

World Energy Outlook 2017
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Corrigendum

Please note that despite our best efforts to ensure quality control, errors have slipped into the World Energy Outlook 2017.

The text in pages 11, 99, 113, 246, 251, 270, 553, 554 and 569 has changed. It should be replaced by the following pages.

World Energy Outlook 2017

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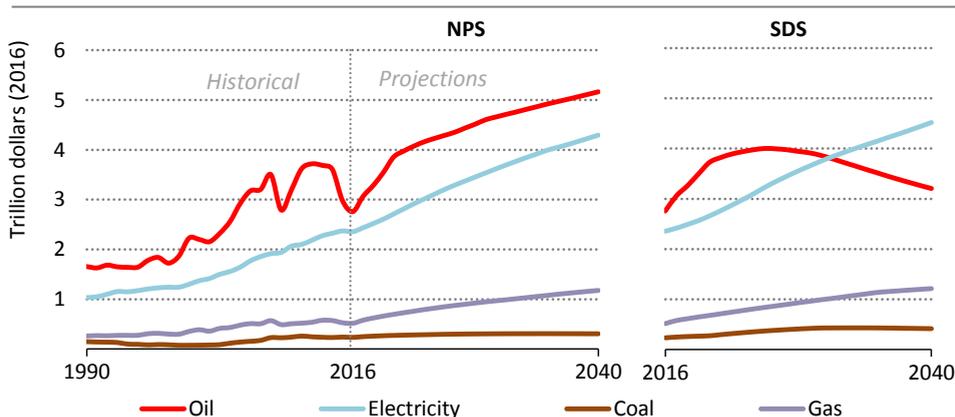


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consumption. This share grows to 23% in both the New Policies Scenario and the Current Policies Scenario by 2040, while in the Sustainable Development Scenario it accelerates to 27%. A rising share of electricity in final consumption is not a new trend – it has been going on for several decades. However, the Sustainable Development Scenario sees a significant step up in the share of electricity, compared with historical trends; this is not because the amount of electricity supplied is much larger than in other scenarios, but because the need to decarbonise and use energy more efficiently causes consumption of other fuels to stop growing and even start contracting.

Figure 2.19 ▶ Global end-user energy expenditure by fuel and by scenario



In the Sustainable Development Scenario, electricity becomes the main item in global end-user spending on energy, taking over from oil products

Notes: NPS = New Policies Scenario; SDS = Sustainable Development Scenario. Global end user expenditure is the aggregate of regional expenditures; international bunkers are excluded.

A similar picture emerges from an analysis of end-user spending on energy. This has traditionally been dominated by oil products, but with the fall in oil prices since 2014, our estimates show an unprecedented closing of the gap at global level between the amounts that consumers spend on oil products versus electricity (Figure 2.19). How this evolves depends on the scenario. In both the New Policies Scenario and the Sustainable Development Scenario, consumer spending on oil products worldwide is projected to increase as demand continues to rise and oil prices recover somewhat. However, from the early 2020s the trends start to diverge. Oil products retain their primacy in end-use expenditure in the New Policies Scenario, while electricity takes over in the Sustainable Development Scenario as its share in end-use consumption rises and the use of oil products for passenger transport starts to decline. The tipping point comes earlier in some regions (in the European Union, for example, the crossover to electricity is observed already in the New Policies Scenario), but it becomes a global phenomenon.

Important progress has also been made in another international arena, with a bearing on climate change: regulation of hydrofluorocarbons under the Montreal Protocol (Box 3.2). Clean air, too, is firmly on the policy agenda; further efforts to improve air quality have been undertaken in developed and developing countries alike. Table 3.1 summarises selected policy developments since the *WEO-2016* that are considered in this *Outlook*.

