World Energy Outlook 2017

Chapter 1: Introduction and scope

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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:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Introduction and scope

Thinking about the future of energy

Highlights

- This year marks the 40th anniversary since the publication of the first *World Energy Outlook.* The breadth and depth of the *WEO* analysis has been transformed since then, but its ambition remains the same: to provide all those with a stake in the energy sector with a robust analysis of possible future energy pathways, under different sets of assumptions, as an aid to their decision-making.

- Two of the scenarios in the *WEO-2017* are retained from previous *Outlooks*. The Current Policies Scenario considers only those policies firmly enacted as of mid-2017; this default setting for the energy system is a benchmark against which the impact of "new" policies can be measured. The New Policies Scenario, our central scenario, incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced policy intentions. Among such announcements over the last year: the change in policy orientation in the United States; a wealth of additional detail on China's plans for an "energy revolution"; a stronger commitment to renewables and electric mobility in India; and plans to shift the power mix in Korea in favour of gas and renewables.

- Alongside these, the Sustainable Development Scenario appears for the first time, setting out a pathway to achieve the key energy-related components of the United Nations Sustainable Development agenda: universal access to modern energy by 2030; urgent action to tackle climate change (in line with the Paris Agreement); and measures to improve poor air quality.

- The principal determinants of energy demand growth are energy policies, which differ between scenarios, and the rates at which economic activity and population grow, which do not. In the *WEO-2017*, global GDP is assumed to grow at a compound average rate of 3.4% per year, close to the level in last year's *Outlook*. The world population is assumed to rise from 7.4 billion in 2016 to 9.1 billion in 2040.

- The price of energy and the costs of key energy technologies evolve differently in the various scenarios, depending on levels of deployment and on supply-demand balances. A common thread however is that costs for key low-carbon technologies – notably solar, wind and batteries – continue to fall in the *Outlook* period, with major implications for investment trends. The outlook for nuclear has meanwhile dimmed somewhat, in response to signs of waning support in some countries.

- Prices for oil and natural gas both rise from today's levels, although the extent of this increase has been revised downwards since the *WEO-2016*. Downward pressure on prices is largely due to higher US production of tight oil and shale gas, for which costs have come down and resource estimates have increased.

1.1 The scenarios

This year's publication marks the 40th anniversary since the first *World Energy Outlook (WEO)* in 1977, and the 20th edition since it became a regular annual publication in 1998.[1] While the main purpose of this analysis – as usual – is to look forward at possible pathways for global energy, this is also a moment to look back at how the *Outlook* has evolved. The first *Outlook* in 1977 appeared in the aftermath of the first oil embargo in 1973-1974 and was unsurprisingly a product of its time. The focus was on oil (45% of the global energy mix at the time, versus 32% today) and on the countries of the Organisation for Economic Co-operation and Development (OECD) (71% of global oil demand at the time, 48% today): the emphasis of the analysis was on how much oil they might consume over the *Outlook* period (to 1985) and where they would get it from. Nonetheless, some essential parameters for the analysis were there from the start. The intention was not to predict the future, but to understand what difference policies could make to that future. There was a recognition of the centrality of energy security. And there were already alternative policy scenarios, looking at the impact of energy conservation measures (as they were called at the time) and the scope for alternative sources of oil supply within the OECD, in order to avoid some of the oil security risks projected in the reference case.

Fast-forward twenty years and the *WEO* had already taken on many of the features that are familiar today. For better or worse, it was bigger (weighing in at more than 450 pages versus the 100 or so pages in 1977) and based on a new *World Energy Model* (*WEM*) covering all regions and fuels – the distant forerunner of the model used today. A central concern was still the outlook for oil markets and oil market security, but gas security also featured strongly: "Our work on natural gas suggests no reserve limitations on production at world level before 2020, although increasing use of unconventional gas in North America is likely." (IEA, 1998). But the most noticeable new element was the attention given to the environmental impacts of energy use, with extensive analysis of energy-related carbon dioxide (CO_2) emissions and the implementation of the 1997 Kyoto Protocol: "New policies will be required if the use of nuclear power and renewable energy sources is to help reduce fossil-fuel consumption and greenhouse-gas emissions […] unit costs of renewable energy must be reduced." (IEA, 1998).

The underlying philosophy and intent of the *Outlook* is captured well in the preface to the 1998 edition. In the words of the (then) IEA Executive Director: "The objective of this book is not to state what the IEA believes will happen to the energy system in future. The IEA holds no such single view. Rather, the aim is to discuss the most important factors and uncertainties likely to affect the energy system over the period to 2020 […] In fact, the IEA expects that the future for world energy will be quite different from that described in the business-as-usual (BAU) projection. This is partly because economic growth, energy prices,

1. The *WEO* was published in 1977, 1982 and from 1993 to 1996, and then again annually from 1998 onwards. All the *WEOs* since 1994 are available to download from *www.iea.org/weo/previousworldenergyoutlooks*.

technology and consumer behaviour will turn out to be different from those assumed for the BAU projection. The most striking difference will most likely occur because governments in developed countries will want to change things." Although we now think in terms of all governments, not just those in developed countries, it is this ability to change things on the part of governments (and others, including energy companies) that is at the heart of the *WEO* process. The intention is to inform decision-makers as they consider their options, not to predict the outcomes of their deliberations.

Box 1.1 ▷ How has the *World Energy Outlook* evolved since 1977?

Although the underlying purpose of the work has remained remarkably constant, much has changed in the *Outlook* since it made its first appearance 40 years ago. Up until 2010, the structure tended to focus on a Reference Scenario, in which policy assumptions were fixed at the present day, with no account taken of announced intentions or targets. This was often accompanied by an alternative scenario to examine the impact of different policy choices to address a specific energy security or environmental issue.

In 2010, the main focus shifted to the New Policies Scenario (and the old Reference Scenario moved to the background, becoming the Current Policies Scenario). The 450 Scenario made its initial appearance as a pathway to limit climate change to below 2 degrees Celsius (°C), cementing the position of climate and other environmental issues at the heart of the analysis (and becoming a global benchmark for climate trajectories). Since then, scenarios have addressed a range of other uncertainties over prices and the deployment of specific technologies.

The geographical reach of the analysis has expanded considerably. From an early focus on the OECD member countries, the *WEO* has broadened its horizons to provide a truly global outlook. Since 2005, this has involved an annual in-depth country or regional focus, starting that year with the Middle East and North Africa, and since then including China and India (2007), Russia (2011), Iraq (2012), Brazil (2013), sub-Saharan Africa (2014), India (2015) and Mexico (2016). Underlining the importance of Asia to the future of global energy, this year the geographic focus again turns to China, ten years on from the 2007 analysis.

The thematic reach of the analysis has also grown. The annual "fuel focus" was added in 2008 and has since covered all the major fuels and technologies, including energy efficiency. Access to modern energy has become a signature issue, with systematic monitoring of the numbers of the global population without basic energy services, together with analysis of the policies, technologies and investment required to close this gap. The *Outlook* has likewise taken a lead in highlighting and quantifying fossil-fuel consumption subsidies, and the links between energy and international competitiveness, air pollution and water use.

In addition, the *WEO* has evolved to include the regular appearance of special reports alongside the main *Outlook*. The first of these, in 2011, asked the question "Are we entering a Golden Age of Gas?". The *WEO-2017* series, in addition to this *Outlook*, includes two special reports: a regional energy outlook for Southeast Asia and an in-depth analysis of the prospects for universal access to modern energy by 2030.

There are however some aspects of the *WEO* that have not changed. One is the focus on objective data and dispassionate analysis. Another is the centrality of energy security, which is an important dimension of all the three main scenarios discussed in the *WEO-2017*.

Given that there is no single story about the future of global energy, the *WEO* continues to use a scenario-based approach to highlight the key choices, consequences and contingencies that lie ahead, and to illustrate how the course of the energy system might be affected by changing some of the key variables, chief among them the energy policies adopted by governments around the world. This approach continues to be underpinned by a system-wide modelling approach that covers all fuels, technologies and regions, providing insights into how changes in one area might have consequences (often unintended) for others.

The main scenarios in this *Outlook* are the New Policies Scenario, the Current Policies Scenario and the Sustainable Development Scenario. Described in more detail in the next section, they are differentiated primarily by the assumptions that they make about government policies. The New Policies Scenario is designed to show where existing policies as well as announced policy intentions might lead the energy sector. The Current Policies Scenario provides a point of comparison by considering only those policies and measures enacted into legislation by mid-2017. And the Sustainable Development Scenario, a new scenario in the *WEO-2017*, examines what it would take to achieve the main energy-related components of the "2030 Agenda for Sustainable Development" adopted in 2015 by member states of the United Nations. The three energy-related goals are: to achieve universal energy access to modern energy by 2030; to take urgent action to combat climate change; and to dramatically reduce the pollutant emissions that cause poor air quality.

References to all of the scenarios are interspersed throughout the chapters. However, the primary focus, as in past editions, is on the New Policies Scenario, which reflects both currently adopted measures and, to a degree, declared policy intentions. That this scenario enjoys most of the limelight in the *Outlook* is often taken as an implicit sign that this is – despite our protestations to the contrary – a forecast. However, the IEA does not have a long-term forecast (Spotlight).

