International Energy Agency
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World Energy Outlook 2016

Chapter 1: Introduction and scope

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

Mapping a changing energy landscape

Highlights

- In a momentous period for global energy, the entry into force of the Paris Agreement in November 2016 was a milestone in the international effort to tackle climate change, deployment of wind and solar technologies reached record levels and governments reaffirmed their intention to ensure universal energy access by 2030. An overhang of supply maintained downward pressure on fossil-fuel prices, even as lower hydrocarbon revenues curbed investment in new oil and gas projects. Among the major consumers, India's energy needs continued to grow rapidly, while China's transition to a less energy-intensive economy gathered speed.

- Our main scenario in *WEO-2016*, the New Policies Scenario, incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced intentions, notably those in the climate pledges submitted for COP21. The Current Policies Scenario includes only those policies firmly enacted as of mid-2016; this default setting for the energy system is a benchmark against which the impact of "new" policies can be measured. The 450 Scenario demonstrates a pathway to limit long-term global warming to 2 °C above pre-industrial levels: we also provide a first assessment of what it would take to reach even more ambitious goals, including a 1.5 °C target.

- Alongside energy policies, which differ between scenarios, the rates at which GDP and population are assumed to grow are the principal determinants of energy demand growth. In *WEO-2016*, global GDP is assumed to grow at a compound average rate of 3.4% per year, slightly below the level assumed in last year's *Outlook*. The world population rises from 7.3 billion in 2015 to 9.2 billion in 2040, with India overtaking China in the early 2020s as the most populous country.

- Energy prices and technology costs vary by scenario, responding to different market dynamics and policies. In the New Policies Scenario, balancing supply and demand requires an oil price approaching $80/barrel in 2020 and further gradual increases thereafter. As the natural gas market globalises, so the various regional prices start to move in tandem, with the US market – where the price rises above $6/MBtu by the late 2030s – increasingly serving as a global reference point. The rebound in coal prices is the slowest, with steam coal imports rising towards $90/tonne by 2040. The projections are very sensitive to the way in which technology learning affects supply costs, including the cost of investing in energy efficiency. Today's progress with deployment of low-carbon technologies is reflected in higher penetration of solar and wind in our projections, compared with *WEO-2015*; but fewer power plants are equipped with carbon capture and storage.

1.1 Defining the scenarios

This 2016 edition of the *World Energy Outlook (WEO)* looks out across an energy landscape in flux. The Paris Agreement on climate change, which entered into force in November 2016, brings together countries representing almost all of the world's greenhouse-gas emissions and energy use: it represents a strong signal of the determination of governments around the world to reduce emissions by accelerating the transition to a cleaner and more efficient energy system. The goals set out in Paris, and the measures that governments have announced to achieve them, significantly influence the projections in this year's *WEO*. Evidence of the momentum behind the energy transition goes beyond the signatures on the Paris Agreement: the latest energy data – on which this *WEO* is based – show how investment in low-carbon and more efficient technologies is having a tangible influence on energy trends. 2015 saw additions of renewable power generation capacity exceed those of fossil fuels. The number of electric cars on the road passed one million. Most significantly, the data for 2014 and 2015 suggested that what was once a very predictable relationship between rising economic activity, growth in energy demand and energy-related carbon-dioxide (CO_2) emissions is starting to weaken.

While the energy transition is unmistakeably gathering momentum, it also has a long way to go. In the power sector, which has the least complicated path to decarbonisation, average investment costs in solar power have fallen between 40% and 80% since 2010, yet solar power still accounts for barely 1% of electricity generation worldwide. In the end-use sectors, alternative fuels and technologies have been even slower to gain ground: 1.3 million electric vehicles is an impressive milestone, but it is only around 0.1% of the global car fleet. Oil, coal and natural gas still account for more than 80% of primary energy demand - a share that has barely moved over the last 25 years. Fossil fuels are abundant (particularly coal, the most carbon-intensive of the three main fossil fuels) and – for the moment at least – relatively cheap. The effects of the tight oil and shale gas revolutions in the United States continue to reverberate across global markets, providing a reminder that innovation and cost reduction are not solely the preserve of renewable energy technologies.

Decarbonisation of the energy system is one of a number of energy-related policy priorities being pursued by governments around the world. In September 2015, countries marked the 70th anniversary of the creation of the United Nations with agreement on new Sustainable Development Goals (SDGs), including the commitment in SDG 7 to "ensure access to affordable, reliable, sustainable and modern energy for all" by 2030. As the *WEO* has emphasised over many years, the absence of universal energy access is a lamentable failure of the world's energy system, with around one-in-six people in the world lacking access to electricity and two-in-five risking their health in the smoky environments caused by cooking over open fires using solid biomass as fuel.

Those without access to energy experience the most profound example of energy insecurity, but concerns about the security and reliability of energy provision extend much more widely. Hundreds of millions of people face daily interruptions to electricity supply, compromising their ability to light and cool their homes and interrupting the activity of their firms or farms. Two consecutive years of declining upstream oil and gas investment in 2015 and 2016 similarly raise concerns about the adequacy of future supply – as do political tensions and instability in major resource-rich countries such as Iraq, Libya, Nigeria and Venezuela.

This is still far from an exhaustive list of the different pressures on energy markets and decision-makers. Consumers prize reliable, affordable energy, so governments typically place a high priority on minimising the costs of energy provision, especially in uncertain economic times. In many countries, the immediate energy-related environmental concern is air pollution – the subject of a special report in the *WEO-2016* series (IEA, 2016a). Even well-laid plans for the future are liable to be disrupted by changes in key energy technologies, particularly as governments and industry step up their efforts to promote clean energy innovation. Public acceptance is a major constraint on policy adoption and implementation: fossil fuels are most subject to criticism, but they are not alone in facing an uncertain and difficult future.

With so many uncertainties and (occasionally competing) priorities, no path of development of the global energy system can be confidently drawn to 2040. That is why as in previous years, this edition of the *World Energy Outlook* presents several scenarios. The structure of the main scenarios is retained from previous *Outlooks*, in order to provide continuity and comparability with previous analysis, but the underlying assumptions have been reviewed carefully to reflect the post-Paris expectations for international co-operation on climate change. The three main global scenarios – Current Policies Scenario, New Policies Scenario and 450 Scenario – are supplemented by a first discussion of pathways that could limit global warming to well below 2 °C and 1.5 °C. 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. In addition to the core scenarios, *WEO-2016* also includes multiple case studies and sensitivity analyses, introduced in the individual chapters, to shed light on specific topics.

New Policies Scenario

Based on a detailed review of policy announcements and plans, the **New Policies Scenario** reflects the way that governments, individually or collectively, see their energy sectors developing over the coming decades. Its starting point is the policies and measures that are already in place, but it also takes into account, in full or in part, the aims, targets and intentions that have been announced, even if these have yet to be enshrined in legislation or the means for their implementation are still taking shape.

The climate pledges, known as Nationally Determined Contributions (NDCs)[1], that are the building blocks of the Paris Agreement provide a rich and authoritative source of guidance for this scenario. They have been carefully and individually assessed for this edition of the *WEO*. Where policies exist to support them and the implementing measures are clearly defined, the

1. Formally, the Intended Nationally Determined Contributions (INDCs) submitted for the Paris Agreement will become Nationally Determined Contributions (NDCs) when each Party ratifies the Agreement. This *Outlook* uses the term NDC to refer to both cases (INDCs and NDCs).

effects are reflected in the New Policies Scenario. Where considerable uncertainties persist, how far and how fast the policy commitments are met depends upon our assessment of the political, regulatory, market, infrastructure and financing constraints; in such cases, the announced targets may, in our *Outlook*, be met later than proclaimed or not at all. On the other hand, there are also cases in which energy demand, macroeconomic circumstances and/or cost trends lead countries to go further and faster than their stated ambitions.

