more rapid decarbonisation of the energy supply is needed.
- **CO_2/capita**: calculated as CO_2 emissions divided by population.
- **Energy intensity (TPES/GDP)**: calculated as TPES per unit of GDP (in 2014 USD PPP). Energy intensity of economic activity, a measure of an economy's energy efficiency, is an example of a useful metric that is not itself expressed in terms of GHG emissions, but nonetheless tracks actions that will have a short-term impact on GHG emission levels.

Regional data and indicators

For each of the ten global regions[5] and the aggregate world region, three graphs illustrate CO_2 emissions data and other energy sector indicators.

The first graph provides a present-day (2014) snapshot of the relative contributions of different fuels and economic sectors to total emissions in each region. As different fuels emit different quantities of CO_2 per unit of energy released during combustion, understanding the relative emissions contributions of different fuels may reveal potential emission reduction opportunities from fuel switching (e.g. replacing coal with gas for electricity generation). Identifying the relative emissions contributions of different economic sectors helps to elucidate which economic sectors may have the greatest potential to reduce emissions. The figure shows CO_2 emissions by fuel and by sector in 2014 for each region:

- **Fuels**: coal, peat and shale oil; oil; gas; and other fuels, including industrial waste and non-renewable municipal waste.
- **Economic sectors**: electricity and heat generation;[6] transport; manufacturing industries and construction;[7] other energy industry own use; residential; and other (includes emissions from commercial/public services, agriculture/ forestry and fishing).

The second graph shows four key indicators from 1990 to 2014, indexed to 1990 levels. 2025 and 2050 results for the 2DS are derived from the *ETP 2016* model:

- **CO_2 emissions from fuel combustion**, including international marine and aviation bunkers but excluding process emissions.
- **Carbon intensity of energy supply (CO_2/TPES)**: calculated as CO_2 per unit of TPES and also referred to as the ESCII.
- **Energy intensity of economic activity (TPES/GDP)**: calculated as TPES per unit of GDP.
- **GDP per capita**: calculated as GDP (in 2014 USD PPP) divided by population. GDP per capita is an indicator of a region's standard of living, and one of the four drivers of CO_2 emissions (Kaya decomposition).

The third graph charts key indicators for the electricity sector from 1990 to 2014 – electricity being the largest sectoral contributor to global CO_2 emissions (42% in 2014) (IEA, 2016a). 2025 and 2050 results for the 2DS are derived from the *ETP 2016* model (IEA, 2016a). Achieving rapid electrification of end-use sectors (particularly heating and transport), in tandem with low- to zero-emission electricity

5. Refer to Table 9.1 at the end of this chapter for the aggregation of countries within each of the ten world regions.

6. Emissions from unallocated autoproducers (entities generating electricity and/or heat wholly or partially for their own use as an activity which supports their primary activity) are included in the electricity and heat sector.

7. "Mfg. industries and construction" in the graph legend denotes manufacturing industries and construction.

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generation, will be critical for achieving 2DS-level emissions reductions by 2050 (IEA, 2016a). The selected electricity sector indicators are:

- **CO_2 intensity of electricity** (left axis, indexed to 1990): calculated using CO_2 emissions[8] from generation of electricity divided by output[9] of electricity. CO_2 intensity of electricity generation (in grammes of carbon dioxide per kilowatt hour [gCO_2/kWh]) is an indicator of the electricity generation mix and of the efficiency of generation technologies. It is a useful measure that can be readily compared across jurisdictions and time scales to indicate relative progress in decarbonisation of the electricity sector.

- **Share of low-carbon generation in the electricity mix** (left axis): calculated as the percentage of gross low-carbon[10] electricity generation per year, out of total gross electricity generation. The share of low-carbon generation in the electricity mix is a key underlying driver of CO_2 intensity of an electricity system. High shares of low-carbon generation are necessary to achieve the deep decarbonisation of the electricity sector required under the 2DS.

- **Net additions of low-carbon power capacity** (right axis, GW per year): calculated as additions of low-carbon power capacity less retirements (note: negative values indicate that retirements exceeded new additions for that year). The green component represents renewable[11] power, while the orange component represents nuclear power and CCS capacity. While CO_2 intensity of electricity and share of low-carbon generation are helpful *outcome* metrics to understand the past and present, *driver* metrics such as net additions of low-carbon power capacity can help to understand the extent to which drivers of future emission trends are in place. With long lifetimes and slow stock turnover of power plants, tracking of both types of indicators is needed for an understanding of both current status and future trends.