New Policies Scenario

The New Policies Scenario is the central scenario of this *Outlook,* and aims to provide a sense of where today's policy ambitions seem likely to take the energy sector. It incorporates not just the policies and measures that governments around the world have already put in place, but also the likely effects of announced policies, as expressed in official targets or plans. The Nationally Determined Contributions (NDCs) made for the Paris Agreement provide important guidance as to these policy intentions in many countries, although in some cases these are now supplemented or superseded by more recent announcements – including the decision by the US administration to withdraw from the Agreement. Our reading of the national policy environment is also influenced by policies and targets adopted by sub-national authorities, i.e. by state-level entities in federal systems, by cities and municipalities, as well as the commitments made by the private sector (see the Spotlight in Chapter 3).

The way that policy intentions, including the NDCs, are reflected in the New Policies Scenario depends on the extent to which their realisation is supported by specific policies and implementing measures. Where these are in place, announced targets are assumed to be met, or indeed exceeded, where macroeconomic, cost or demand trends point to this. However, given that announced policy intentions are often not yet fully incorporated into legislation or regulation, the prospects and timing for their full realisation depend on our assessment of the institutional context and relevant political, regulatory, market, infrastructure and financing constraints.

Current Policies Scenario

The Current Policies Scenario excludes the realisation of announced, new policy targets and considers only the impact of those policies and measures that are firmly enshrined in legislation as of mid-2017. In addition, where existing policies target a range of outcomes, the assumption in the Current Policies Scenario is that the least ambitious end of this range is achieved. In this way, the scenario provides a cautious assessment of where momentum from existing policies might lead the energy sector in the absence of any additional impetus from governments. It therefore provides a reference against which the impact of any additional "new" policies can be measured.

Sustainable Development Scenario

The Sustainable Development Scenario is introduced for the first time in the *WEO-2017* and takes a fundamentally different approach from those discussed above. While the Current Policies and New Policies scenarios start with certain assumptions about policies and see where they lead the energy sector, the Sustainable Development Scenario (as with the previous 450 Scenario) starts with a certain vision of where the energy sector needs to go and then works back to the present. This vision of the future incorporates three major elements. First, it describes a pathway to the achievement of universal access to modern energy services by 2030, including not only access to electricity but also clean cooking.

Second, it paints a picture to 2040 that is consistent with the direction needed to achieve the objectives of the Paris Agreement, including a peak in emissions being reached as soon as possible, followed by a substantial decline.[2] Third, it posits a large reduction in other energy-related pollutants, consistent with a dramatic improvement in global air quality and a consequent reduction in premature deaths from household air pollution.

These three goals are interlinked and in many ways complementary. They reflect the key energy-related aspects of the United Nations Sustainable Development Goals (SDGs), including affordable and clean energy for all (SDG 7), action on climate change (SDG 13), as well as the efforts to reduce air pollution which are included under the goals for health (SDG 3) and cities and sustainable communities (SDG 11). These linkages are clear in the Paris Agreement, whose objective to strengthen the global response to the threat of climate change is explicitly framed in the context of sustainable development and efforts to eradicate poverty. In the same way, the NDCs of many developing countries make the connection between universal access and the implementation of their climate pledges.

Action on one of these goals can often assist in achieving another. For example, the universal provision of clean cooking facilities means a comprehensive shift away from the traditional use of solid biomass as a cooking fuel, and thereby also removes the main cause of household energy-related air pollution. The climate imperatives to deploy more efficient technologies and to reduce reliance on energy from fuel combustion – including through electrification of end-uses – have co-benefits in terms of lower pollutant emissions.

At the same time, there are potential trade-offs that have to be addressed. All else being equal, the achievement of universal access – even at relatively low levels of per capita consumption and widespread provision of access using low-carbon technologies – results in a slight increase in global CO_2 emissions. Even if the impacts are very small in global terms, this does require a modest extra effort elsewhere in order to compensate (an effort in which reductions in other greenhouse-gas emissions due to lower biomass consumption for cooking play an important role). Pollution control technologies for fossil fuel-fired power plants and large industrial facilities may help to improve air quality without reducing CO_2 emissions. Some modern bioenergy technologies may be suitable for reducing CO_2 emissions, but risk an increase in fine particulate matter that is damaging to human health.

The methodological approach adopted in the Sustainable Development Scenario is to focus first on universal access. Low-carbon technologies provide a suitable route in many instances to achieve energy access, not least because most of the population lacking

2. The temperature rise in 2100 associated with the Sustainable Development Scenario would depend on the point, in the second-half of this century, when the world reached a balance between anthropogenic emissions and their removal by sinks (by means of measures such as afforestation or carbon capture and storage). If this "net zero" emissions point targeted by the Paris Agreement is achieved right at the end of the century, in 2100, then this scenario has a roughly even chance of limiting the temperature rise to below 2 degrees Celsius. If this net zero point is achieved earlier in the second-half of the century, or if it is followed by a period of net negative emissions, the likely rise in temperature is lower. As described in Chapter 3, the Sustainable Development Scenario puts the world on a pathway that would be consistent with a range of such outcomes; we also present a Faster Transition Scenario which would increase the chances of a lower temperature rise.

electricity is in rural areas where decentralised energy solutions can be cheaper than grid extension. But this is not always the case: we consider all technologies and fuels in the analysis, including fossil fuels, as the contribution of achieving universal access to modern energy by 2030 to CO_2 emissions is small, and can be offset by declines in other greenhouse-gas (GHG) emissions. Developments in all countries are then modelled to remain within the required carbon constraint, guided by the policy and technology preferences that countries have today (but, in almost all cases, extending their reach). The mixture of technologies deployed to meet climate objectives is also shaped by the requirement to improve air quality.

Other scenarios and cases

Other scenarios and cases referred to in this report are:

- **Faster Transition Scenario**[3] **–** This scenario, developed in 2017, plots an emissions pathway to "net zero" energy sector CO_2 emissions in 2060 (see footnote 2), resulting in lower emissions than the Sustainable Development Scenario in 2040.
- **Low Oil Price Case –** This case, considered in Chapter 4, looks at the conditions that would allow the oil price to remain "lower for longer"; it updates the work done in the *WEO-2015* on a Low Oil Price Scenario.
- **Energy for All Case –** Developed specifically for the *WEO-2017,* this case examines the achievement of modern energy for all against the backdrop of the New Policies Scenario. It provides a point of comparison with the way that a similar goal is covered in the Sustainable Development Scenario.
- **450 Scenario –** This scenario was not modelled for the *WEO-2017*, but in recent *Outlooks* it has been the main decarbonisation scenario. Previous results are used on occasion for purposes of comparison.
- **Clean Air Scenario –** Introduced in a Special Report in the *WEO-2016* series[4], this set out a cost-effective strategy, based on existing technologies and proven policies, to cut 2040 pollutant emissions by more than half compared with the New Policies Scenario.
- **Bridge Scenario –** Featured in another Special Report, this time in the *WEO-2015* series[5], this put forward a bridging strategy, based on five specific energy sector measures, to achieve an early peak in energy-related CO_2 emissions.

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3. This scenario was originally developed by the IEA in 2017 as a contribution to a joint study "Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System" with the International Renewable Energy Agency (IEA/IRENA, 2017); the work was supported by the government of Germany as input to the 2017 German G20 presidency. The report is available at *www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf*.

4. The *WEO-2016* Special Report, *Energy and Air Pollution* (IEA, 2016) is available at: *www.iea.org/publications/freepublications/publication/weo-2016-special-report-energy-and-air-pollution.html.*

5. The *WEO-2015* Special Report, *Energy and Climate Change* (IEA, 2015) is available at: *www.iea.org/publications/freepublications/publication/weo-2015-special-report-2015-energy-and-climate-change.html*.

SPOTLIGHT

Why doesn't the IEA have a long-term forecast?

The scenario results presented in the *WEO* are sometimes mischaracterised as forecasts. They are not. Each scenario depicts an alternative future, a pathway along which the world could travel if certain conditions are met. The IEA does provide short- to medium-term forecasts for different fuels and technologies, but there are no long-term IEA forecasts; in our judgement, there are simply too many variables in play for this to be a viable approach.

One major uncertainty concerns policy. A central tenet of the New Policies Scenario is that it reflects only those policies that are either already in place or those that have been announced. As a scenario assumption this works well – it allows us to investigate the direction in which today's decision-makers are taking the energy system – and therefore to provide them with essential feedback on their choices and ambitions. But this would not be a sensible way to approach forecasting. There will undoubtedly be additional policy shifts between now and 2040, beyond those already announced by governments around the world. These could be in response to concerns about energy security (e.g. to offset rising import dependency) or affordability (e.g. to mitigate the effect of upward pressure on prices) or to temper rising emissions (e.g. via the commitment in the Paris Agreement to update pledges every five years with the intention to increase climate ambition). If we did forecast, we would try and second-guess these future responses.

A second area where there is major uncertainty is technological change. Our current modelling incorporates a process of learning-by-doing that affects the costs of various fuels and technologies, including the cost of investing in energy efficiency. However, while technology learning is integral to the *WEO* approach, the *WEO* does not try to anticipate technology breakthroughs as these are, by their nature, impossible to predict. Scenarios are the only way to try to understand the impact on the energy system of potential step-changes in the cost of different technologies.