The projections in the New Policies Scenario signal to policy-makers and other stakeholders the direction in which today's policy ambitions are likely to take the energy sector. This does not, however, make this scenario a forecast – a point that needs constantly to be kept in mind. Alongside other uncertainties, like the pace of economic growth and technology change, adjustments will be made to policies affecting energy consumption and the evolution of the power sector in the future, beyond those already announced, responding to new circumstances or priorities. We do not attempt to anticipate such future shifts in policy[2] or to predict major technological change; indeed, to do so would be to undermine the value and purpose of this scenario. The New Policies Scenario is not a normative scenario: it does not depict a future that the International Energy Agency (IEA) deems desirable or one that policy-makers or other stakeholders should try to bring into being. It provides a well-founded basis for expectations about the future and thereby also serves as an invitation for improvement: if the outcomes described are sub-optimal or, even, unacceptable, then policies and other conditions and factors need to change. Our intention in the *World Energy Outlook* is to stimulate those changes through evidence-based analysis.

Current Policies Scenario

The accomplishment of announced, new policy targets cannot be taken for granted. The **Current Policies Scenario** depicts a path for the global energy system shorn of the implementation of any new policies or measures beyond those already supported by specific implementing measures in place as of mid-2016. No allowance is then made for additional implementing measures or changes in policy beyond this point, except that – as with the New Policies Scenario – when current measures are specifically time-bound and expire, they are not normally assumed to lapse on expiry, but are continued at a similar level of intensity through to 2040.

Where policies taken into account in the Current Policies Scenario leave scope for a range of possible outcomes, this scenario assumes that only the lower level of ambition is attained. That is, this scenario not only describes a world in which there are no new policies, but also one in which the implementation of some existing commitments is sluggish. It depicts, for example, a world without the implementation of many of the policy changes promised at the United Nations Framework Convention in Climate Change (UNFCCC) Conference of

2. A partial exception relates to fossil-fuel supply, where there is a generic assumption, in all scenarios, that governments make efforts to stimulate domestic production where resources and market conditions offer opportunities to do so. Such efforts are subject to policy and political constraints, including public acceptance, that are taken into account, but the outcome may involve assuming the development of resources that are not currently foreseen for exploitation.

the Parties in Paris (COP21). This is likewise not a prediction but, rather, a "default setting" for the global energy system, with little or no change to settled, established positions. In this way, the Current Policies Scenario provides a benchmark against which the impact of "new" policies can be measured.

Decarbonisation scenarios

The decarbonisation scenarios examined in this *Outlook* are quite different in approach from those discussed above. The New Policies Scenario and Current Policies Scenario start with certain assumptions on policy and then see where they take the energy sector. The decarbonisation scenarios start from a certain vision of where the energy sector needs to end up and then work back to the present. The decarbonisation scenario described in detail in *WEO-2016* is the **450 Scenario**, which has the objective of limiting the average global temperature increase in 2100 to 2 degrees Celsius above pre-industrial levels.[3] A 2 °C target was mentioned explicitly in the Cancun Agreements in 2010 (the first time that it appeared in a document agreed under the UNFCCC framework[4]) and it has also been used as a yardstick in reports from the Intergovernmental Panel on Climate Change. As such, it has become a widely recognised benchmark for government policies and company strategies on climate change.

With this in mind, and to provide continuity with previous *WEOs*, the 450 Scenario retains a prominent position in this *Outlook*. We have, though, revisited important features of this 450 Scenario in the light of progress with the deployment of key low-carbon technologies. As described in more detail in Chapter 8 and Chapters 10-12, the 450 Scenario in *WEO-2016* relies more heavily on renewables, in particular wind and solar, to achieve the necessary reduction in energy-related CO_2 emissions. It relies less than in the past on the deployment of carbon capture and storage (CCS), given the slow pace at which this technology is being tested and deployed in practice, and the constraint that this implies on the pace of its future growth. The results of the 450 Scenario are a point of reference throughout this report, as well in the detailed tables in Annex A.

In addition to the 450 Scenario, *WEO-2016* includes a first appraisal (but not yet in the detail required for a full scenario) of two more ambitious emissions reduction pathways, derived from the Paris Agreement (Box 1.1). These would aim to limit warming to "well below 2 °C" and to 1.5 °C, respectively.[5] While the goal of the latter is well defined, to

3. The 450 Scenario was first introduced in *WEO-2008* at a time when climate targets were typically expressed in terms of the concentration of greenhouse gases in the atmosphere. This set out an energy pathway aiming to limit the concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2 equivalent. To reflect changes in the public and academic discourse surrounding climate change mitigation, the 450 Scenario is now expressed as realising a 50% chance of limiting warming to a 2 °C temperature rise in 2100. This is consistent with the previous concentration-based objective.

4. Article 2 of the 1992 UN Framework Convention on Climate Change committed the Parties to "stabilisation of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system", without specifying what such a concentration might be.

5. Chapter 8 presents some initial findings in these areas. However, further research is required, in close collaboration with other relevant stakeholders, in order to understand in more detail the ways that such pathways could be achieved. This work is in hand.

date there is no commonly agreed definition of what would constitute a "well below 2 °C" outcome: this discussion is expected to gather momentum in political and scientific circles over the coming months and years. Pending the outcome of this debate, *WEO-2016* explores a trajectory with a 66% probability of limiting the global temperature rise in 2100 to below 2 °C, rather than the 50% chance offered by the 450 Scenario: that is, a trajectory with a higher likelihood of over achievement or, in other words, a higher prospect of a temperature rise less than 2 °C.

Box 1.1 ▷ Key provisions of the Paris climate change agreement

The accord reached in December 2015 at the Paris UNFCCC conference (COP21) was the culmination of a long and complicated negotiating process. The agreement, referred to as the "Paris Agreement", was already ratified by a sufficient number of Parties (the threshold of 55 Parties accounting for at least 55% of total global greenhouse-gas emissions) to allow it to enter into force on 4 November 2016, just before the start of the COP22 in Marrakech, Morocco.

The Paris Agreement sets out the common goal to limit global warming and identifies ways in which this might be achieved. It aims to strengthen the global response to the threat of climate change, by:

> *"Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels."*

Countries are committed to reach this goal via "global peaking of greenhouse-gas emissions as soon as possible", recognising that this will take longer for developing countries, and then by reducing emissions rapidly to a point – sometime in the second-half of this century – when the world achieves a balance between anthropogenic emissions and their removal by sinks, by means of measures such as afforestation or carbon capture and storage.

How is this goal to be achieved? The main mechanism is via Nationally Determined Contributions (NDCs), the pledges made in advance of Paris that outlined climate ambitions and which, implicitly or explicitly, include commitments relating to the energy sector. The first round of NDCs for the period from 2020 are formalised when countries ratify or accede to the Agreement; subsequent NDCs will be communicated every five years, with the next round set by 2020.

To facilitate implementation of the NDCs, particularly in developing countries, the Paris Agreement established various complementary obligations and mechanisms related to finance (the commitment to mobilise $100 billion per year in climate-related finance by 2020 was extended to 2025), capacity-building and technology development and transfer. Outside the formal Agreement framework, 20 countries and the European Union also agreed to double their clean energy research and development spending over the next five years as part of Mission Innovation, supported by commitments by companies – like those in the Breakthrough Energy Coalition – to invest capital in early-stage technology development.

The Paris Agreement includes provisions on adaptation to climate change, market-based emissions reduction mechanisms (establishing a successor to the Clean Development Mechanism), the roles of non-state actors and the need to achieve universal access to sustainable energy. There is also a unified system to track progress, with all countries reporting regularly on their emissions, progress with implementation of NDCs and adaptation actions.

1.2 Developing the scenarios

The World Energy Model (WEM) generates the energy projections used in this report.[6] The WEM is a large-scale simulation tool, developed in-house at the IEA over a period of more than 20 years, designed to replicate how energy markets function. It covers the whole energy system in detail, allowing the analysis to focus not only on global or regional aggregates but also to zoom in on a multitude of indicators, such as the roles of distinct technologies and end-uses, the evolution of power sector and end-user prices, and the implications of different pathways for investment, trade and greenhouse-gas emissions. 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. In addition to the main modules covering energy demand, fossil fuel and bioenergy supply, and energy transformation, there are supplementary tools to amplify the analytical capacity. The model is updated and enhanced each year in order to reflect ever more closely how energy markets operate and how they might evolve. The major changes introduced for the *WEO-2016* include:

- A new, more granular model of the power market, developed for the special focus on renewable energy, to assess the scope for the integration of variable renewables and the related costs (see Chapters 10-12). This allows for a more detailed understanding of the implications of seasonal, daily and hourly variations in the output of certain renewable energy technologies, notably wind and solar, in different markets and the flexibility that is required of other power system components.
- A detailed stock model for industrial electric motor-driven systems, enabling explicit modelling of the impact of policies on elements including the motor, the driven equipment, the use of a variable speed drive and system-wide improvements.
- A new sub-module for international shipping, developed in collaboration with the IEA's Mobility Model (MoMo).
- More detailed representation of renewable energy heat applications in various end-uses.