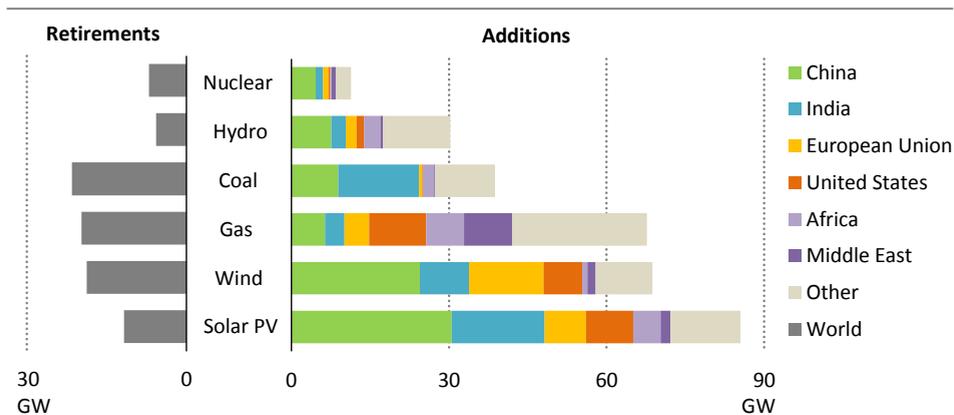
Table 3.1 ▶ **Selected recent climate change and air pollution policy developments**

Country/region	Selected recent policies
Australia	<ul style="list-style-type: none"> Safeguard Mechanism requiring largest emitters (140 businesses) to keep emissions within individual baseline levels.
Canada	<ul style="list-style-type: none"> Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, phase-out of traditional coal-fired electricity by 2030 (Nov 2016). Economy-wide carbon pricing from CAD10 per tonne of CO₂ (tCO₂) in 2018, rising to CAD 50/tCO₂ in 2022.
Chile	<ul style="list-style-type: none"> Carbon tax of \$5 per tonne of CO₂ on emissions from large power plants and industrial emitters introduced in January 2017; includes a local air quality component.
China	<ul style="list-style-type: none"> 13th Five-Year Plan (2016-20): includes energy, climate and air quality measures. Energy Supply and Consumption Revolution Strategy, setting out overall targets and strategies of Chinese energy sector for 2016-30. Carbon pricing: China national Emissions Trading Scheme rolling out from late 2017.
European Union	<ul style="list-style-type: none"> Clean Energy Package (Nov 2016): energy efficiency (30% reduction below business-as-usual by 2030); power market design; capacity markets. Carbon pricing: Proposal for EU Emissions Trading System (ETS) revision for Phase 4 is ongoing. National Emission Ceilings Directive on local air pollutants for 2020 and 2030.
France	<ul style="list-style-type: none"> Carbon tax on the use of fossil fuels not covered by the EU ETS, from EUR 22/tCO₂ in early 2016 to EUR 56/tCO₂ in 2020, rising to EUR 100/tCO₂ in 2030. Announced ban on sales of gasoline and diesel cars from 2040.
Germany	<ul style="list-style-type: none"> Climate Action Plan 2050, a mid-century strategy as called for by the Paris Agreement.
India	<ul style="list-style-type: none"> Tax on coal, lignite and peat rising to INR 400/tonne. Compliance with new standards to reduce power plant emissions of air pollutants PM₁₀, SO₂, NO_x under the Environment Protection Amendment Rules. Consideration of target of 100% electric vehicle sales by 2030.
Japan	<ul style="list-style-type: none"> Revised Act on Special Measures for Renewable Energy from 2017, including competitive tenders for large-scale solar PV. Energy Efficiency Technology Strategy 2016.
Sweden	<ul style="list-style-type: none"> Target to become carbon neutral by 2045.
United Kingdom	<ul style="list-style-type: none"> Announced ban on sales of gasoline and diesel cars from 2040.
United States	<ul style="list-style-type: none"> Intention at federal level to withdraw from the Paris Agreement. US Executive Order on “Promoting Energy Independence and Economic Growth”. Review of the Clean Power Plan. Potential delay to regulation of methane emissions from the oil and gas industry. Re-opening of the Corporate Average Fuel Economy (CAFE) standards. Carbon pricing: Revisions to the existing Cap-and-Trade Program in California and the Regional Greenhouse Gas Initiative (RGGI).