Another uncertainty is the unpredictable boom-and-bust cycles to which parts of the energy sector are subject. Parts of the oil and gas sectors are currently in the low-price "bust" phase, and how and when these sectors rebalance is a major question for short- and medium-term forecasts. Attempting to model such cycles over the longer term would not only be challenging, but would also obscure the policy effects that we seek to examine. Instead, our *Outlook* projections consider an energy system that finds and retains equilibrium, i.e. it does not try to capture long-term cyclical dynamics. In reality, some markets might remain in disequilibrium for an extended period, e.g. if today's low levels of upstream investment eventually lead to a price spike that then produces a further over-correction and the start of a new cycle, and so on.

The bottom line is that, with so many uncertainties and so many moving parts, a forecast as far out as 2040 would be highly susceptible to intervening events. More than that, if we did try to forecast, we would be altering fundamentally the purpose of the *Outlook* and – we are convinced – reduce its utility. The aim of a forecaster is to be correct; presumably, forecasters celebrate when their predictions turn out to be true. Our aim is to illuminate and inform debate and decision-making. If the projections in our Current Policies Scenario or even our New Policies Scenario turn out to be true in 2040, this will not be a sign of success. Success for the *WEO* is about helping countries to achieve the long-term energy and related goals that they have chosen.

1.2 Developing the scenarios

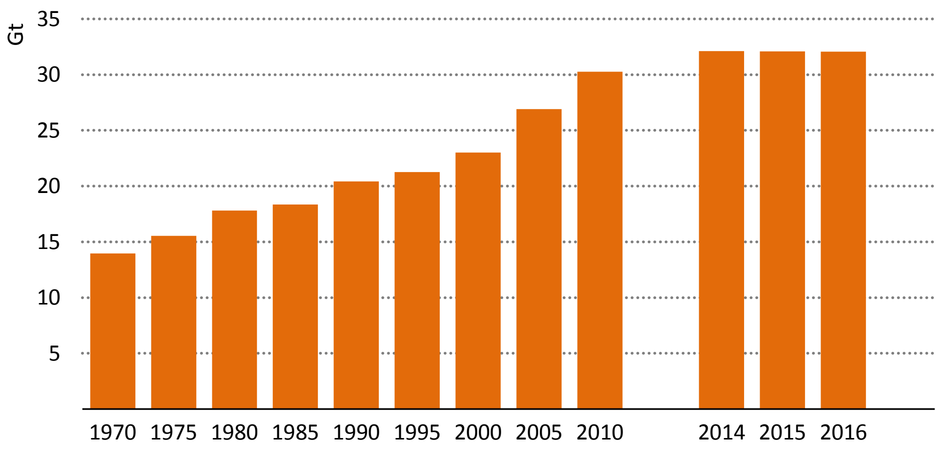
The starting point for all of the scenarios in the *WEO-2017* is the latest data on today's energy consumption, costs, prices and policies. The formal base year for this year's projections is 2015, as this is the last year for which a complete picture of energy demand and supply is in place, but we have used more recent data wherever available, and we include – for the first time – our 2016 estimates for energy production and demand in the annexes to this *WEO* that summarise the projections. The tables and discussion in the chapters typically refer to 2016 data, even if these are, in many cases, provisional.

What do these latest energy data show? They portray an energy sector in which demand patterns and traditional distinctions between consumer and producer countries are evolving rapidly (Box 1.2). They suggest significant market imbalances that are likely to maintain downward pressure on prices for some time to come: this is the case not only for oil and gas, but also for some other parts of the energy sector such as solar photovoltaic (PV) panels. They also show an energy system that is changing at considerable speed, with the dramatic falls in the costs of key renewable technologies upending traditional assumptions on relative costs.

While some global trends are unambiguous, it remains unclear in other instances whether we have reached genuine inflexion points, or whether there are cyclical and temporary factors involved that might be reversed with time. A critical uncertainty relates to energy-related CO_2 emissions, which have remained flat since 2014 (Figure 1.1). Multiple factors contributed to this outcome: the large expansion in low-carbon power generation, led by rapid deployment of wind and solar; a reduction in the energy intensity of global gross domestic product (GDP); and a fall in estimated global coal use, driven by developments in China and coal-to-gas switching in the United States. The question, examined in detail in this *Outlook*, is whether momentum in these areas can be sustained and, in turn, whether the next move for CO_2 emissions is up or down.

The answer to this question (and many others) varies across the different scenarios examined in this *Outlook*, underlining how changing key assumptions can put the entire energy system on a different future course. This also comes through clearly from a look back at previous *WEOs*, in particular at instances where things turned out differently from the projected outcomes. For example, initial *WEO* projections (in our then Reference Scenario) did not capture the eventual extent of the rise in China's coal consumption in the mid-2000s: the pace of GDP growth assumed in the modelling turned out to be lower than what China achieved in practice.

Figure 1.1 ▷ Global energy-related CO_2 emissions



Analysis of estimated 2016 data suggests another year of flat global CO_2 emissions, even though the global economy continued to grow

Note: Gt = gigatonnes.

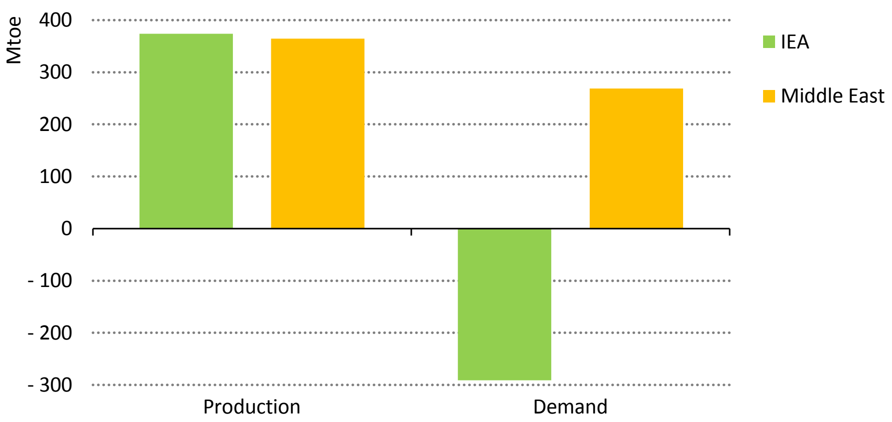
Box 1.2 ▷ A new way to look at the world of energy

The presentation of data and projections in the *WEO* has traditionally divided the world into OECD and non-OECD. This was the guiding principle for the country and regional groupings shown in the tables and annexes and, at least for some time, represented some important features of the global energy system. The OECD accounted for major energy-consuming regions of the world, including North America, Japan, Korea and large parts of Europe, all of whom were reliant – to greater or lesser degrees – on energy imported from other parts of the world, notably the Middle East and Russia.

This way of categorising the global energy system has been steadily becoming less meaningful. From 60% in 1977, the share of the OECD in global primary energy demand is now 39%. The powerhouses of global energy demand growth are elsewhere, led by the developing economies of Asia: this is indeed why the IEA has opened its doors to new players, with Brazil, China, India, Indonesia, Morocco, Singapore and Thailand, all now IEA Association countries. The customary producer-consumer division needs to accommodate the fact that, at least in recent years, a major share of global production growth has come from IEA countries, while some resource-rich regions – notably the

Middle East – are facing rapid increases in consumer demand (Figure 1.2). There are also global environmental challenges, whose resolution requires the development of more widely dispersed renewable resources and new models of energy co-operation. With all of these changes, this *Outlook* moves to a purely geographical presentation of results, and OECD and non-OECD aggregates are retained only for reference (in Annex A).

Figure 1.2 ▷ Change in total primary energy production and demand in IEA member countries relative to the Middle East, 2005-2015

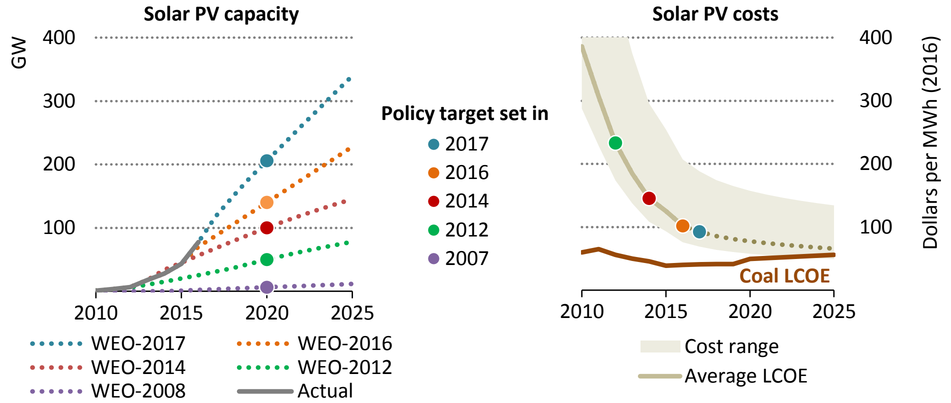


In a reversal of oft-assumed roles, IEA members increased energy production more than the Middle East in recent years

Notes: Mtoe = million tonnes of oil equivalent. Data for IEA considers membership status as of mid-2017.