6. For details on the WEM methodology, see the "WEO Model" section of the *World Energy Outlook website: www.worldenergyoutlook.org.*

- More definition on finding and development costs for different types of conventional oil and gas, as well as a revised representation of associated gas production.
- New play-by-play models for tight oil and shale gas in the United States.
- An overhaul of the way that trade in natural gas is represented, incorporating the best available information on supply contracts and infrastructure plans, disaggregation by country in North America and more detail on gas imports by the European Union.

The WEM is very data-intensive, containing detailed and up-to-date data on energy demand, supply and transformation, as well as time series for a range of energy prices and costs. These data are drawn primarily from IEA databases, which are maintained by the IEA Energy Data Centre on the basis of submissions from IEA member and non-member countries, supplemented by additional research and other sources: historical cost data for wind and solar, for example, are drawn from the International Renewable Energy Agency. The base year for all of the scenarios is 2014, as comprehensive market data for all countries were available only up to the end of 2014 at the time the modelling work was completed. However, where preliminary data for 2015 were available (which was often the case), they have been incorporated. The outputs from the WEM are coupled with quantitative models from other organisations to generate additional findings and insights. Such collaboration in 2016 contributed importantly to two *WEO Special Reports*: *Energy and Air Pollution* (IEA, 2016a) with the International Institute of Applied Systems Analysis; and with the Organisation of Economic Co-operation and Development (OECD) computable general equilibrium model, ENV-Linkages, on the economic impacts of energy policies for the *Mexico Energy Outlook* (IEA, 2016b).

1.2.1 Inputs to the modelling

Energy policies

The policies that are assumed to be pursued by governments around the world vary by scenario: indeed, different policy assumptions are instrumental in producing the divergent outcomes that we see between the Current Policies Scenario, the New Policies Scenario and the decarbonisation scenarios. A good example of such policy differentiation between scenarios arises in relation to the Clean Power Plan in the United States, which aims to cut emissions of carbon dioxide and other pollutants from the US power sector. The Plan was first proposed by the US Environmental Protection Agency in June 2014 and a final version followed in August 2015. Once it was announced in 2014, it was incorporated into the New Policies Scenario. Once the final rules had been put in place, the Plan would normally have become part of the Current Policies Scenario as well. However, in February 2016, the US Supreme Court suspended implementation of the Clean Power Plan, pending judicial review. Even though some US states are moving ahead with implementation, the Clean Power Plan is therefore currently included only in the New Policies Scenario and not in the Current Policies Scenario.

The guidance that countries provided on future energy policies in their NDC's, submitted to the UNFCCC in the run-up to the Paris COP21, is an important input to the *WEO-2016*. The impact of the energy-related component of these climate pledges was analysed in the

WEO-2015 cycle, notably in *Energy and Climate Change: World Energy Outlook Special Report* (IEA, 2015a), published in advance of COP21 and in a *WEO* Special Briefing for COP21.[7] However, more complete information on all the NDCs, as well as proposed implementing measures, is now available and has been considered in detail in the preparation of this *Outlook*. A detailed list of the policies assumed to be implemented in the various scenarios is included in Annex B. They include programmes to support renewable energy and improve energy efficiency, to promote alternative fuels and vehicles, and to change the way that energy is priced, for example, by reforming subsidised consumer prices for oil, gas and electricity.

On the latter point, during the recent period of lower oil prices many countries have signalled intent to remove fossil-fuel subsidies. But their removal is not assumed in the Current Policies Scenario unless a formal programme is already in place. In the New Policies Scenario, all net-importing countries and regions phase out fossil-fuel subsidies completely within ten years. In the 450 Scenario, while all subsidies are similarly removed within ten years in net-importing regions, they are also removed in all net-exporting regions, except the Middle East, within 20 years.

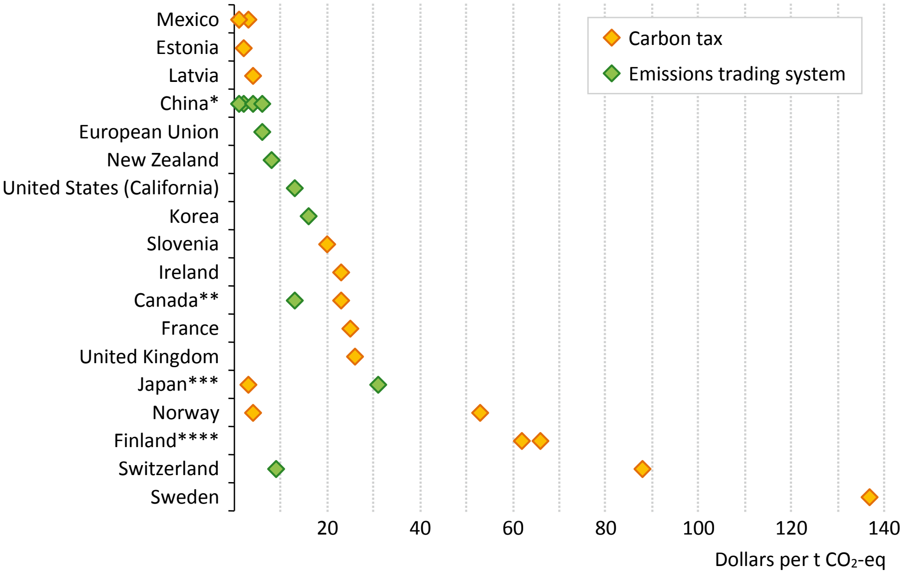
Another influential policy variation between the scenarios is the scope and level of carbon pricing, which has a major impact on the relative costs of using different fuels. As of mid-2016, 63 carbon pricing instruments were in place or scheduled for implementation, either cap-and-trade schemes or carbon taxes, with wide variations in coverage and price (Figure 1.1). In addition to schemes already in place, which are assumed to remain throughout our *Outlook* period, the New Policies Scenario includes the introduction of new carbon pricing instruments where these have been announced but not yet introduced. A notable example is China's carbon trading scheme, due to come into force by the end of 2017 for six large energy-consuming sectors: power, iron and steel, chemicals, building materials, paper and nonferrous metals. In the 450 Scenario, the use of carbon pricing instruments becomes much more widespread, especially within the OECD, and prices are significantly higher (Table 1.1).

Table 1.1 ▷ CO_2 price assumptions in selected regions by scenario

$2015 per tonne	Region	Sectors	2020	2030	2040
Current Policies Scenario	European Union	Power, industry, aviation	18	30	40
	Korea	Power, industry	18	30	40
New Policies Scenario	European Union	Power, industry, aviation	20	37	50
	Chile	Power	6	12	20
	Korea	Power, industry	20	37	50
	China	Power, industry	10	23	35
	South Africa	Power, industry	7	15	24
450 Scenario	United States, Canada, Japan, Korea, Australia, New Zealand	Power, industry	20	100	140
	European Union	Power, industry, aviation	20	100	140
	China, Russia, Brazil, South Africa	Power, industry	10	75	125

7. *www.iea.org/media/news/WEO_INDC_Paper_Final_WEB.PDF.*

Figure 1.1 ▷ Selected carbon pricing schemes in place as of mid-2016



Countries put a wide range of prices on carbon in different parts of the energy sector