In the United States, solar PV (and wind power) is set for strong growth over the medium term, but then capacity growth slows, on the assumption that the Clean Power Plan is not implemented at the federal level. State-level action and competitive costs help renewables remain relevant in the long term.

Hydropower capacity continues to grow in all regions, and plays an important role in expanding electricity supply in developing economies. China is again the leader in terms of capacity expansion, with over 180 GW of new capacity added to 2040, alongside the massive buildout of wind and solar PV. In Central and South America, hydropower represents the largest share of capacity additions to 2040, tapping into high-quality resources. Sub-Saharan Africa, with several large-scale projects under development, is looking to hydropower as a means of affordably expanding centralised electricity supply, complementing efforts to provide electricity access to tens of millions through mini-grid and off-grid solar PV systems (IEA, 2017b). In Southeast Asia, hydropower capacity more than doubles to 2040 in the New Policies Scenario, both to meet domestic demand and for export (IEA, 2017d). Hydropower capacity continues to expand in advanced economies as well, though expansion is mainly achieved through upgrading and re-powering existing dams, rather than developing new projects.

Figure 6.8 > **Global average annual capacity additions and retirements by technology in the New Policies Scenario, 2017-2040**

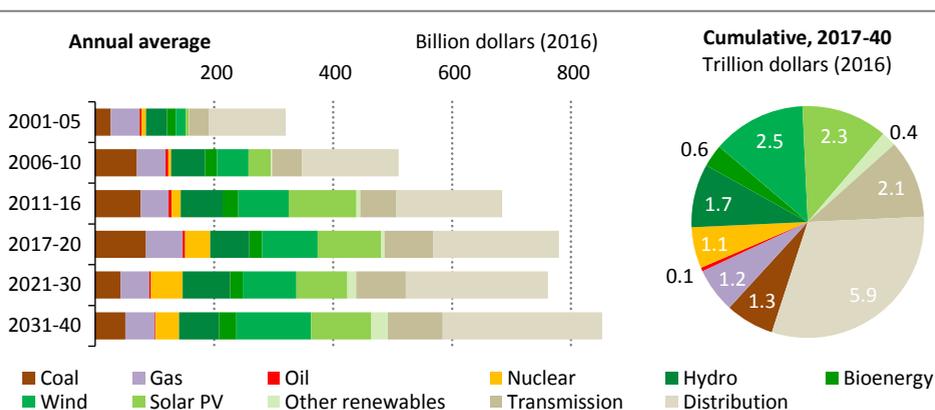


After a century of dominance, fossil-fuelled power plants no longer lead, as renewables account for more than 60% of total capacity additions to 2040

In the New Policies Scenario, the fleet of fossil-fuelled power plants continues to expand to 2040. On average, each year to 2040 sees 68 GW of gas-fired power generation capacity come online worldwide, plus 39 GW of coal-fired power plants and 4 GW of oil-fired capacity (Figure 6.8). Among fossil fuels, gas-fired power plants continue to be the option of choice in many regions, thanks to the low upfront investment costs of new

transmission and distribution (T&D) networks to support the efficient delivery of supply (Figure 6.10). Distribution, the last step in the delivery of power to consumers, captures over 30% of total power sector investment to 2040. Power plant investment is dominated by renewables, as they account for two-thirds of the global total (wind and solar PV together make up close to 45%).