In a similar way, the oft-commented projections in successive *WEOs* for wind and solar deployment reflected the policy and technology environment at the time that the projections were made. Taking China again as an example (since it has outsize influence on global solar PV trends), policies and targets have strengthened dramatically over the last ten years. The 2007 "Mid- to Long-Term Plan of Renewable Energy" set a target of 1.8 GW of total solar capacity for 2020 (reflected in the *WEO-2008*); in this edition, we are taking into account new guidance from the Chinese authorities that sets a cumulative upper target of 160 GW for utility-scale solar PV in 21 provinces (deployment in the rapidly growing distributed solar PV market is additional) (Figure 1.3). As these targets stepped up so our projections changed as well, with increased policy-driven deployment creating a virtuous circle – clearly visible in successive *WEO*s – of lower technology costs and higher policy ambition. In line with the methodology of the New Policies Scenario, we did not try to anticipate future changes in policy; however, we also recognise that – with sufficient support from policy – at a certain point costs fall to a level that is competitive with other forms of generation without subsidy; deployment then becomes far less reliant on specific policy targets. Solar PV in China is a good example: in the *WEO-2017*, the levelised costs of new solar PV are set to fall below those of new coal-fired power plants by the late 2020s.

Figure 1.3 ▷ Evolution of China policy targets and projections for solar PV installed capacity, and solar PV levelised costs, in selected *WEOs*



The projections for solar PV in China in successive WEOs show the virtuous circle of policy-driven deployment & lower costs, bringing the technology to competitiveness with coal

Note: PV = photovoltaic; LCOE = levelised cost of electricity.

World Energy Model

The *WEM* generates the energy projections used in this report.[6] The *WEM* is a large-scale simulation tool, developed at the IEA over a period of more than 20 years. It is designed to replicate how energy markets function and covers the whole energy system, allowing for a range of analytical perspectives from global aggregates to elements of detail, such as the prospects for a particular technology or the outlook for end-user prices in a specific country or region. The current version models global energy demand in 25 regions, 12 of which are individual countries. Global oil and gas supply is modelled in 120 distinct countries and regions, while global coal supply is modelled in 31 countries and regions. The main modules cover energy consumption, fossil fuel and bioenergy production, and energy transformation (including power generation and refining), and there are supplementary tools that allow more detailed analysis of specific issues. The model is updated and enhanced each year and the major changes introduced for the *WEO-2017* include:

- Offshore energy production, for oil, gas and wind, has been modelled in more detail, including detailed hourly simulations of the evolving market value of offshore wind and more granular consideration of the outlook for different oil and gas resource types and water depths.

6. For details on the *WEM* methodology, see *www.iea.org/weo/weomodel*.

- A range of technologies and costs for reducing methane leaks along the oil and gas value chains are now included in the model, allowing for more detailed consideration of the costs and benefits of abatement.
- Additional detail on technologies and efficiencies in the road freight sector has been incorporated into the model, following an in-depth study.[7]
- Industrial energy use has been further disaggregated, allowing differentiation between demand for different temperatures of heat and related technology choices.
- For the special focus on China:
  - The hourly power generation model that was introduced in the *WEO-2016* to offer insights into the integration of variable renewables (including elements such as demand-side response and energy storage) has been extended to China, with six Chinese regions now modelled separately.
  - More disaggregation has been introduced into the services sector model to account for the energy consumption profiles of different types of commercial and public service buildings.

Other modelling has helped to generate additional insights. The outputs from the *WEM* have been coupled with the Greenhouse-gas – Air Pollution Interactions and Synergies (GAINS) model of the International Institute of Applied Systems Analysis (IIASA) to generate an outlook for air pollutants. The OECD computable general equilibrium model (ENV-Linkages) was used to assess the links between the economic transition in China and the energy outlook. The Open Source Spatial Electrification Tool (OnSSET) and the Open Source Energy Modelling System (OSeMOSYS) of the Swedish Royal Institute of Technology provided geospatial analysis of least-cost electricity generation options for energy access.

1.2.1 Inputs to the modelling

Energy policies

The policy actions assumed to be taken by governments are a key variable in the *Outlook* and the main reason for the differences in outcomes across the scenarios. An overview of the policies and measures that are considered in the various scenarios is included at Annex B. The "new policies" that are considered in the New Policies Scenario are derived from an exhaustive examination of announcements and plans in countries around the world. There have been some notable developments over the past year:

- The **United States** announced a new direction in energy policy. An Executive Order in March 2017 emphasised the importance of US energy resources for domestic economic growth and employment, and instructed relevant agencies to review existing regulations that potentially hinder the development of these resources, with a view to suspending, revising or rescinding them. The Executive Order includes a review of

7. See *The Future of Trucks: Implications for energy and the environment* (IEA, 2017) available at: *www.iea.org/publications/freepublications/publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf*.

the Clean Power Plan, the impact of which is now no longer considered in the New Policies Scenario. A number of state and city-level authorities however have pledged to continue support for low-carbon technology development and deployment, and the New Policies Scenario factors this in. The US also subsequently announced its decision to withdraw from the Paris Agreement on climate change, meaning that implementation of the US NDC commitments is likewise no longer part of the New Policies Scenario. The announcement on the Paris Agreement was accompanied by the stated intent for the United States to maintain a leadership position in clean energy.

- **China** released an Energy Production and Consumption Revolution Strategy (2016-2030), following the President's call in 2014 for an "energy revolution". This detailed measures to support the implementation of the 13th Five-Year Plan. The latter includes plans for coal, oil, gas, power, shale gas, coalbed methane, nuclear, hydropower, wind, solar, biomass, geothermal and energy technology innovation. Each of these plans identifies specific medium-term binding or indicative targets. The State Council has also issued guidance on the future direction of market reforms in the oil and gas sectors, following on from a similar document on the electricity sector issued in 2015. Air pollution remains the focus of many regulatory measures.
- **India's** government released a draft national energy policy that proposes a co-ordinated strategy to achieve announced national and sectoral policy goals. These include targets for electrification (universal "24x7" access for all by 2022); for a higher share of manufacturing in GDP and a reduction in oil imports; for 175 gigawatts (GW) of renewable capacity by 2022; as well as the NDC commitments to reduce the emissions intensity of the economy by 33-35% by 2030 (from the 2005 baseline) and to boost the share of non fossil-fuel capacity in the power sector to 40% over the same period.
- **Korea** announced a policy shift that will reduce the role of nuclear power and coal-fired plants in the generation mix, and support an expanded role for renewable energy technologies and natural gas.
- **Japan** began the liberalisation of its retail gas market in April 2017, following liberalisation of its retail power market the previous year. In the same month, it revised feed-in tariffs and introduced a new auction system for large-scale solar PV.
- The **European Commission** proposed a new "Clean Energy for All" package, which proposes new legislation on energy efficiency, renewables, the design of the electricity market, security of electricity supply and governance rules for the Energy Union.
- Some European countries announced plans to phase out coal-fired power completely, including **France** by 2023, the **United Kingdom** by 2025 and **Finland** by 2030.
- The **United Kingdom** and **France** both proposed an outright ban on sales of new diesel and gasoline vehicles by 2040.
- **Saudi Arabia** announced its intention to phase out most fuel subsidies by 2020, accompanied by measures to support vulnerable low-income households and to help industry with the transition.

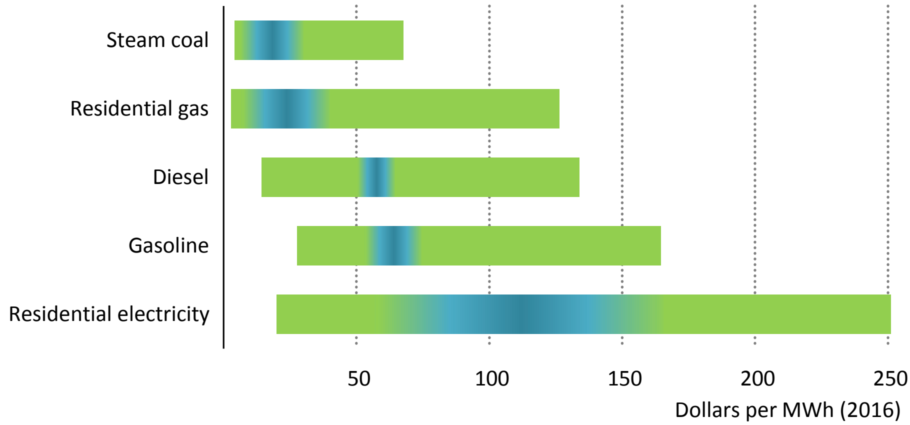
- **Qatar** lifted a self-imposed moratorium on development of its part of the world's biggest natural gas field that it shares with Iran (known as the North Field in Qatar, South Pars in Iran).

Pricing policies

Alongside policies, the prices paid for energy by end-users are a critical variable in determining patterns of consumption. Overall, relatively low international prices for fossil fuels (at least by recent standards) have exerted downward pressure on end-user prices; the range of end-user prices worldwide is nonetheless huge.