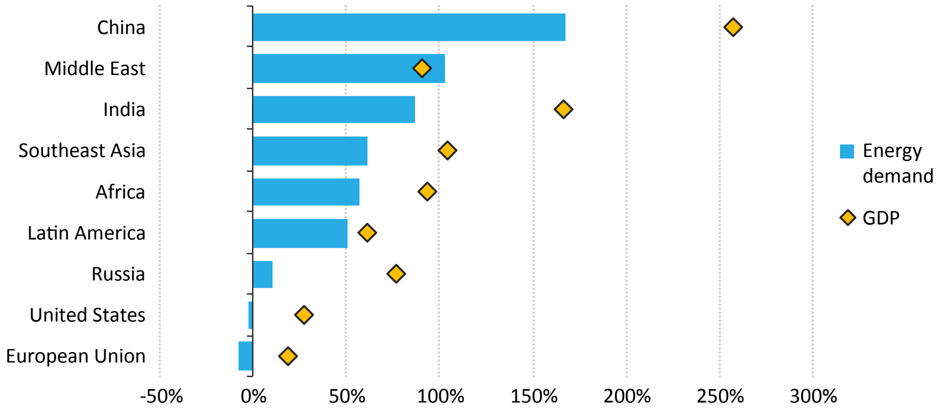
Notes: All prices as of 1 July 2016. $/t$CO_2$-eq = US dollars per tonne of carbon-dioxide equivalent. The coverage of the various schemes varies widely, with many limited to specific sub-sectors and/or fuels. Values for Norway cover lower and upper values of carbon tax. * China includes pilot schemes introduced in Shanghai, Guangdong and Chongqing ($1-2/t$CO_2$-eq), Hubei and Tianjin ($4/t$CO_2$-eq), Beijing and Shenzhen ($6/t$CO_2$-eq). ** Canada includes initiatives introduced by Québec ($13/t$CO_2$-eq), Alberta ($15/tCO_2-eq) and British Columbia ($23/t$CO_2$-eq). *** Japan includes national carbon tax ($3/t$CO_2$-eq) and Tokyo emissions trading ($31/t$CO_2$-eq) **** Finland includes initiatives covering heating fuels ($62/t$CO_2$-eq) and the transport sector ($66/t$CO_2$-eq).

Sources: World Bank Group; Ecofys; Carbon Pricing Watch 2016.

Economic outlook

Economic prospects play a critically important role in determining the outlook for energy consumption, not only the headline rate of growth in gross domestic product (GDP), but also the way in which growth rates might vary across different sectors of the economy. For the world as a whole, GDP growth is pushing energy consumption higher. However, this relationship has diverged substantially across countries over recent years. Among the OECD group of economies, growth in GDP (expressed in real purchasing power parity [PPP] terms) was even associated with a slight decline in primary energy demand for the period 2000-2014. This is a noteworthy turn of events, but not necessarily a surprising one given that structural economic shifts, saturation effects and efficiency gains produced a peak in primary energy demand in Japan (in 2004) and the European Union (in 2006), since when demand in both has fallen by more than 10%; and demand in the United States is already 5% below the high point reached in 2007. Elsewhere, however, the links between economic growth and energy consumption remain strong (Figure 1.2). Overall, for every one percentage point rise in non-OECD economic growth over the period 2000-2014, energy demand increased by around 0.7%.

Figure 1.2 ▷ Changes in GDP and energy demand in selected countries and regions, 2000-2014



Comparing the pace of economic growth from 2000 to 2014 with energy demand growth over the same period shows wide country and regional variations

Note: GDP = gross domestic product.

In each of the scenarios included in this *Outlook*, the world economy is assumed to grow at a compound average annual rate of 3.4% over the period 2014 to 2040 (Table 1.2). This represents a slight reduction in anticipated growth compared with the 3.5% rate assumed in *WEO-2015*. The main differences occur over the period to 2020, where the new growth assumptions reflect the more subdued economic forecasts made by the International Monetary Fund (IMF), the primary source for our medium-term GDP outlook.[8] The downward revisions over this period have been sharpest for hydrocarbon exporters, particularly those in Latin America and Africa, where deteriorating fiscal and external balances have forced cuts to consumption and investment spending. Even for net hydrocarbon importers, the period of lower oil prices has proved to be less of an economic boost than many had expected. In many cases, the drop in fuel prices seen by consumers has been much less than the headline fall in the oil price: many countries have taken the opportunity of lower prices to cut domestic energy subsidies or raise fuel taxes. Exchange rate fluctuations and the strong US dollar have also had an impact (Box 1.2).

The way that future growth in economic activity translates into demand for energy is heavily dependent on policies (notably energy efficiency policies, the intensity of which

8. The medium-term outlook for GDP was adjusted slightly, in consultation with the IMF, to align with IEA expectations about energy market conditions.

varies by scenario) and structural changes in the economies.[9] Future GDP growth based on an expansion of industrial output, especially in energy-intensive sectors, such as iron and steel, cement or petrochemicals, has much stronger implications for energy demand than a similar expansion based on the services sector. For the global economy as a whole, services account for the largest share of current GDP, at 62%, and this share rises steadily to reach 64% by 2040. The rising role of the services sector in GDP is particularly striking in the case of China, whose economy is already rebalancing away from a reliance on manufacturing and exports towards a more domestic- and service-oriented economy, with a much less energy-intensive pattern of growth than in the past. The share of industry in China's GDP is projected to fall from 42% today to 34% in 2040.

Table 1.2 ▷ Real GDP growth assumptions by region

	Compound average annual growth rate				
	2000-14	2014-20	2020-30	2030-40	2014-40
OECD	**1.6%**	**2.0%**	**1.9%**	**1.7%**	**1.9%**
Americas	1.8%	2.3%	2.2%	2.1%	2.2%
United States	1.7%	2.3%	2.0%	2.0%	2.0%
Europe	1.4%	2.0%	1.7%	1.5%	1.7%
Asia Oceania	1.7%	1.4%	1.6%	1.3%	1.4%
Japan	0.7%	0.4%	0.8%	0.7%	0.7%
Non-OECD	**6.0%**	**4.6%**	**4.9%**	**3.8%**	**4.4%**
E. Europe/Eurasia	4.4%	1.1%	3.0%	2.7%	2.4%
Russia	4.1%	0.0%	2.6%	2.5%	2.0%
Asia	7.6%	6.1%	5.5%	3.9%	5.0%
China	9.6%	6.2%	5.2%	3.2%	4.6%
India	7.2%	7.5%	7.0%	5.3%	6.5%
Southeast Asia	5.3%	5.0%	4.9%	3.7%	4.5%
Middle East	4.6%	3.0%	3.8%	3.4%	3.4%
Africa	4.7%	4.0%	4.8%	4.3%	4.4%
South Africa	3.1%	1.7%	2.8%	2.9%	2.6%
Latin America	3.5%	0.8%	3.1%	3.1%	2.6%
Brazil	3.3%	-0.5%	2.9%	3.1%	2.2%
World	**3.7%**	**3.5%**	**3.7%**	**3.1%**	**3.4%**
European Union	1.3%	1.9%	1.6%	1.4%	1.6%

Note: Calculated based on GDP expressed in year-2015 dollars in PPP terms.

Sources: IMF (2016); World Bank databases; IEA databases and analysis.

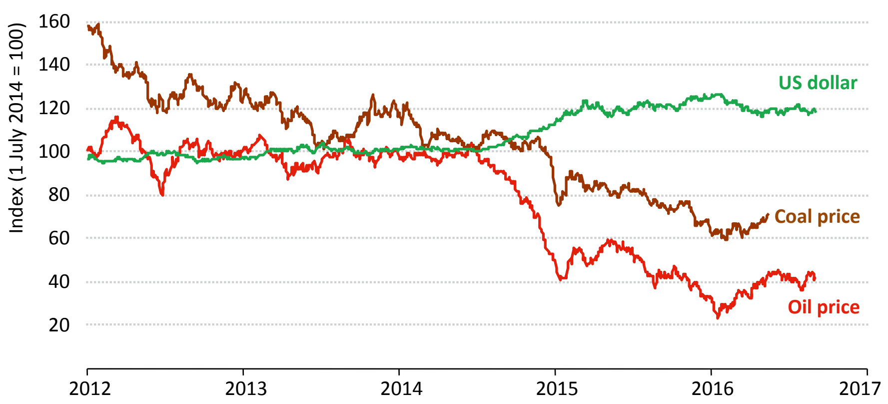
9. The shift in energy use in some developing countries away from the traditional use of solid biomass (particularly for cooking) towards modern fuels also has a large impact on measured energy use, as well as significant co-benefits in reducing exposure to air pollution.