Figure 6.10 ▶ **Global annual average power sector investment and cumulative investment to 2040 in the New Policies Scenario**



Renewables make up two-thirds of total power plant investment, while continued network investment supports the efficiency and security of electricity supply

Developing economies account for two-thirds of global investment in the power sector in the New Policies Scenario, in order to meet growing electricity demand and to build the supporting infrastructure. Collectively, they account for the bulk of global investment in power plants (65% of the total), particularly coal (86%) and hydropower (78%), but also solar PV (65%), nuclear (63%), gas (61%) and wind (52%). China alone accounts for close to 30% of global wind power investment to 2040, while China and India make up 45% of solar PV investment. In advanced economies, an average of \$280 billion per year to 2040 is invested in the power sector in the New Policies Scenario. While the total increase in electricity demand in advanced economies is only one-sixth that of developing economies, power plant investment is about half as much per year on average due to efforts to decarbonise electricity supply and the need to replace ageing power plants. Advanced economies make up close to 40% of global investment in renewables to 2040, and nearly half of the investment in wind power and bioenergy-based power plants. Within advanced economies, renewables account for almost three-quarters of power plant investment to 2040, and more than two-thirds of renewables investment goes to wind and solar PV. Gas-fired power accounts for 12% of the total, nuclear 10% (falling after 2030) and coal only 5%. Over 60% of power plant investment in advanced economies to 2040 is required just to maintain the status quo, replacing capacity retirements.

very low priced gas (below \$3/MBtu) has helped gas-fired power plants to out-compete coal plants in the short term and contributed to the retirement of older, less efficient, coal plants. Thus gas overtook coal as the leading generation source in the United States in 2016, and some coal plant retirements were accelerated, shifting the long-term balance in the process. Nonetheless, coal remains an important part of the power mix in the United States, and is projected to provide about one-quarter of total generation through to 2040.

The costs of batteries have also fallen substantially in recent years, catching the attention of the industry and giving rise to new consideration of potential utility-scale applications of battery storage and their economics, including as a means of replacing peaking power plants (Box 6.2). We project total battery system costs to decline by about two-thirds by 2040, from about \$700/kWh of storage capacity in 2016 to less than \$300/kWh, with the balance of system costs making up close to three-quarters of the total installation costs for stationary battery storage systems.¹⁴ Batteries are also garnering attention for individual businesses and consumers. When paired with solar PV, storage can help consumers use more of the electricity that they generate, which may improve the economics of their system. Energy storage at the site of consumption can also increase the reliability of electricity supply, by providing a source of backup if there is an outage on the network. For off-grid and mini-grid systems, energy storage is essential to improving the quality of electricity services provided by variable renewables, including solar PV and wind power.

Box 6.2 > Will utility-scale batteries replace peaking power plants?

In recent years, the momentum behind battery storage – and lithium-ion batteries in particular – has increased significantly. With greater deployment of EVs and wider use of battery storage at both utility- and the consumer-scale, the cost of batteries has fallen significantly and is expected to decrease further.

The nature of a battery differentiates it from a typical generator in that it can both inject energy into and withdraw energy from the grid (as do other storage technologies, such as pumped hydropower), and can alter its output or consumption more rapidly than most other technologies. This allows batteries to provide a variety of services to different customers and earn revenues from different markets. In order to maximise the revenue potential of batteries, they must optimise their performance so as to accrue revenue from multiple services, known as revenue stacking. Possible revenue streams for batteries can come from ancillary markets (including frequency control and reserves), capacity markets, energy markets (energy arbitrage) and grid services (including voltage control and T&D investment deferrals). Batteries may also be coupled with renewable energy projects in order to increase their value by reducing the variability of their output.

14. Indicative costs are for a lithium-ion battery and balance of system for utility-scale applications, with four hours of storage per unit of output. Analysis suggests that this level of storage provides for capturing the full capacity value (ICF, 2016).

Additional flexibility can also come from less complex and less expensive measures, and through changing operational practices. Gains have been made elsewhere through the use of advanced optimisation software, training programmes, and increasing collaboration between engineers, plant operators and plant dispatchers.