As demonstrated in Figure 1.4, in some parts of the world average end-user prices remain well below the relevant international benchmarks. In many cases this reflects fossil-fuel consumption subsidies, representing either an explicit effort to lower the price of an imported product for domestic sale, or the opportunity cost for a producer of pricing domestic energy below market levels (or a combination of the two). During a period of relatively low international prices, many countries have signalled their intent to remove fossil-fuel subsidies. However, their removal is not assumed in the Current Policies Scenario unless a formal programme is already in place. In the New Policies Scenario, net-importing countries and regions phase out fossil-fuel subsidies completely within ten years. In the Sustainable Development Scenario, while all fossil-fuel consumption subsidies are similarly removed within ten years in net-importing regions, they are also removed in all net-exporting regions, except some countries in the Middle East, within 20 years.

Figure 1.4 ▷ Range of prices paid by consumers for final energy, 2015



End-user prices for energy carriers vary widely around the world, due to underlying variations in delivered costs but also subsidies, taxes and other charges

Notes: MWh = megawatt-hour. The areas shaded in blue represent the range of reference prices used for the purposes of calculating energy consumption subsidies. Variations in quality may explain a part of the variations in price, especially for electricity where differences in reliability of services mean that it is not a homogenous product across countries.

Another influential policy variation between the scenarios is the scope and level of carbon pricing, which has a major impact on the relative costs of using different fuels. In addition to schemes already in place, which are assumed to remain throughout the period to 2040, the New Policies Scenario includes the introduction of new carbon pricing instruments where these have been announced but not yet introduced. In the Sustainable Development Scenario, the use of carbon pricing instruments becomes much more widespread, especially within the advanced economies, and prices are significantly higher (Table 1.1). An important change compared with last year's *Outlook* relates to Canada, where the Pan-Canadian Framework on Clean Growth and Climate Change includes the commitment to price carbon pollution across the country by 2018. The implementation of this commitment varies across the country and is subject to review in 2022.[8] It is modelled in our scenarios with the introduction of a carbon price for power, industry and aviation sectors in the Current Policies Scenario and for all sectors in the New Policies Scenario.

Table 1.1 ▷ CO_2 price in selected regions by scenario ($2016 per tonne)

	Region	Sector	2025	2040
Current Policies Scenario	Canada	Power, industry, aviation	15	31
	European Union	Power, industry, aviation	22	40
	Korea	Power, industry	22	40
New Policies Scenario	South Africa	Power, industry	10	24
	China	Power, industry, aviation	17	35
	Canada	All sectors	25	45
	European Union	Power, industry, aviation	25	48
	Korea	Power, industry	25	48
Sustainable Development Scenario	Brazil, China, Russia, South Africa	Power, industry, aviation*	43	125
	Advanced economies	Power, industry, aviation*	63	140

* Coverage of aviation is limited to the same regions as in the New Policies Scenario.

Economic outlook

Global economic activity is expected to pick up in the coming years, with an anticipated cyclical recovery in investment, manufacturing and trade. From global growth of 3% in 2016, growth rates are expected to rise to around 3.5% in 2018. This figure is close to the long-term global average that is assumed in this *Outlook*: in each of the scenarios, the world economy is assumed to grow at a compound average annual rate of 3.4% over the period

8. The approach provides jurisdictions the flexibility to implement either an explicit price-based system (a carbon tax such as the one in British Columbia), or a hybrid approach composed of a carbon levy and an output-based pricing system (such as in Alberta) or a cap-and-trade system (such as those in Quebec and Ontario). The federal government plans to put in place a backstop that would apply in jurisdictions that do not have a carbon pricing system in place.

to 2040 (Table 1.2). Overall, the global aggregates are quite similar to those of the *WEO-2016*, although there are some slight downward revisions for medium-term economic growth in some regions, notably for oil-exporting countries in the Middle East and Africa, reflecting the assessment from the International Monetary Fund (IMF, 2017).

Table 1.2 ▷ Real GDP growth assumptions by region

	Compound average annual growth rate			
	2000-16	2016-25	2025-40	2016-40
North America	1.8%	2.1%	2.1%	2.1%
United States	1.8%	2.0%	2.0%	2.0%
Central & South America	2.8%	2.3%	3.0%	2.8%
Brazil	2.4%	1.9%	3.0%	2.6%
Europe	1.7%	1.9%	1.6%	1.7%
European Union	1.4%	1.7%	1.4%	1.5%
Africa	4.4%	4.1%	4.4%	4.3%
South Africa	2.9%	2.1%	2.9%	2.6%
Middle East	4.4%	3.0%	3.5%	3.3%
Eurasia	4.1%	2.3%	2.7%	2.6%
Russia	3.4%	1.7%	2.4%	2.1%
Asia Pacific	6.0%	5.4%	4.0%	4.5%
China	9.2%	5.8%	3.7%	4.5%
India	7.2%	7.7%	5.7%	6.5%
Japan	0.8%	0.7%	0.7%	0.7%
Southeast Asia	5.2%	5.1%	4.0%	4.5%
World	**3.6%**	**3.7%**	**3.3%**	**3.4%**

Notes: Calculated based on GDP expressed in year-2016 dollars in purchasing power parity (PPP) terms. See Annex C for composition of regional groupings.

Sources: (IMF, 2017); World Bank databases; IEA databases and analysis.

The way that economic growth translates into energy demand growth varies substantially by country, depending on each country's economic structures and stages of development, as well as pricing and efficiency policies. In most advanced economies, energy demand is now on a path of gradual structural decline, despite continued growth in national output. Elsewhere, however, economic expansion has much stronger implications for energy demand, particularly in countries where energy-intensive industrial activity accounts for a larger share of GDP. For the global economy as a whole, as of 2016 a 1% rise in GDP is associated with a 0.3% increase in primary energy demand. The level of this demand increase has however reduced: as recently as 2000-05, a 1% increase in GDP meant an average 0.7% rise in energy use. The rate at which the energy intensity of the global economy improves is a critically important indicator.

Demographic trends

As in previous years, the *WEO-2017* uses the medium variant of the United Nations' projections as the basis for population growth in all scenarios (UNPD, 2015). The world population rises by 0.9% per year on average, from 7.4 billion in 2016 to 9.1 billion in 2040 (Table 1.3). This is a critical determinant of many of the trends in our *Outlook* and is naturally subject to a degree of uncertainty: the range in the UN projections for 2040 is from 8.5 billion to 9.8 billion. The fastest growth in population is in Africa, underlining the scale of the challenge to provide universal access to modern energy. By 2040, three-out-of-four people in the world are living either in the Asia Pacific region or in Africa.

Table 1.3 ▷ Population assumptions by region

	Compound average annual growth rate			Population (million)		Urbanisation rate	
	2000-16	2016-25	2016-40	2016	2040	2016	2040
North America	1.0%	0.8%	0.7%	487	570	81%	86%
United States	0.8%	0.7%	0.6%	328	378	82%	86%
Central & South America	1.2%	0.9%	0.7%	509	599	80%	85%
Brazil	1.1%	0.7%	0.5%	210	236	86%	90%
Europe	0.3%	0.1%	0.1%	687	697	74%	80%
European Union	0.3%	0.1%	0.0%	510	511	75%	81%
Africa	2.6%	2.4%	2.2%	1 216	2 063	41%	51%
South Africa	1.5%	0.7%	0.6%	55	64	65%	75%
Middle East	2.3%	1.7%	1.4%	231	321	69%	76%
Eurasia	0.4%	0.3%	0.1%	230	236	63%	67%
Russia	-0.1%	-0.2%	-0.3%	144	133	74%	79%
Asia Pacific	1.1%	0.8%	0.6%	4 060	4 658	47%	59%
China	0.5%	0.3%	0.0%	1 385	1 398	57%	73%
India	1.5%	1.1%	0.9%	1 327	1 634	33%	45%
Japan	0.0%	-0.3%	-0.4%	127	114	94%	97%
Southeast Asia	1.2%	1.0%	0.7%	638	763	48%	60%
World	**1.2%**	**1.0%**	**0.9%**	**7 421**	**9 144**	**54%**	**63%**

Sources: UN Population Division databases; IEA databases and analysis.

An increasing share of the global population is living in cities and towns, and the global urbanisation rate is projected to rise from 54% in 2016 to 63% in 2040. In absolute terms, this means an extra 1.7 billion people added to the urban population over the next 25 years – the equivalent of a new city the size of Shanghai about every four months. There are many different avenues for urbanisation, from new "smart" cities to the expansion of slum areas with limited access to basic services, but overall this transition has major implications for energy consumption: urbanisation accelerates the switch to modern fuels, the rise in appliance and vehicle use, and demand for construction materials, including energy-intensive products such as steel and cement.

1.2.2 International prices and technology costs

Energy price trajectories and the evolution of costs for various energy technologies are generated within the *WEM* for each of the scenarios. Energy prices, in particular, are a major element of uncertainty. In each of the scenarios, the international prices for oil, natural gas and coal need to be at a level that brings the long-term projections for demand and supply into balance, avoiding either surfeits or shortfalls in investment: multiple model iterations are typically required to meet this condition. These are not price forecasts.