Box 1.2 ▷ Impact of exchange rate fluctuations

All energy prices, investments and other costs are expressed in constant US dollars in our scenarios. This is an appropriate simplification for a modelling effort aimed at understanding the long-term dynamics of the energy sector and that seeks equilibrium only in this sector, rather than across entire economies. But, particularly in the short term, fluctuations in exchange rates can have important implications for energy trends, notably if the dollar – the currency in which much internationally traded energy is priced – gains or loses value against other currencies.

The steady strengthening of the dollar since mid-2014 is a good case in point (Figure 1.3). For economies whose currencies lost value against the dollar at a time when prices for oil, gas and coal were falling, the fall in prices for consumers was partly offset. Similarly, producers were shielded from some of the revenue loss. An oil price fall in US dollars of 50% can result in a price change of barely 25% in countries where currencies have suffered a fall against the dollar. It is not just energy prices that are affected, but also energy technologies. For countries looking to import solar photovoltaic (PV), for example, the striking decline in panel costs (expressed in US dollars) is much less impressive in local currencies that have lost value against the dollar. In Australia, for example, the costs of residential PV fell by half between 2012 and 2015, when expressed in US dollars, but in local currency terms – a much more relevant indicator for consumer uptake – they dropped by only a little more than a quarter. The energy implications for any individual country depend on the way that it sources energy products, services and technologies, whether locally or from the international market. We have taken this into account in *WEO-2016* when establishing the base year technology costs in markets that have seen large, recent currency swings.

Figure 1.3 ▷ Trends in oil and coal prices and US dollar value



A rise in the value of the US dollar has affected the way that falling fossil-fuel prices affect consumers in many countries

Note: The US dollar index is a measure of the value of the dollar against a basket of non-US currencies.

Demographic trends

Population and demographics are important underlying determinants of energy use. As in previous years, the *WEO-2016* adopts the medium variant of the latest United Nations' projections as the basis for population growth in all scenarios (UNPD, 2015). According to these projections, the world population is expected to grow by 0.9% per year on average, from 7.3 billion in 2014 to 9.2 billion in 2040 (Table 1.3). The increase in the global population is concentrated in Africa, India, Southeast Asia and the Middle East. Africa experiences the fastest rate of growth, its population nearly doubling to 2.1 billion people. India overtakes China to become the world's most populous country in the early 2020s, with its population exceeding 1.6 billion by the end of the period. A number of countries experience a decline in population over the period to 2040, including Japan (whose population in 2040 is projected to be almost 10% smaller than it is today), Russia and Germany. People increasingly concentrate in cities and towns, pushing the global urbanisation rate up from 53% in 2014 to 63% in 2040.

Table 1.3 ▷ Population assumptions by region

	Population growth*			Population (million)		Urbanisation	
	2000-14	2014-25	2014-40	2014	2040	2014	2040
OECD	**0.7%**	**0.5%**	**0.4%**	**1 272**	**1 394**	**80%**	**85%**
Americas	1.0%	0.8%	0.7%	496	592	81%	86%
United States	0.9%	0.7%	0.6%	323	377	82%	86%
Europe	0.6%	0.3%	0.2%	570	599	76%	82%
Asia Oceania	0.3%	0.1%	0.0%	206	203	90%	93%
Japan	0.0%	-0.3%	-0.4%	127	114	93%	97%
Non-OECD	**1.4%**	**1.2%**	**1.0%**	**5 983**	**7 758**	**48%**	**59%**
E. Europe/Eurasia	0.0%	0.1%	-0.1%	343	335	63%	68%
Russia	-0.1%	-0.1%	-0.3%	144	133	74%	79%
Asia	1.1%	0.8%	0.6%	3 779	4 459	43%	57%
China	0.6%	0.3%	0.1%	1 372	1 398	55%	73%
India	1.5%	1.1%	0.9%	1 295	1 634	32%	45%
Southeast Asia	1.3%	1.0%	0.8%	623	763	47%	60%
Middle East	2.4%	1.7%	1.4%	224	323	70%	75%
Africa	2.5%	2.4%	2.3%	1 156	2 062	40%	51%
South Africa	1.5%	0.7%	0.6%	54	63	64%	75%
Latin America	1.2%	0.9%	0.7%	481	578	79%	85%
Brazil	1.1%	0.7%	0.5%	206	236	85%	90%
World	**1.2%**	**1.0%**	**0.9%**	**7 255**	**9 152**	**53%**	**63%**
European Union	0.3%	0.1%	0.0%	510	511	75%	81%

* Compound average annual growth rate.

Sources: UN Population Division databases; IEA analysis.

1.2.2 International prices and technology costs

The variables discussed so far – assumptions on future energy policies, economic activity and demographic trends – are all introduced from outside the model (they are exogenous variables). Another set of variables, of considerable importance to the operation of the World Energy Model, is generated within the model itself. These are our price trajectories for each of the fossil fuels and the evolution of costs for different energy technologies. In the case of fossil-fuel prices, the need is to reach a level which brings the long-term projections for supply and demand into balance, and price trajectories are adjusted in iterative model runs until they satisfy this criterion (Table 1.4). The price trajectories are smooth trend lines, and do not attempt to anticipate the cycles and short-term fluctuations that characterise all commodity markets in practice.

Table 1.4 ▷ Fossil-fuel import prices by scenario

		New Policies Scenario			Current Policies Scenario			450 Scenario		
Real terms ($2015)	2015	2020	2030	2040	2020	2030	2040	2020	2030	2040
IEA crude oil ($/barrel)	51	79	111	124	82	127	146	73	85	78
Natural gas ($/MBtu)										
United States	2.6	4.1	5.4	6.9	4.3	5.9	7.9	3.9	4.8	5.4
European Union	7.0	7.1	10.3	11.5	7.3	11.1	13.0	6.9	9.4	9.9
China	9.7	9.2	11.6	12.1	9.5	12.5	13.9	8.6	10.4	10.5
Japan	10.3	9.6	11.9	12.4	9.9	13.0	14.4	9.0	10.8	10.9
Steam coal ($/tonne)										
OECD average	64	72	83	87	74	91	100	66	64	57
United States	51	55	58	60	56	61	64	53	52	49
European Union	57	63	74	77	65	80	88	58	57	51
Coastal China	72	78	86	89	79	92	98	73	72	67
Japan	59	66	77	80	68	84	92	61	59	53

Notes: MBtu = million British thermal units. Gas prices are weighted averages expressed on a gross calorific-value basis. All prices are for bulk supplies exclusive of tax. The US price reflects the wholesale price prevailing on the domestic market. The China and European Union gas import prices reflect a balance of LNG and pipeline imports, while the Japan import price is solely LNG.

In the case of technology costs, the WEM incorporates a process of learning that brings down costs with the cumulative deployment of a given technology: the more a given technology is used, the quicker costs come down – so again it varies by scenario. Learning applies, in different ways, to all technologies across the entire energy system – from upstream oil and gas to renewables and energy efficiency, but the downward pressure on costs of greater scale of deployment is offset, in some cases, by other considerations, such as the effects of depleting a finite resource (most obviously, in the case of oil and gas) or other limits (such as the availability of prime onshore sites for wind power).

Oil

Moving into the last quarter of 2016, there are signs that the market rebalancing anticipated in last year's WEO (and in the IEA's short- and medium-term analysis) is underway; but the process is a slow one. With Saudi Arabia and other key Organization of Petroleum Exporting Countries (OPEC) producers raising output in 2016 to historic highs, the adjustment in the market has depended on the interaction between two other variables: the stimulus that a lower price gives to oil demand and the check that it provides on supply from more expensive sources, much of which is non-OPEC. Oil demand growth has indeed been relatively strong, and is anticipated to reach 1.2 million barrels per day (mb/d) for 2016 as a whole. Investment cuts are also starting to take their toll on non-OPEC output, which is expected to decline by around 0.9 mb/d in 2016. But output from the main low-cost Middle East producers has been rising steadily and – with no clear global surplus of demand over supply – global inventories remain at record levels.