Methodology

- CO_2 emissions are calculated based on the methodology of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, although the IEA has previously used the Revised 1996 IPCC Guidelines. For a more detailed description of the impact of changing methodologies on IEA estimates, please consult *CO_2 Emissions from Fuel Combustion* (IEA, 2016b).

- TPES is derived from the IEA Energy Balances, 2016 (converted into MJ) and has been adjusted to include international marine and aviation bunkers (IEA, 2016c).

- GDP PPP data have been compiled for individual countries at market prices in local currency and annual rates. These data have been scaled up/down to 2014 price levels and then converted to USD using the yearly average 2014 PPPs.

- Renewable power capacity figures are from the *Medium-Term Renewable Energy Market Report* (IEA, 2015b).

- Table 9.1 summarises the aggregation of countries within each of the ten world regions.

8. CO_2 emissions comprise emissions from fossil fuels, industrial waste and non-renewable municipal waste that are consumed for electricity generation.

9. Output comprises electricity generated from all fossil and non-fossil sources (excluding pumped hydro), including electricity from combined heat and power (CHP) plants.

10. Low-carbon comprises renewable sources (bioenergy, hydropower including pumped storage, onshore and offshore wind, solar PV, CSP, geothermal, and ocean technologies) plus nuclear and CCS sources.

11. Renewable power comprises bioenergy, hydropower including pumped storage, onshore and offshore wind, solar PV, CSP, geothermal, and ocean technologies.

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Table 9.1

Regional aggregation

Region	Countries
OECD Americas	Canada, Chile, Mexico and the United States
OECD Asia Oceania	Australia, Israel,[1] Japan, Korea and New Zealand
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Republic of the Congo, Democratic Republic of the Congo, Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Western Sahara (from 1990), Zambia and Zimbabwe
Non-OECD Americas	Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Brazil, British Virgin Islands, Cayman Islands, Colombia, Costa Rica, Cuba, Curaçao, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Nicaragua, Panama, Paraguay, Peru, Plurinational State of Bolivia, Puerto Rico (for natural gas and electricity), Saba, Saint Eustatius, Sint Maarten, Saint Kitts and Nevis, Saint Lucia, Saint Pierre et Miquelon, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay and Bolivarian Republic of Venezuela
Middle East	Bahrain, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates and Yemen
Non-OECD Europe and Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus,[2] Georgia, Gibraltar, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Former Yugoslav Republic of Macedonia (FYROM), Malta, Republic of Moldova, Romania, Russian Federation, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Former Soviet Union (prior to 1990) and Former Yugoslavia (prior to 1990)
Asia (excluding China and India)	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Chinese Taipei, Cook Islands, Fiji, French Polynesia, Indonesia, Kiribati, DPR of Korea, Lao People's Democratic Republic, Macau (China), Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Palau (from 1994), Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Tonga, Vanuatu and Viet Nam
China	People's Republic of China and Hong Kong (China)
India	India

[1] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[2] 1) Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue". 2) Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

2DS	2°C Scenario
4DS	4°C Scenario
6DS	6°C Scenario
ACEEE	American Council for an Energy-Efficient Economy
ACP	alternative compliance payment
ADB	Asian Development Bank
AfDB	African Development Bank
ASCE	American Society of Civil Engineers
ASEAN	Association of Southeast Asian Nations
BAU	business-as-usual
BECCS	bioenergy with carbon capture and storage
BNDES	*Banco nacional do desenvolvimento* (Brazil)
CCGT	combined-cycle gas turbine
CCS	carbon capture and storage
CEF	Connecting Europe Facility
CEM	Clean Energy Ministerial
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CFE	Comisión Federal de Electricidad
CFL	compact fluorescent lamp
CHP	combined heat and power
CIF	Climate Investment Funds
CPS	Current Policies Scenario
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	concentrated solar power
DOE	US Department of Energy
DOEB	Department of Energy Business
DR	demand response
EBRD	European Bank for Reconstruction and Development
ECEEE	European Council for an Energy Efficient Economy
ECRA	European Cement Research Academy
EIA	environmental impact assessment
EPA	US Environmental Protection Agency
ESCI	energy sector carbon intensity
ESCII	Energy Sector Carbon Intensity Index
ESI	Emirates Steel Industries
ETP	*Energy Technology Perspectives*
ETS	emissions trading system
EU	European Union
EU ETS	EU emissions trading system
FEMA	US Federal Emergency Management Agency
FIP	feed-in premium
FIT	feed-in tariff
FYP	Five-Year Plan
GCF	Green Climate Fund
GDC	Geothermal Development Corporation
GDP	gross domestic product
GEIR	*Global Energy Investment Report*
GHG	greenhouse gas
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IHA	International Hydropower Association
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITC	investment tax credit
ITF	International Transport Forum
ITMO	internationally transferred mitigation outcome
KEPCO	Korea Electric Power Corporation
LCOE	levelised cost of energy
LEDS	low-emission development strategies
LNG	liquefied natural gas
MDB	multilateral development bank
MEPS	minimum energy performance standard