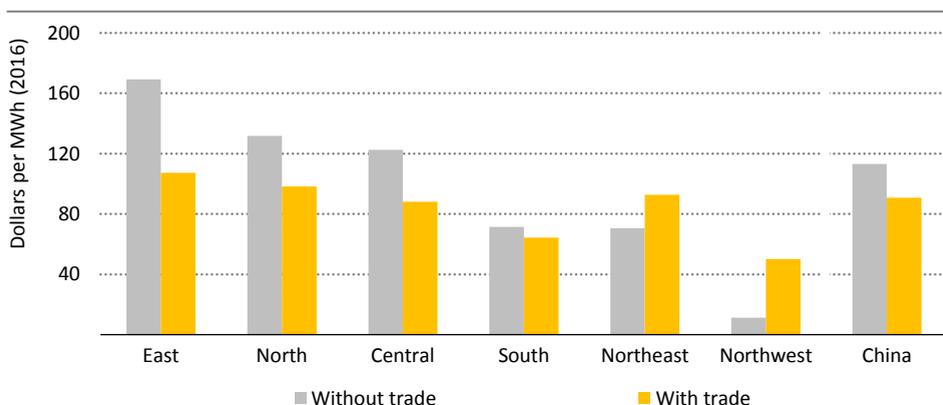
The capacity for active demand response to support the energy transition is another aim of market reform in China. The reforms mean looking at demand as a part of the system to be actively managed rather than as something fixed that just has to be passively accepted. The need for demand response, however, depends to a large extent on the state of the rest of the system. If planned transmission expansions are completed and if the flexibility of coal-fired power plants is improved as planned, demand response will have a limited role to play, but may still potentially reduce the level of investment needed in new power plants by moderating peak load. If, however, either the expansion of transmission or plans to increase the flexibility of coal-fired power plants deliver only in part, a higher level of demand response will be needed to help minimise the curtailment of output from newly constructed wind and solar PV projects.

Price reform: reflecting costs

Pricing reforms in China aim to reduce costs, prices and ultimately electricity bills for consumers by building market mechanisms and competition where possible to provide price discovery, so that prices reflect costs and so that there is no longer any need for price-setting by the government. The wholesale power generation market and the retail market are two key areas where competition may help drive down costs to consumers. Network infrastructure does not lend itself to competition, and reform here is aimed at ensuring that the costs charged to consumers directly reflect costs in the network.

In the New Policies Scenario, average power generation costs in China increase steadily over time, with rising fuel costs and the implementation of a CO₂ price through an emissions trading scheme, rising by one-quarter between 2016 and 2040. The expansion of trade in electricity between regions serves to keep down average power generation costs in China overall, balancing electricity demand and supply across an enormous area. It also has significant impacts on the average cost in each region, and therefore the average end-user price. The high-quality renewable energy resources in the Three Norths, supplemented by coal-fired power, provide cheap electricity across the country. Importing from other regions lowers average wholesale energy market prices by over one-third in the East region, compared to what they would have been without electricity trade (Figure 13.25). Average prices are reduced by roughly one-quarter in the Central and North regions. While they are raised in the Northwest and Northeast, there is a broad efficiency gain across the system that is reflected in 25% lower average market prices in 2040.

Figure 13.25 ▸ China average hourly wholesale energy market prices by region in the New Policies Scenario, 2040



Expanded trade in electricity balances market-based electricity prices across China, bringing them down significantly in the East, North and Central regions

Industrial consumers in China currently pay relatively high electricity prices, and, in effect, subsidise low prices for residential consumers. Residential end-user electricity prices are below \$90/MWh, which puts them among the lowest in the world: they are 30% lower than the average price in the United States and 60% lower than the average price in the European Union and Japan. In the New Policies Scenario, both the residential and industry end-user prices increase to 2040, as the average costs of power generation in China increase by about one-quarter from about \$55/MWh today to close to \$70/MWh in 2040. This is mainly due to the increase over time in the price of CO₂, which is assumed to reach \$35 per tonne of CO₂ in 2040. Electricity prices for industry increase by 17% to 2040, reflecting the gains of expanded electricity trade. Electricity prices to residential consumers increase more substantially over time as they become better aligned with the underlying costs of supply. However, at \$135/MWh in 2040, residential electricity prices in China are still among the lowest in the world, and less than half the average price paid in the European Union.