As argued in last year's *Outlook*, the process of market rebalancing is rarely a smooth one and the oil market could well enter a new period of price volatility as it seeks a new equilibrium. A key consideration is the long lead times associated with most upstream projects, which mean that – in the majority of cases – the large cuts in upstream spending seen in many non-OPEC countries have yet to work their way through into lower supply. *WEO-2016* does not attempt to model short-run price fluctuations, but indicates that, in the New Policies Scenario, a price of around $80/barrel would be sufficient and necessary to balance the market in 2020.

The possibility that the oil market could settle at a lower price level cannot be ruled out: indeed, the market expectations expressed in the forward curve for Brent crude oil (as of October 2016) suggest prices around $60/barrel in 2020. Arguments in favour of such a price level as the "new normal" rest on the perception of a strong structural component in the recent decline in upstream costs, particularly in the case of US tight oil, implying resilience among key non-OPEC sources to a lower price environment. In addition, such arguments rely on the assumption that the main resource-holders, led by Saudi Arabia, are less able (or less willing) to exert meaningful influence on the market by restraining output than they have been in the past. A scenario in which ample supply keeps oil prices in the $50-60/barrel range until the early 2020s, before rising very gradually to $85/barrel in 2040, was examined in *WEO-2015* (Box 1.3) and the results of that Low Oil Price Scenario remain a point of reference and comparison in this *Outlook*.

Box 1.3 ▷ Are we in a Low Oil Price Scenario?

With the oil price only rarely breaking above $50/barrel in the first three-quarters of 2016, the idea that oil prices could stay "lower for longer" has gained a firm foothold in discussions on the oil market outlook. But how much longer could a period of lower prices plausibly last? In *WEO-2015*, we tested the long-term durability of this idea in a Low Oil Price Scenario, in which we examined a set of conditions that would allow lower oil prices to persist all the way through to 2040.

The main assumptions that differentiated this scenario from the New Policies Scenario were lower near-term economic growth and a more rapid phase out of fossil-fuel consumption subsidies (both restraining growth in oil consumption); greater resilience among some non-OPEC sources of supply to a lower price environment, notably tight oil in the United States; a lasting commitment by OPEC countries to give priority to market share and to a price that limits substitution away from oil; and favourable assumptions about the ability of the main oil-producing regions to weather the storm of lower hydrocarbon revenues.

One year on, some of these assumptions are holding. Economic prospects have indeed dimmed and many countries – including not just oil importers but also oil exporters – have announced their intention to reform energy prices, dampening prospects for strong demand growth. Production in some key non-OPEC countries, notably the United States and Russia, has held up well under testing conditions, although the shift towards greater reliance on lower cost producers in the Middle East, another feature of the Low Oil Price Scenario, is already visible, with the share of the Middle East in global output rising to 35%, a level not seen since the late 1970s.

However, other assumptions are looking shakier. Some other anticipated sources of future non-OPEC supply are showing the strain. In Brazil, Petrobras' annual investment plans have been slashed, as lower revenues, high debt and the repercussions of a corruption scandal take their toll on spending. In Canada, drilling activity in 2016 is set to be lower than at any point in the country's 40-year recorded drilling activity history.

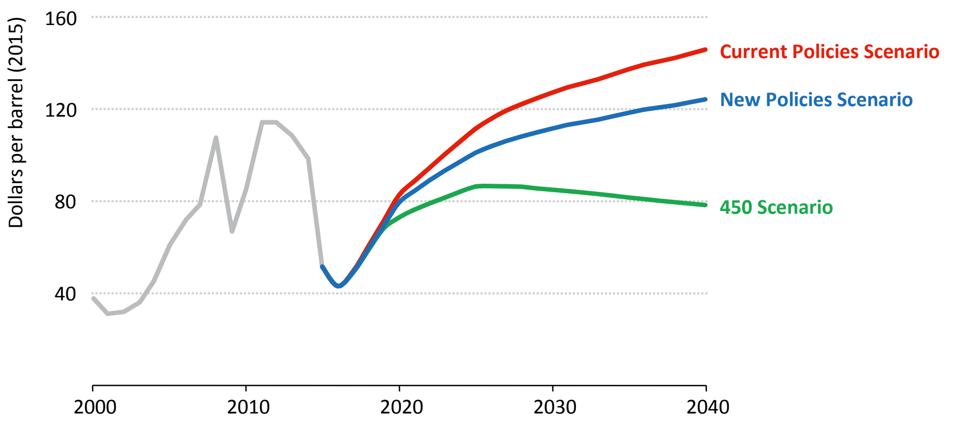
Moreover, after a long period in which consensus proved difficult to reach, OPEC countries announced a plan to return to active market management at a meeting in Algiers in September 2016, agreeing to cap crude oil output at a level between 32.5 mb/d and 33 mb/d (the group's first deal to cut production since 2008). The details of the agreement and the potential effect on market balances remain to be seen, but the announcement was indicative of the testing conditions that lower oil prices have created for many OPEC producers, especially those that faced the downturn with limited accumulated financial reserves. The budgetary cuts necessary to adjust to the reduced levels of revenue have been deeply destabilising in countries like Venezuela, Iraq, Nigeria and Libya, especially when considered alongside existing political and security challenges.

In practice, this tallies with a finding of *WEO-2015*: the Low Oil Price Scenario offers the potential for lower cost producers to expand their output (because of the stimulus to demand and because higher cost producers are squeezed out of the supply mix); but they also stand to lose more from the lower price than they gain from higher production. The pressure that a lower price trajectory puts on the fiscal balances of these key producers ultimately makes such a scenario look increasingly unlikely, the further it is extended out into the future.

In the New Policies Scenario, the oil price trend continues to edge gradually higher post-2020, with three main considerations underpinning this rise (Figure 1.4). The first relates to the amount of new production that is required to keep pace with demand. This might appear modest at first glance, since oil use rises only by 13 mb/d over a 25-year period; but most of the investment required in all scenarios is to replace declining production from existing fields (a point discussed in Chapter 3). Second, in almost all cases, oil is more costly to produce in 2040 than today. There have been strong cost reductions in many upstream activities in recent years, but, in our estimation, there is a cyclical component to these reductions that is set to reverse as upstream activity picks up and the supply and services markets tighten (see Chapter 3). We incorporate continued improvements in technology and efficiency into our *Outlook*, but their impact on upstream costs is more than counterbalanced, for most resource types, by the effects of depletion: as "easy oil" is depleted, so producers are forced to move to more challenging and complex reservoirs, that are more expensive to develop. This is the case also for tight oil in the United States, as operators eventually deplete the main "sweet spots", the most productive areas in the various plays, and are forced to move into areas of lower resource quality.

As well, logistical and other constraints on the rate at which oil can be developed (in both OPEC and non-OPEC countries) can easily keep the oil price trajectory above the marginal cost of the barrel required to meet demand. These include geopolitical risks, that might constrain investment and output of the world's lowest cost oil, and our assumption that the main low-cost resource-holders in OPEC follow through with efforts (following the recent meeting in Algiers) to defend a global price level above that implied by the global supply-cost curve.

Figure 1.4 ▷ Average IEA crude oil import price by scenario



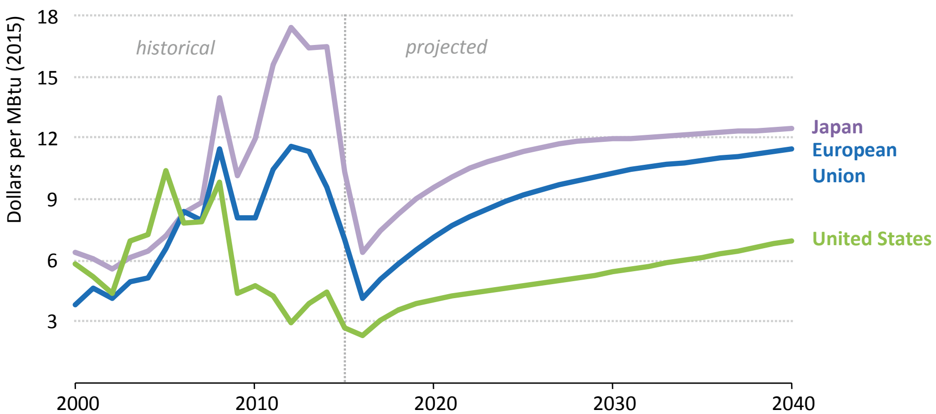
Oil prices vary widely by scenario, depending on the level of demand

Oil prices in the other main scenarios are similarly determined by the need for investment to meet projected demand. Higher demand in the Current Policies Scenario means a higher call on oil from costly fields in non-OPEC countries. Conversely, in the 450 Scenario, more aggressive policy action to curb demand means that a market equilibrium can be found at a lower price.