Since they keep supply and demand in each fuel and scenario in equilibrium, the price trajectories shown in Table 1.4 are smooth and do not attempt to track the fluctuations that characterise commodity markets in practice. By avoiding any new boom-and-bust cycles, the scenarios therefore skirt what is – in the view of the IEA – a significant vulnerability in today's energy markets. In the case of oil, where the risks appear to be greatest, there is an imbalance in upstream investment between a very dynamic shale sector in the United States and a slump in activity in many other parts of the oil sector. Indeed, these two phenomena are arguably related: the recent cost reductions in US shale production and its ability to respond relatively quickly to price upswings in the market – including those arising from the Organization of Petroleum Exporting Countries' attempts at market management – may be keeping short-term prices at levels that deter some necessary investments in other oil projects with longer lead times. Where the oil market finds its new balance depends to a significant degree on what happens with costs, both for tight oil and for other types of projects (see Chapter 4 for a detailed discussion).

The future evolution of the costs of producing all fossil fuels is determined within the *WEM* as a result of the interplay of three key factors. Technology learning and efficiency improvements continually exert downward pressure on costs; a deterioration in resource quality offsets this, as producers work their way through the resource base in a given area, which pushes costs up; meanwhile the cost of services and supplies can move up or down depending on the price of other materials (cement, steel, etc.) and the tightness of the market for skilled specialists and other equipment, e.g. rigs. In our scenarios, we make the simplifying but historically justifiable assumption that the cost of these services and supplies is correlated with movements in oil prices. The balance between these variables, and therefore the future trajectory of production costs, varies across different resource types and countries, and indeed across the different scenarios in this *Outlook*.

A similar process of technology improvement determines the future cost evolution of other energy technologies, both those in use today and those that are judged to be approaching commercialisation. The rapid cost decline for key renewable technologies is a critically important global energy trend, and the future evolution of costs for renewables, batteries, efficient electric motors and other new low-carbon technologies could fundamentally alter the long-term evolution of energy markets. In the *Outlook*, we do not make allowance for technological breakthroughs, as their timing and form are inherently unpredictable, but the process of continuous technology learning nonetheless has a major impact on our projections. The rate of improvement is related in many cases to the level of deployment;

it can therefore differ substantially by scenario. As in the case of fossil fuels, downward pressure on costs from technological improvements can be offset in some cases by depletion effects: this is a discernible factor affecting renewable resources in some countries and regions, for example, where the most advantageous sites for wind turbines have been fully exploited and developers have to look to second-tier sites. Overall, however, the trends in costs across the energy sector reinforce policy preferences for lower carbon energy options: oil and gas gradually become more expensive to extract, while the costs of renewables and of more efficient end-use technologies continue to fall.

Table 1.4 ▷ Fossil-fuel import prices by scenario

				New Policies				Current Policies		Sustainable Development	
Real terms ($2016)	**2000**	**2010**	**2016**	**2025**	**2030**	**2035**	**2040**	**2025**	**2040**	**2025**	**2040**
IEA crude oil ($/barrel)	38	86	41	83	94	103	111	97	136	72	64
Natural gas ($/MBtu)											
United States	5.9	4.8	2.5	3.7	4.4	5.0	5.6	4.3	6.5	3.4	3.9
European Union	3.8	8.2	4.9	7.9	8.6	9.1	9.6	8.2	10.5	7.0	7.9
China	3.5	7.4	5.8	9.4	9.7	10.0	10.2	10.4	11.1	8.2	8.5
Japan	6.4	12.1	7.0	10.3	10.5	10.6	10.6	10.8	11.5	8.6	9.0
Steam coal ($/tonne)											
United States	37	63	49	61	61	62	62	62	67	56	55
European Union	46	101	63	77	80	81	82	81	95	67	64
Japan	44	118	72	82	85	86	87	86	101	71	68
Coastal China	34	127	80	87	89	90	91	90	101	78	77

Notes: MBtu = million British thermal units; LNG = liquefied natural gas. The IEA crude oil price is a weighted average import price among IEA member countries. Natural gas prices are weighted averages expressed on a gross calorific-value basis. The US gas price reflects the wholesale price prevailing on the domestic market. The EU and China gas prices reflect a balance of pipeline and LNG imports, while the Japan gas price is solely LNG imports; the LNG prices used are those at the customs border, prior to regasification. Steam coal prices are weighted averages adjusted to 6 000 kilocalories per kilogramme. The US steam coal price reflects mine-mouth prices (primarily in the Powder River Basin, Illinois Basin, Northern Appalachia and Central Appalachia markets) plus transport and handling cost. Coastal China steam coal price reflects a balance of imports and domestic sales, while the EU and Japanese steam coal price is solely for imports.

Oil prices

The long-term oil prices in all the scenarios of the *WEO-2017* are lower than in last year's *Outlook*. In the New Policies Scenario, the reduction is strongest in the period to 2025, by which time the oil price reaches $83/barrel (in year-2016 dollars) before rising to reach $111/barrel by 2040 (respectively $18 and $14/barrel lower than in the *WEO-2016*). This adjustment reflects three main factors:

- First, a substantial upward revision in the resource estimate for technically recoverable tight oil and natural gas liquids in the United States. US tight oil is some 30% higher in this year's *Outlook* (up from 80 billion barrels to 105 billion barrels of crude and condensate). There is still considerable uncertainty over this estimate and, in a Low Oil Price Case, we test the implications of a much higher tight oil resource estimate of 210 billion barrels.

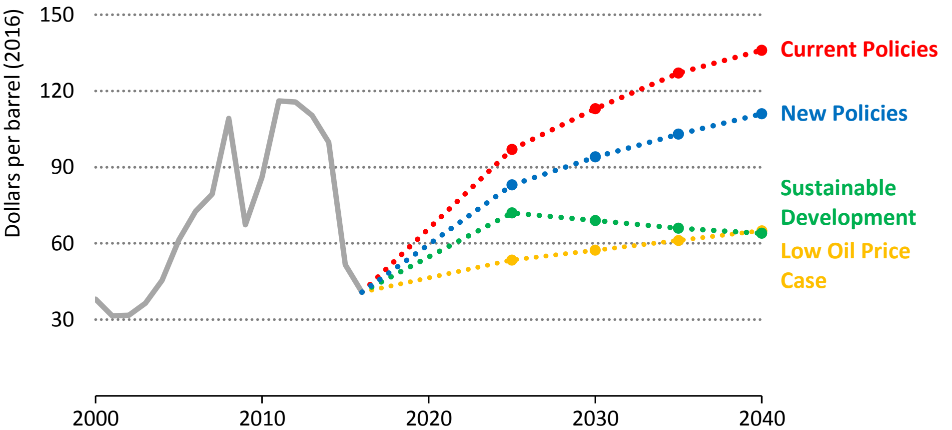
- Second, a reduction in the cost outlook for a variety of upstream projects, which means that more oil can be brought to market at lower prices than in the past. In North American shale, there has been a significant cost reduction effect from technology and efficiency gains, and through rationalising acreage ownership via mergers and acquisitions. On the conventional side, some projects that had been considered to have full-cycle breakeven costs in the range of $70-80/barrel as recently as 2014 are now claimed as viable at $30-50/barrel. A significant share of these reductions could yet prove cyclical and are reversed in the New Policies and Current Policies scenarios as prices rise, investment picks up and markets for supplies and services tighten. However, in our estimation, some of the cost reductions since 2014 are also of a structural nature, due in part to more efficient and standardised processes and project designs and to a degree of technological change over and above the technology learning that is built into the model.
- Third, a greater share of shorter cycle investments on the supply side. In the past, we have argued that the price for oil is always likely to be higher than the cost of the marginal barrel, because the market never quite reaches a classical equilibrium. This reflects a number of factors, including constraints on investment in some key resource-owning countries, and the need to take into account geopolitical risks. But one additional consideration was the long timescales of new projects, where uncertainty over future market conditions and other bottlenecks (notably the availability of sufficient skilled personnel) meant that investment decisions and production rates were always liable to fall behind the level required to keep pace with demand. However, the last few years have seen a definite shift towards shorter project timelines and investment cycles; to the extent that this is maintained in the future, it becomes easier for supply to follow demand quickly and therefore for price to get closer to the cost of the marginal barrel.

There remains an upward drift in the oil price over the period to 2040 in the New Policies Scenario, one that is even more pronounced in the Current Policies Scenario (where demand is significantly higher). This is due to the large requirement for new resource development: some 670 billion barrels in the New Policies Scenario to 2040, most of which is needed to compensate for declines at existing fields. The need to move to higher cost oil in more challenging and complex reservoirs, such as additional deepwater projects and smaller marginal onshore fields, and to less productive areas for tight oil production, means that the marginal project required to balance the market becomes steadily more expensive in this scenario, despite continued technological progress.

Market dynamics and price trends are however quite different in the Sustainable Development Scenario. In this scenario, the resilience of US tight oil means that the up-cycle that is visible in the New Policies Scenario does not have time to play out before demand peaks around 2020. This limits the call on higher cost oil to balance the market and the price therefore stays "lower for longer". We have revised downwards the equilibrium oil price for this scenario significantly compared with the 450 Scenario in the *WEO-2016*.