13.5 Environmental implications

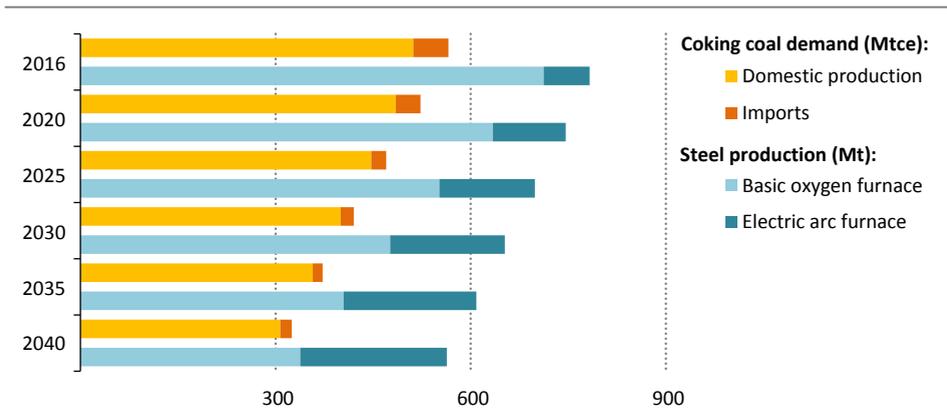
Growth in energy demand in China since 2000 has gone hand-in-hand with economic growth, but at a high cost to the environment. Today, China is the largest contributor to global energy-related CO₂ emissions, accounting for 28% of the world total, even though its per-capita emissions of 6.5 tonnes of CO₂ are still one-quarter below the average of advanced economies. Domestic environmental concerns are also pressing, as the scale and speed of China's growth has resulted in a significant deterioration of air quality in many cities, in particular in the main industrialised areas. But China's energy sector is changing rapidly

Production prospects

In the *Outlook*, coal production in China decreases from just over 2 500 Mtce in 2016 to 2 370 Mtce in 2040. Production of steam coal, which accounts for the vast majority of China's coal production, declines slightly: the prospects for domestic production are helped somewhat by a shift in demand away from coastal areas and towards inland regions where domestic coal is more competitive, allowing Chinese coal companies to back out imports (see section on imports). The story, however, is different for coking coal, production of which declines by around 40% over the coming 25 years.

The declining fortunes of domestic coking coal producers are tied to the outlook for China's steel industry. China currently produces some 800 Mt of crude steel, accounting for half of global production, but output drops below 600 Mt by 2040, as domestic steel needs decline and other countries become more competitive in steel making. Another important trend that weighs on coking coal production is the way that steel is produced: with growing availability of scrap, electric arc furnaces gain market share at the expense of basic oxygen furnaces and this reduces the demand for coke. In our projections, the share of steel produced in basic oxygen furnaces drops to 60% in 2040 from over 90% today. There are few export opportunities available to compensate for reduced domestic demand: Chinese coking coal exports cannot compete with Australian, Canadian or Mozambican coking coal in India, the largest growth centre of the international coking coal trade.

Figure 14.5 ▶ China's coking coal demand by source and steel output by production route



A declining share of basic oxygen furnaces in China's steel production reduces coking coal demand

Note: Mtce = million tonnes of coal equivalent.

Currently over 80% of China's coal production comes from underground mines (depths of 700-1 000 metres are not unusual), a much higher share than in most other major coal producing countries. We expect this share to remain relatively stable over the