Natural gas

There is, for the moment, no single global price for natural gas. Instead, a set of regionally determined prices, loosely connected, reflect the distinct market dynamics and pricing mechanisms of different regional markets (Figure 1.5). In this *Outlook*, we focus on three regional prices: North America, Asia and Europe. In North America, 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 price of gas paid by North American consumers is calculated on the basis of a series of differentials from Henry Hub, reflecting the costs of transmission and distribution, and other fees and charges. The price of gas exported from North America as liquefied natural gas (LNG) reflects the additional costs of liquefaction, shipping in LNG tankers and regasification at the importing terminal.

Figure 1.5 ▷ Natural gas prices by region in the New Policies Scenario



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

Notes: US price is a wholesale price; other prices are average import prices.

Projected Henry Hub prices vary by scenario (Table 1.4). As of September 2016, Henry Hub prices are around $3/MBtu; our view is that this price will need to rise, in all scenarios, in order to balance the market – although the extent of this increase is highly contingent on the trajectory for composite demand (local and for export) and also on the size of US shale gas resources (as discussed in the sensitivity analysis in Chapter 4). Perhaps counter-intuitively, our US gas price trajectory in the New Policies Scenario remains relatively low over the medium-term as a result of the anticipated rebound in the global oil price: by increasing the value of the liquids produced along with the gas, and by encouraging tight oil production and its associated gas volumes, gas output remains buoyant at prices around $4/MBtu until well into the 2020s. However, looking further ahead, the need for the United States and Canada to produce more than 1 trillion cubic metres (tcm) of gas each year starts to tell. The twin cost pressures of relying more on dry gas production and depleting the most productive areas of the various shale gas plays has the effect of pushing the price gradually higher and by 2040 it is closing in on $7/MBtu. A similar narrative on the supply side, but accompanied by significantly different prospects for demand, explains the higher price trajectory in the Current Policies Scenario and, conversely, the lower path in the 450 Scenario.

The other regional gas price markers that are pivotal to the *Outlook* are the European and Asian import prices. The prices in Table 1.4 are the average prices paid in each case by importers: they reflect the different pricing arrangements prevailing in the various markets. In the case of Europe, this currently means an increasing share of imported gas priced off trading hubs, particularly in north-western Europe, but with a sizeable residual volume with prices indexed in full or in part to oil product prices (concentrated in southern and south-eastern Europe). In Asia, oil-indexation 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 (such as the US Henry Hub). Throughout the world, the trend is towards greater flexibility of contract terms, shorter contract duration and a greater share of gas available on a spot basis. However, there are still multiple contractual, regulatory and infrastructure barriers that prevent the gas market from operating like a standard commodity market.

A key strategic question for gas markets is the speed at which a truly global gas market might emerge, in which internationally traded gas is no longer tied to specific consumers or defined geographical areas but is free to move in response to price signals that are determined by the dynamics of gas-to-gas competition. This is indeed the direction in which gas markets are assumed to move, such that, by the latter part of the projection period, the price differentials between the various regional markets in *WEO-2016* settle into a range that essentially reflects the costs of moving gas between them.

The current period of over supply in gas markets, alongside the low level of oil prices, has brought down prices in all the major markets. In the New Policies Scenario (as examined in more detail in Chapter 4), the global LNG market does not rebalance until the mid-2020s, a consideration that curbs profitable export opportunities in the meantime. But the increased competition, combined with the arrival of the United States as a major LNG exporter, creates a propitious backdrop for movement towards more flexible pricing and trading arrangements. Large US resources and production flexibility, combined with an LNG export industry actively seeking arbitrage opportunities, means that Henry Hub is projected to become not only a regional but also a global reference point, shaping investment and marketing strategies in other exporting countries and regions. As a result, over the longer term, the European import price settles at around $4-5/MBtu above the US price (in all scenarios), a differential that reflects the cost of delivering gas to exporting terminals, its liquefaction, shipping and then regasification in the importing country. The Asian import price rises more quickly, due to the continued importance of oil-linked pricing in this region, but as this link weakens the "Asian premium" disappears and the differentials from the US price fall to around $5-6/MBtu (the additional sum, compared with Europe, reflecting the extra shipping distance to Asian markets).[10]

Coal

The global coal market consists of various regional sub-markets that interact with each other through imports, exports and arbitrage opportunities. Although less than one-fifth of the global coal production is traded between countries, the international coal market plays a pivotal role in connecting the different sub-markets and in determining overall price trends. Coal prices vary significantly between the regional markets – the differences are primarily due to transportation cost, infrastructure constraints and coal quality – but they typically move in lockstep with international coal prices.

All major coal prices had been in steep decline for four consecutive years before bottoming out in early 2016 (Figure 1.6). The average price of imported steam coal in Europe fell to $57/tonne in Europe and $59/tonne in Japan in 2015. Such price levels were last seen in the early 2000s, just before the big price hike started in the mid-2000s. While much of the price increase between 2007 and 2011 had to do with strong global coal demand growth, China's emergence as a major importer, supply capacity shortages, overheated supply chains and the relative weakness of the US dollar; much of the price decline over the last four years has to do with a reversal of these fundamentals. Global coal demand growth has stalled, Chinese imports are declining, supply capacity is amply available, the US dollar has appreciated against all major currencies and supply chains (shipping and infrastructure but also machinery and consumables supply) have slackened.

It is not unusual for coal markets to follow business cycles, but the key question for this *Outlook* is whether the coal market will find a way out of the current downturn and achieve an economically viable price trajectory. Our coal price trajectories rest on four pillars:

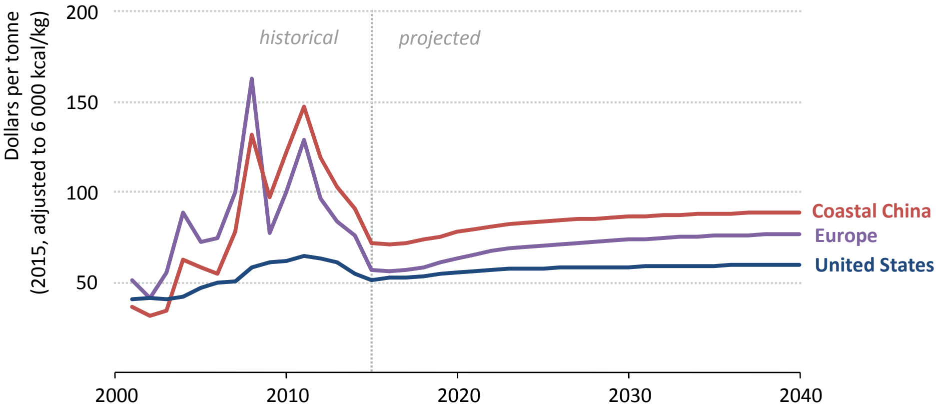
- Policies and market forces underpin the closure of mines that are unable to recoup their costs, which leads to a reduction of excess capacity and supports a balancing of supply and demand by the early 2020s, with the profitability of the industry by-and-large restored.

10. Moving LNG between markets is expected to become slightly less expensive over the period to 2040, as a result of efficiency and technology improvements that bring down liquefaction costs (and, to a more limited extent, shipping and regasification costs). See Chapter 5 in *WEO-2015* (IEA, 2015b).

- Global coal demand growth of 0.2% per year, in combination with gradual depletion of existing mines, partially absorbs overcapacity and requires investments in coal supply of $45 billion per year over the *Outlook* period in the New Policies Scenario.
- Geological conditions are worsening, new mines are deeper or further away from markets and coal quality is deteriorating; all of these factors put modest upward pressure on costs that cannot be fully offset by productivity gains.
- Current exchange rates remain unchanged, while cyclically low input prices for steel, tyres and fuel trend upwards in the long term.