Another set of conditions under which oil prices could remain lower than in our central scenario is examined in a Low Oil Price Case (see Chapter 4). This analysis is derived from the New Policies Scenario, but changes some key assumptions in a way that keeps the oil price trajectory flat at around $50/barrel until the mid-2020s, before rising slowly to $65/barrel in 2040 (Figure 1.5). The main changes, relative to our central scenario, are a much more rapid growth of electric cars, a doubling of the assumed size of the US tight oil resource base, more rapid technology learning in the upstream and a favourable assumption about the ability of the main oil-dependent producing regions to weather the impact of lower hydrocarbon revenues.

Figure 1.5 ▷ Average IEA crude oil import price by scenario and case



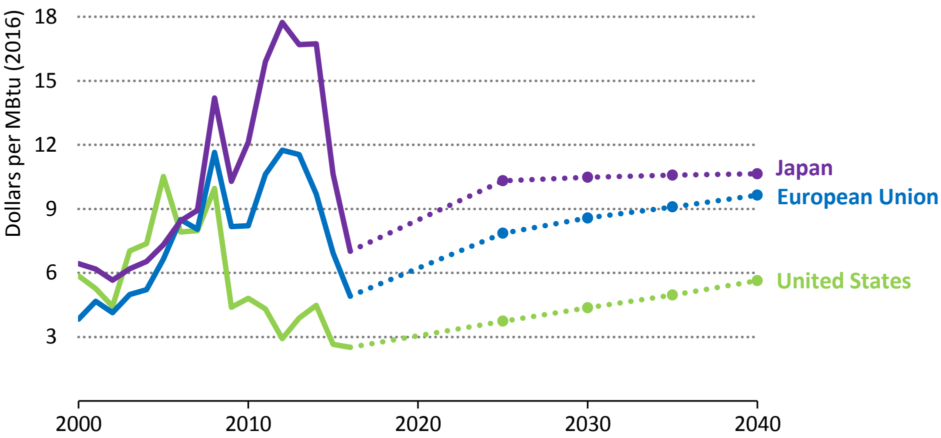
Oil prices vary widely by scenario, reflecting the different ways in which resources, costs and policies could affect the supply-demand balance

Natural gas prices

Like oil prices, natural gas prices in the *WEO-2017* are lower than in last year's *Outlook*. However, there is no single global price for gas, as there is for oil (Figure 1.6). Instead we have a range of regionally determined prices, all with their own specificities, that become gradually more interlinked as we move towards a more interconnected global market, driven by the increasing share of liquefied natural gas (LNG) in global trade, and by the increasing flexibility of this trade to seek the most advantageous commercial destination

The price trajectory for North America plays a critical role in our formation of global prices. The reference price is that of Henry Hub, a distribution hub in the US pipeline system in Louisiana where the price is set entirely by gas-to-gas competition, i.e. it is a price that balances regional supply and demand (including demand for gas for export). The projected price at this hub is lower in each scenario than in the *WEO-2016*. As with oil, this reflects an increase in the resource estimate for shale gas in the United States, and lower assumed costs for its production (see Chapter 9). It also reflects larger volumes of associated gas as a result of higher anticipated tight oil production.

Figure 1.6 ▷ Natural gas prices by key region in the New Policies Scenario



Natural gas prices in the main regions are connected by an increasingly flexible global trade in LNG

Note: See Table 1.4 for more details on natural gas price definitions.

The current period of ample supply in gas markets, alongside the low level of oil prices, has brought down prices in all the major markets, even though the way that gas prices are determined varies by region. In the case of Europe, an increasing share of imported gas is priced off trading hubs, particularly in north-western Europe, but a sizeable residual volume concentrated in southern and south-eastern Europe has prices indexed in full or in part to oil product prices. In Asia, oil-indexation still remains the norm for most imported gas, but new contracts in many parts of the region are weakening this linkage by including references to other indices, including the US Henry Hub.

In our projections, we assume movement in the direction of an integrated global gas market, in which internationally traded gas moves in response to price signals that are determined by the balance of gas supply and demand in each region, i.e. by gas-to-gas competition, and the differences between regional prices reflect only the costs of transporting gas between them. In this new, more liquid market, described in more detail in the special focus on natural gas (see in particular Chapter 9), large US resources and production flexibility, combined with an LNG export industry actively seeking arbitrage opportunities, make Henry Hub not only a regional but also an important global reference for gas price formation. Exporters trying to sell gas at a level above the delivered cost of US supply ultimately find themselves priced out of the market.

Profitable export opportunities from the United States are constrained for the moment by the global supply glut. As markets find a new equilibrium in the 2020s, however, European average import prices settle at around $4/MBtu (in year-2016 dollars) above the Henry Hub price in all scenarios, a differential that reflects the cost of delivering US gas to exporting terminals together with liquefaction and shipping costs. Oil-linked pricing is stronger in Asia than elsewhere, but this link weakens and in Japan the differentials from the US price fall to around $5/MBtu (the additional sum, compared with Europe, reflecting the extra shipping distance to Asian markets).[9]

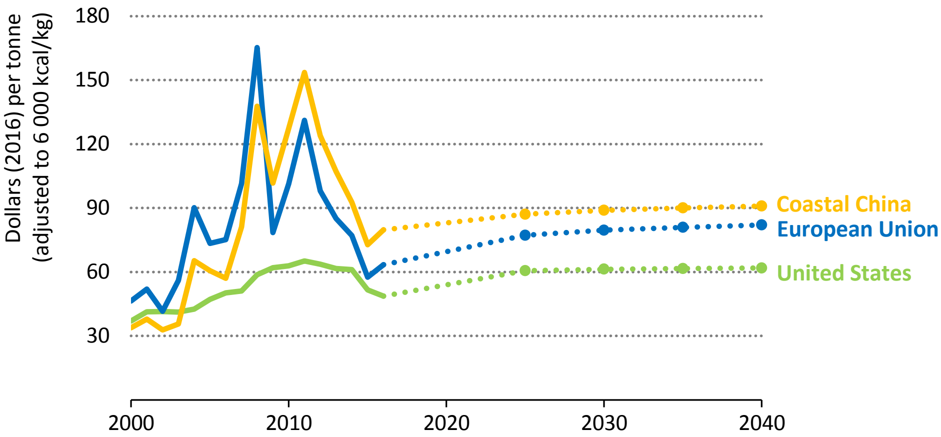
Coal prices

As in the case of natural gas, there is not a single global coal price but various regional coal prices that are usually closely correlated. The difference between the regional coal prices reflect the transport cost between locations, infrastructure bottlenecks and differences in coal quality. Although coal pricing follows market-based principles in most major coal producing countries, there are a few notable exceptions. In India, the state-owned coal giant Coal India Limited maintains a system of regulated "notified" prices. And in South Africa, the state-owned utility Eskom procures its coal needs through long-term contracts on a cost-plus basis from the mines. Although most of the coal trade in these countries is disconnected from the ups and downs of the international market, spot sales are on the rise in both of them, gradually introducing a market-based element in their coal pricing. We see this evolution continuing over the *Outlook* period, with coal pricing in both countries moving towards coal-to-coal competition in the long term.

Coal prices declined for four consecutive years before bottoming out in early 2016, at less than half the levels they reached in 2011. The price slump was caused by massive overcapacity from the building of new capacity when prices were high. Despite cost cutting, the drop in prices has put many coal companies around the world in a tight corner, forcing them to close mines or even go into bankruptcy. This consolidation process has contributed to the bottoming out of prices, together with the capacity cuts administered in China (see Chapter 14 for detail). We believe that Chinese coal prices will continue to be subject of state interventions for the next few years, and that measures to allow flexible adjustment of China's coal output and fine-tuning of price movements will aim at a price range in China of $80/tonne to $90/tonne, with the aim of balancing the needs of China's coal producers and consumers. This price range serves as important guidance for our price outlook for the coming ten years, with coastal China prices rising to $87/tonne in 2025 (Figure 1.7). Similarly, Japanese and European coal prices increase to $82/tonne and $77/tonne respectively in 2025.

9. The continued differentials in average import prices between Japan and China shown in Table 1.4 reflect the additional shipping distance for LNG to Japan, compared with the main Chinese LNG terminals and the slightly lower projected border prices for Chinese pipeline imports, especially those from Central Asia.

Figure 1.7 ▷ Steam coal prices by key region in the New Policies Scenario



Steam coal prices recover from recent lows, but the long-term trend remains markedly below historical highs

Notes: kcal/kg = kilocalorie per kilogramme. See Table 1.4 for more details on steam coal price definitions.

In the long term, worsening geological conditions, declining coal quality in mature mining regions, and longer transport distances in new mining regions combine to put modest upward pressure on coal prices. Mining costs are also increasing as cyclically low prices for consumables like fuel, explosives and tyres are trending upwards. By 2040, Chinese coal prices stand at around $90/tonne in our projections, while those in Japan and the European Union reach $87/tonne and $82/tonne respectively. Although Chinese coal imports decline over the *Outlook* period, arbitrage opportunities between domestic and imported coal remain key for coal pricing, and so the cost of bringing additional domestic coal to China's southern coast continues to act as a price ceiling for international coal prices.

Technology innovation, deployment and costs

The pace of technology change and innovation has the potential to alter fundamentally the future orientation of the energy system. This applies not only to low-carbon energy technologies, but also in some instances to fossil fuels. A reminder of this came in 2016 when the largest reduction in cost was not in wind or solar, but in the cost of producing tight oil in the United States.

