

Four large-scale shifts in the global energy system set the scene for the *World Energy Outlook-2017 (WEO-2017)*:

- The **rapid deployment and falling costs of clean energy technologies**; in 2016, growth in solar PV capacity was larger than for any other form of generation; since 2010, costs of new solar PV have come down by 70%, wind by 25% and battery costs by 40%.
- The **growing electrification of energy**; in 2016, spending by the world's consumers on electricity approached parity with their spending on oil products.
- The **shift to a more services-oriented economy and a cleaner energy mix in China**, the world's largest energy consumer, subject of a detailed focus in this *Outlook*.
- The resilience of **shale gas and tight oil in the United States**, cementing its position as the biggest oil and gas producer in the world even at lower prices.

These shifts come at a time when traditional distinctions between energy producers and consumers are being blurred and a new group of major developing countries, led by India, moves towards centre stage. How these developments play out and interact is the story of this *Outlook*, with particular attention paid to their implications for natural gas, this year's fuel focus. Together, they are opening up new perspectives for affordable, sustainable access to modern energy, reshaping responses to the world's pressing environmental challenges, and entailing a reappraisal and reinforcement of approaches to energy security.

Our new *Outlook* describes multiple future pathways for global energy through to 2040. Among them, the **New Policies Scenario** describes where existing policies and announced intentions might lead the energy system, in the anticipation that this will inform decision-makers as they seek to improve on this outcome. The **Sustainable Development Scenario**, a major new scenario introduced in the *WEO-2017*, outlines an integrated approach to achieve the energy-related aspects of the UN Sustainable Development Goals: determined action on climate change; universal access to modern energy by 2030; and a dramatic reduction in air pollution. These are all areas in which progress in the New Policies Scenario falls short of what would be required.

### ***Add an extra China-plus-India to global energy demand by 2040***

**In the New Policies Scenario, global energy needs rise more slowly than in the past but still expand by 30% between today and 2040, the equivalent of adding another China and India to today's global demand.** A global economy growing at an average rate of 3.4% per year, a population that expands from 7.4 billion today to more than 9 billion in 2040, and a process of urbanisation that adds a city the size of Shanghai to the world's urban population every four months are key forces that underpin our projections. The largest contribution to demand growth – almost 30% – comes from India, whose share of global energy use rises to 11% by 2040 (still well below its 18% share in the anticipated global population). Southeast Asia, a region covered in a separate special report in the *WEO-2017*

series, is another rising heavyweight in global energy, with demand growing at twice the pace of China. Overall, developing countries in Asia account for two-thirds of global energy growth, with the rest coming mainly from the Middle East, Africa and Latin America.

### ***Renewables step up to the plate; coal strikes out***

**Compared with the past twenty-five years, the way that the world meets its growing energy needs changes dramatically in the New Policies Scenario, with the lead now taken by natural gas, by the rapid rise of renewables and by energy efficiency.** Improvements in efficiency play a huge role in taking the strain off the supply side: without them, the projected rise in final energy use would more than double. Renewable sources of energy meet 40% of the increase in primary demand and their explosive growth in the power sector marks the end of the boom years for coal. Since 2000, coal-fired power generation capacity has grown by nearly 900 gigawatts (GW), but net additions from today to 2040 are only 400 GW and many of these are plants already under construction. In India, the share of coal in the power mix drops from three-quarters in 2016 to less than half in 2040. In the absence of large-scale carbon capture and storage, global coal consumption flatlines. Oil demand continues to grow to 2040, albeit at a steadily decreasing pace. Natural gas use rises by 45% to 2040; with more limited room to expand in the power sector, industrial demand becomes the largest area for growth. The outlook for nuclear power has dimmed since last year's *Outlook*, but China continues to lead a gradual rise in output, overtaking the United States by 2030 to become the largest producer of nuclear-based electricity.

**Renewables capture two-thirds of global investment in power plants as they become, for many countries, the least-cost source of new generation.** Rapid deployment of solar photovoltaics (PV), led by China and India, helps solar become the largest source of low-carbon capacity by 2040, by which time the share of all renewables in total power generation reaches 40%. In the European Union, renewables account for 80% of new capacity and wind power becomes the leading source of electricity soon after 2030, due to strong growth both onshore and offshore. Policies continue to support renewable electricity worldwide, increasingly through competitive auctions rather than feed-in tariffs, and the transformation of the power sector is amplified by millions of households, communities and businesses investing directly in distributed solar PV. Growth in renewables is not confined to the power sector; the direct use of renewables to provide heat and mobility worldwide also doubles, albeit from a low base. In Brazil, the share of direct and indirect renewable use in final energy consumption rises from 39% today to 45% in 2040, compared with a global progression from 9% to 16% over the same period.