Spurred by the implementation of a first set of capacity cuts in China, coal prices started rising in the second-quarter of 2016. The New Policies Scenario sees this process continuing slowly, with European and Japanese import prices reaching $70/tonne and $73/tonne respectively in 2025 and thereafter increasing gradually to $77/tonne and $80/tonne in 2040. China's coast line provides the link between the international market and the vast Chinese domestic coal market and remains of the utmost importance for international coal pricing, although a similar arbitrage point is projected to arise on India's west coast (see *India Energy Outlook 2015: World Energy Outlook Special Report*). Chinese coastal steam coal prices increase to almost $90/tonne in 2040 (assuming no change in taxation). Over the long term, average prices in the United States increase at a more moderate rate than international coal prices. This comes as production gradually shifts to the west, where prices are lower. Both the Powder River Basin and the Illinois Basin capture market share at the expense of the Appalachian basins, albeit in a rapidly declining market.

Figure 1.6 ▷ Steam coal prices by region in the New Policies Scenario



Steam coal prices recover from current lows but the long-term trend remains markedly below previous highs

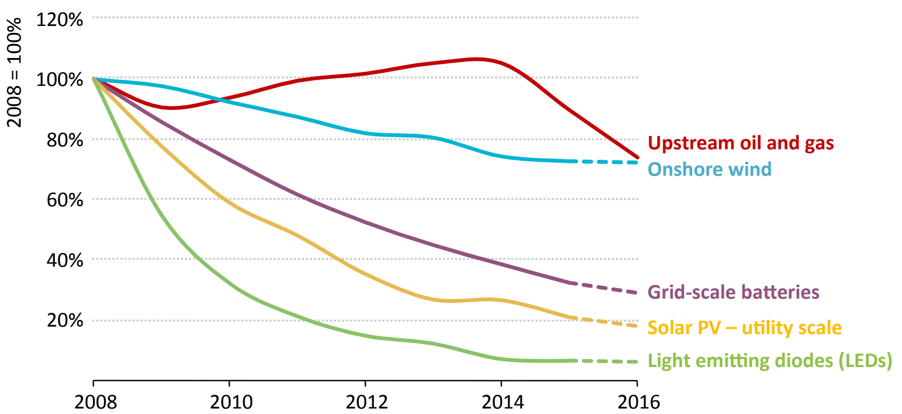
Notes: kcal/kg = kilocalorie per kilogramme. Coastal China represents imports and domestic sales (including domestic taxes). The European price is for imports. The US price is an average delivered price (primarily composed of mine-mouth prices in the sub-markets of the Powder River Basin, Illinois Basin, Northern Appalachia, Central Appalachia etc., plus transport and handling cost).

Technology innovation and costs

Many parts of the global economy have seen rapid, sometimes transformational technology change in recent years, most clearly in areas such as information technologies and communications. The energy sector is not yet one of these areas. The share of fossil fuels in primary energy demand remains almost exactly where it was 25 years ago, with the fastest growth among the fossil fuels over the last quarter-century registered by coal. Centralised power systems reliant on fossil fuels remain by far the dominant model in the electricity sector. Liquid petroleum-based fuels, feeding internal combustion engines, account for well over 90% of transport energy demand.

Yet efforts to overturn this apparently stable picture are gathering momentum and some contours of an alternative vision for the energy sector are taking shape: the rise of high-efficiency, variable renewable energy technologies led by wind and solar; a greatly reduced role for fuel combustion (with the possible exception of bioenergy), allied with control technologies to capture pollutants and greenhouse gases before they are released to the atmosphere; a major increase in the role of electricity across all the end-use sectors, combined with a surge in distributed generation and storage technologies that alter the traditional model of power delivery. All this would be tied together through efficient, integrated system management via smart metering and grids.

Figure 1.7 ▷ Recent cost trends for selected technologies



Cost deflation has affected diverse technologies across the energy spectrum

Source: IEA World Energy Investment 2016 (IEA, 2016c).

There are different views on whether and how quickly such a transformation might take place. Costs for many of the emerging energy supply technologies have fallen rapidly in recent years (as have costs for upstream oil and gas since 2014) (Figure 1.7). Yet they still remain, in most cases, above those of the competing conventional technologies, and so require some measure of government support to gain market share. In addition, major parts of the world's existing capital stock (today's power plants, buildings, factories, vehicles and energy supply infrastructure) have long lifetimes, typically being renewed or replaced only slowly. This creates substantial inertia in the system, even if the rate of change can be accelerated by policies that encourage building retrofits, efficiency upgrades or early retirement of some assets.

The projections in this *Outlook* are very sensitive to the way that technological changes affect the cost of different fuels and technologies, including the cost of investing in energy efficiency. The process of learning and cost reduction is fully incorporated into the WEM, both on the demand and supply sides, and applies not only to technologies in use today, but also to those approaching commercialisation. The extent of learning and cost reduction is linked to the level at which a given technology is deployed, which affects not just the costs of the technology itself, e.g. the batteries for electric vehicles or panels for solar PV, but also related costs for design, installation, inspection and maintenance. As a result, cost reductions for key renewable energy technologies are significantly greater in the 450 Scenario than in the New Policies Scenario.

Although technology learning is an integral part of the *WEO* approach, the *Outlook* does not attempt to predict technology breakthroughs, i.e. an advance that produces a step-change in technologies and costs. These are inherently unpredictable. Typically, they also take many years to proceed from the research laboratory to large-scale commercialisation. They cannot, of course, be ruled out for the period to 2040 and it is at least arguable that the pace of technological change and clean energy innovation will rise in the coming years. That is the express objective of a growing number of international initiatives, including Mission Innovation and the Breakthrough Energy Coalition (both launched at the Paris climate conference in 2015), as well as of established bodies, like the Clean Energy Ministerial.[11] The 20 countries, plus the European Union, participating in Mission Innovation are committed to double investment in clean energy research and development over the five years to 2021. The link to private sector investment in new energy technologies comes via the Breakthrough Energy Coalition, a group of private companies. Their success or failure can only be seen as a risk factor qualifying the numbers produced by our scenarios.

Electricity generation and storage is a focus for much of the work on technology innovation and improvement. On the generation side, the costs of solar PV and onshore wind have fallen dramatically in recent years: from 2010 to 2015, indicative global average onshore wind generation costs for new plants fell by an estimated 20% on average, while costs for

11. The Clean Energy Ministerial (CEM) is a high-level global forum to promote policies and programmes that advance clean energy technology, bringing together 24 countries and the European Commission that are estimated to represent around 75% of global greenhouse-gas emissions and 90% of global clean energy investment. Following a selection process in 2016, the secretariat supporting the work of the CEM will be housed at the IEA. The IEA also has close working ties with Mission Innovation, the Breakthrough Energy Coalition and other energy technology initiatives, as well as its own network of Technology Collaboration Programmes (*www.iea.org/tcp/*).

new utility-scale solar PV declined by two-thirds and further cost reductions are anticipated, albeit at a slower pace, in our projections for solar PV. Onshore wind projects also benefit from lower costs, although the effect of technology learning is offset, in some countries, by the need to move to less favourable sites for wind generation, as the most favourable sites are fully developed. Chapter 11 reviews in detail the impact of envisaged cost reductions on the competitiveness of various renewable energy technologies.

Storage technologies are expected to play a growing role in improving the flexibility of power systems and in the market penetration of electric vehicles, heating and cooling systems, and small- or medium-size off-grid installations. Although pumped storage hydropower continues to dominate the provision of large-scale energy storage, developments in battery storage have won the headlines, as costs have come down, performance has improved and new models of electric vehicles and residential-scale power storage have entered the market. The role of electricity storage in integrating large shares of renewable energy, alongside other sources of power system flexibility, is considered in detail in Chapter 12.

Some technologies and investment projects are not (yet) experiencing cost declines and could see lower deployment as a result. Policy and financial support for CCS in recent years has been lower than anticipated, meaning that deployment has also stalled: only one new CCS project came on line in 2015, at a Canadian oil upgrader. Such technologies risk falling further behind. The uptake of CCS in both the New Policies Scenario and the 450 Scenario has been revised downward in *WEO-2016* compared with last year's *Outlook*.

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Chapter 1: Introduction and scope

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