Much current research and policy support is concentrated on low-carbon energy technologies and key issues for the *Outlook* period include: which clean energy technologies might be best placed to gain momentum; how deep an impact the increasing application of information and communications technologies might have in the energy sector (Box 1.3); and, at the other end of the spectrum, which energy technologies might be in danger of being left behind.

Box 1.3 ▷ How might digitalisation affect the future of energy?

Digital technologies are becoming ubiquitous, driven by declining costs of sensors and data storage, faster and cheaper data transmission, and rapid advances in analytical computing capabilities. The use of digital technologies across the economy – "digitalisation" – could have significant implications for energy demand and supply, and could bring about potentially transformational changes in both established energy systems and in fast-growing economies (IEA, 2017).

In residential and commercial buildings, for instance, widespread adoption of digitally enabled smart thermostats and smart lighting could reduce energy use in this sector by up to 10% by 2040 compared with the New Policies Scenario. In industry, technologies such as 3D printing could yield significant energy savings within and outside the sector (e.g. by reducing demand for international freight and shipping). On the supply side, digitalisation could bring down the costs of new oil and gas developments and bring new resources into play (see the Low Oil Price Case in Chapter 4).

The transformative potential of digitalisation is greatest in the power sector, given the progressive electrification of the energy system and the need to integrate more decentralised and variable sources of power. For instance, if 1 billion households actively participate in demand-side programmes and 11 billion smart appliances are connected to the grid, we estimate that nearly 185 GW of demand-side flexibility could be deployed cost-effectively by 2040. This would increase the capacity of the power system to respond to changes in electricity supply and demand – removing the need for around $270 billion in new electricity infrastructure investment and facilitating a higher share of wind and solar in the mix. Digital technologies could also save on the electricity supply side by reducing operation and maintenance costs, improving power plant and network efficiency, limiting unplanned outages and extending the operational lifetime of assets.

While digital technologies enable efficiency opportunities across the energy system, the data centres, data transmission networks and connected devices that underpin the burgeoning digital economy are also an important source of energy demand. Data centres and networks already account for about 2% of global electricity use, and this could increase as demand for their services rises. Energy efficiency trends in this area will be an important variable for projecting future electricity consumption.

Given the rapid pace of technological change, and uncertainty in behavioural response, the impacts on longer term energy trends are still quite uncertain (and, for that reason, are only incorporated in part into our projections). For instance, in road transport, automated and shared mobility could improve safety and efficiency, and smart charging of electric vehicles could also reduce the need for new power infrastructure. However, under a different set of assumptions, highly automated vehicles could also increase demand for mobility and push up energy use and emissions.

The benefits of digitalisation come with their own set of risks, requiring active management of the digital transition. Chief among these are potentially increased vulnerability to cyber-attacks as well as data privacy and data ownership issues. Both the opportunities and the risks created by the intersection of energy and digitalisation need increased attention from policy-makers.

A review of the current state-of-play for different clean energy technologies reveals some striking differences. Deployment of solar power had another very strong year in 2016, with record low long-term contract prices in Asia, Latin America and the Middle East. In 2016, solar PV annual additions surpassed those of wind power for the first time, with more than 70 GW coming on line, some 50% higher than the previous year. China accounted for around half of global solar PV additions and deployment in 2017 has remained very strong.

Global additions of wind power fell in 2016, compared with 2015. This was largely due to developments in China, which connected 19 GW of new onshore wind capacity, down significantly on the 33 GW seen the previous year. China cut its feed-in tariff in the meantime, but the fall in deployment also reflected difficulties that China has faced absorbing new wind power capacity in some regions: roughly 50 terawatt-hours (TWh) of potential wind generation was curtailed in 2016 because the power system could not accommodate it. These developments underline the continuing challenges of integrating wind (and other variable renewables), but the falling costs of wind power means that future prospects remain promising.

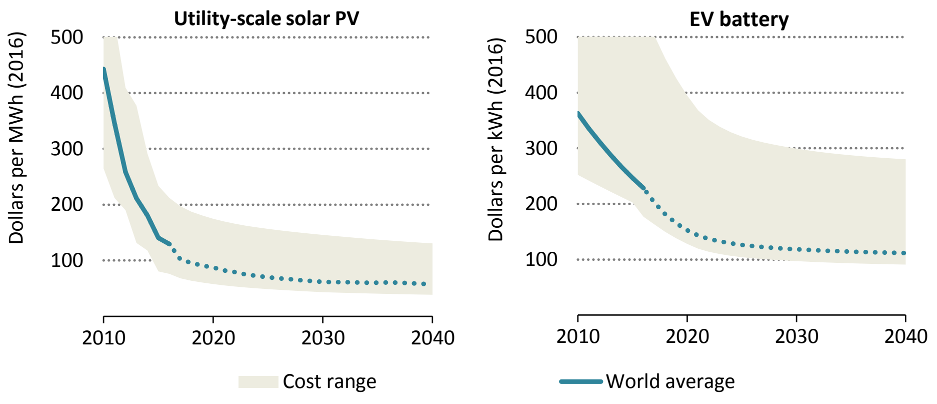
The global average levelised cost of electricity (LCOE) from utility-scale solar PV projects (weighted by deployment) declined by 70% from 2010 to 2016.[10] Over the projection period, this indicator declines by an additional 60% to 2040, although there is a wide range of regional averages both in the historical data and in our projections, reflecting different regulatory frameworks, delivered solar PV module costs and other costs including land, labour and supporting infrastructure (Figure 1.8). The assumed rate at which costs decline for solar PV in the future also varies slightly depending on local conditions, but in general it is around 20% for each doubling of cumulative installed capacity.

Another technology on the move is electric vehicles (EVs). In 2016, more than 750 000 electric cars were sold worldwide, taking the global stock to more than 2 million. As with some other low-carbon technologies, China is leading the way with almost half of global electric car sales (China is also the undisputed champion of electric scooters). For the moment, worldwide sales continue to be dependent on supportive policies and incentives and, where these were reduced, sales have often been badly affected: for example, electric car sales in Denmark collapsed in 2016 after

10. LCOEs represent only the direct costs of projects in real terms, they do not include system integration costs or other system costs that may be related to the deployment of solar PV. A standard weighted average cost of capital is applied to all projects (between 7-8% in real terms, depending on the region), though the availability of low-cost financing may enable developers to achieve lower levelised costs.

the phase-out of a tax break (it has since been partially reinstated). Overall, though, cost trends and policy support for EV deployment have become more favourable since the *WEO-2016,* and this is reflected in higher penetration in the New Policies Scenario.

Figure 1.8 ▷ Evolution of global average cost for selected technologies in the New Policies Scenario



Reductions in costs of key technologies continue to give strong impetus to the energy transition

Note: PV = photovoltaic; EV = electric vehicle.

The key technology variable for EVs is the cost of batteries, given the significant share of batteries in total EV cost (see Chapter 2, section 2.8). Two types of battery are considered in our assumptions: those for battery electric vehicles (BEVs), and those for plug-in hybrid electric vehicles (PHEV), which have slightly different characteristics and requirements. Since 2010, EV battery costs have been coming down at an annual rate of around 7% for major manufacturers, and the deployment that we project in the New Policies Scenario sees continued substantial reductions – at around 6% per year on average – until 2025. The decrease in costs then levels off as it closes in on the ambitious floor costs that we assume of $80 per kilowatt-hour (kWh) for BEV batteries and $100/kWh for PHEV batteries.

Among other critical technologies, batteries are also important for energy storage, which is showing some promising signs. This is an area that continues to be dominated by pumped-storage hydropower, but over 500 MW of other capacity was added in 2016, primarily lithium-ion batteries. Battery storage is still a relatively expensive option to provide flexibility to power systems, but it is starting to grow both at utility-scale and (particularly in countries with significant solar PV capacity) in the nascent market for behind-the-meter storage installations.

The recent record for carbon capture and storage (CCS) has been more mixed. On the positive side, the Petra Nova project in the US state of Texas, commissioned in 2017, retrofitted post-combustion capture technology on an existing coal-fired power station – a vitally important model for the future if operation of today's relatively young global coal-fired fleet is to be compatible with a low-emissions future. Another important step was the world's first large-scale CCS project in the iron and steel industry, which commenced operation in Abu Dhabi. Yet, overall, the global portfolio of CCS projects is not expanding at anything like the rate that would be needed to meet long-term climate goals. The decision in June 2017 to suspend start-up activities for the Kemper gasification system in the United States, due to the project's economics, is a reminder of the challenges that first-of-a-kind technology faces.

The picture for nuclear power is similarly mixed. On the one hand, commissioning of new capacity was up in 2016 to 10 GW, the highest level since 1990. However, the amount of capacity that started construction in 2016 was only 3 GW, well below the recent average. Nuclear plants, especially those in the United States, are struggling to keep a foothold in liberalised markets where competition is fierce. Korea, one of the four previous pillars of growth in projected nuclear capacity in previous *WEOs* (alongside China, India and Russia), has announced a review of its plans. The policy and technology landscape continues to change – and our projections in the *WEO* change in response.

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Part A: Global Energy Trends

Chapter 1: Introduction and scope

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