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METI	Ministry of Economy, Trade and Industry of Japan
NDC	Nationally Determined Contribution
NEA	National Energy Administration of China
NGO	non-governmental organisation
NPS	New Policies Scenario
OCGT	open-cycle gas turbine
OECD	Organisation for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets
PDCA	plan-do-check-act cycle
PPA	power purchase agreement
PPP	public-private partnership
PRI	Principles for Responsible Investment
PSE&G	Public Service Electric and Gas
PTC	production tax credit
PV	photovoltaic
R&D	research and development
RD&D	research, development and demonstration
RDD&D	research, development, demonstration and deployment
RGGI	Regional Greenhouse Gas Initiative
RPO	renewable purchase obligation
RPS	renewable portfolio standard
SAIL	Steel Authority of India Limited
SMGR	PT Semen Indonesia Tbk
SOE	state-owned enterprise
STE	solar thermal electricity
SUBCR	subcritical technology
SUPERC	supercritical technology
T&D	transmission and distribution
TFC	total final consumption
TPED	total primary energy demand
TPES	total primary energy supply
TS&D	transmission, storage and distribution
ULTRSC	ultra-supercritical technology
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
USGCRP	United States Global Change Research Program
VAP	voluntary action plan
VRE	variable renewable energy
WCX	West Coast Infrastructure Exchange
WEO	*World Energy Outlook*

Units of measure

bcm	billion cubic metres
CO_2	carbon dioxide
CO_2-eq	carbon dioxide-equivalent
EJ	exajoules
g	gramme
gCO_2	grammes of carbon dioxide
GJ/t	gigajoules per tonne
Gt	gigtonnes
$GtCO_2$	gigatonnes of carbon dioxide
$GtCO_2$-eq	gigatonnes of carbon dioxide-equivalent
GW	gigawatt
GWh	gigawatt hour
GW_{th}	gigawatt thermal capacity
Kt	kilotonne
kWh	kilowatt hour
m^2	square metre
m^3	cubic metre
MJ	megajoule
Mt	million tonnes
$MtCO_2$-eq	million tonnes of carbon dioxide-equivalent
Mtoe	million tonnes of oil-equivalent
mtpa	million tonnes per annum
MW	megawatt
MWh	megawatt hour
MW_{th}	megawatt hour of thermal heat

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PJ	petajoule
pkm	passenger-kilometre
ppm	parts per million
t	tonne
tCO_2	tonnes of carbon dioxide
tCO_2-eq	tonnes of carbon dioxide-equivalent
TJ	terajoule
tkm	tonne-kilometre
toe	tonnes of oil-equivalent
TWh	terawatt hour
vkm	vehicle-kilometre
W	watt

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Energy, Climate Change & Environment

2016 Insights

The historic Paris Agreement on climate change sets the course for a fundamental transformation of the global economy over the next decades. The Agreement's overarching goal of limiting global average temperature rise to "well below 2 °C" will entail profound changes in the global energy system. Achieving the deep cuts in global carbon emissions that this vision requires is no small task given the enormous challenge of implementing – and eventually exceeding – current country climate pledges. This publication examines key sectors, technologies, and policy measures that will be central in the transition to a low-carbon energy system. It addresses the following questions:

- What are the roles of coal and gas in meeting the stringent decarbonisation requirements for the power sector consistent with IEA modelling of global climate goals?
- What are moderate carbon prices accomplishing in the electricity sector, and how can they be helpful as part of a package of other policies?
- Where are the opportunities for expanding renewables and energy efficiency, and what policies and regulatory frameworks are needed to boost these low-carbon energy sources?
- How can state-owned companies, which produce a large share of global GHG emissions but are also major developers of clean energy, be encouraged to play a more effective role in the energy transition?

This report also looks at building climate resilience in the energy sector, and the use of tracking tools and metrics to monitor the progress of energy sector decarbonisation. Finally, it provides global energy and emissions data, including interregional comparisons and in-depth analysis for ten regions.