### ***The future is electrifying***

**Electricity is the rising force among worldwide end-uses of energy, making up 40% of the rise in final consumption to 2040 – the same share of growth that oil took for the last twenty-five years.** Industrial electric motor systems account for one-third of the increase in power demand in the New Policies Scenario. Rising incomes mean that many millions of households add electrical appliances (with an increasing share of “smart” connected

devices) and install cooling systems. By 2040, electricity demand for cooling in China exceeds the total electricity demand of Japan today. The world also gains, on average, 45 million new electricity consumers each year due to expanding access to electricity, although this is still not enough to reach the goal of universal access by 2030. Electricity makes inroads in supplying heat and mobility, alongside growth in its traditional domains, allowing its share of final consumption to rise to nearly a quarter. A strengthening tide of industry initiatives and policy support – including recent decisions by governments in France and the United Kingdom to phase out sales of conventional gasoline and diesel vehicles by 2040 – pushes our projection for the global electric car fleet up to 280 million by 2040, from 2 million today.

**To meet rising demand, China needs to add the equivalent of today’s United States power system to its electricity infrastructure by 2040, and India needs to add a power system the size of today’s European Union.** The scale of future electricity needs and the challenge of decarbonising power supply help to explain why global investment in electricity overtook that of oil and gas for the first time in 2016 and why electricity security is moving firmly up the policy agenda. Cost reductions for renewables are not sufficient on their own to secure efficient decarbonisation or reliable supply. The policy challenge is to ensure sufficient investment in electricity networks and in a mix of generation technologies that are the best fit for power system needs, providing the flexibility that is increasingly vital as the contribution of wind and solar PV increases (a consideration that reinforces the links between electricity and gas security). The increasing use of digital technologies across the economy improves efficiency and facilitates the flexible operation of power systems, but also creates potential new vulnerabilities that need to be addressed.

### *When China changes, everything changes*

**China is entering a new phase in its development, with the emphasis in energy policy now firmly on electricity, natural gas and cleaner, high-efficiency and digital technologies.** The previous orientation towards heavy industry, infrastructure development and the export of manufactured goods lifted hundreds of millions out of poverty – including energy poverty – but left the country with an energy system dominated by coal and a legacy of serious environmental problems, giving rise to almost 2 million premature deaths each year from poor air quality. The president’s call for an “energy revolution”, the “fight against pollution” and the transition towards a more services-based economic model is moving the energy sector in a new direction. Demand growth slowed markedly from an average of 8% per year from 2000 to 2012 to less than 2% per year since 2012, and in the New Policies Scenario it slows further to an average of 1% per year to 2040. Energy efficiency regulation explains a large part of this slowdown, without new efficiency measures, end-use consumption in 2040 would be 40% higher. Nonetheless, by 2040 per-capita energy consumption in China exceeds that of the European Union.

**China’s choices will play a huge role in determining global trends, and could spark a faster clean energy transition.** The scale of China’s clean energy deployment, technology exports and outward investment makes it a key determinant of momentum behind the low-carbon

transition: one-third of the world's new wind power and solar PV is installed in China in the New Policies Scenario, and China also accounts for more than 40% of global investment in electric vehicles (EVs). China provides a quarter of the projected rise in global gas demand and its projected imports of 280 billion cubic metres (bcm) in 2040 are second only to those of the European Union, making China a lynchpin of global gas trade. China overtakes the United States as the largest oil consumer around 2030, and its net imports reach 13 million barrels per day (mb/d) in 2040. But stringent fuel-efficiency measures for cars and trucks, and a shift which sees one-in-four cars being electric by 2040, means that China is no longer the main driving force behind global oil use – demand growth is larger in India post-2025. China remains a towering presence in coal markets, but our projections suggest that coal use peaked in 2013 and is set to decline by almost 15% over the period to 2040.

### *The shale revolution in the United States is turning to exports*

**A remarkable ability to unlock new resources cost-effectively pushes combined United States oil and gas output to a level 50% higher than any other country has ever managed; already a net exporter of gas, the US becomes a net exporter of oil in the late 2020s.** In our projections, the 8 mb/d rise in US tight oil output from 2010 to 2025 would match the highest sustained period of oil output growth by a single country in the history of oil markets. A 630 bcm increase in US shale gas production over the 15 years from 2008 would comfortably exceed the previous record for gas. Expansion on this scale is having wide-ranging impacts within North America, fuelling major investments in petrochemicals and other energy-intensive industries. It is also reordering international trade flows and challenging incumbent suppliers and business models. By the mid-2020s, the United States become the world's largest liquefied natural gas (LNG) exporter and a few years later a net exporter of oil – still a major importer of heavier crudes that suit the configuration of its refineries, but a larger exporter of light crude and refined products. This reversal is by no means only a supply-side story; without continued improvements in fuel-economy standards, the United States would remain a net oil importer. In our projections, factoring in extra volumes from Canada and Mexico, North America emerges as the largest source of additional crude oil to the international market (growth in refinery capacity and demand in the Middle East limits the supply of extra crude from this region). By 2040, around 70% of the world's oil trade ends up in a port in Asia, as the region's crude oil imports expand by a massive 9 mb/d. The shifting pattern of risks implies a significant reappraisal of oil security and how best to achieve it.

### *EVs are coming fast, but it is still too early to write the obituary for oil*

**With the United States accounting for 80% of the increase in global oil supply to 2025 and maintaining near-term downward pressure on prices, the world's consumers are not yet ready to say goodbye to the era of oil.** Up until the mid-2020s demand growth remains robust in the New Policies Scenario, but slows markedly thereafter as greater efficiency and fuel switching bring down oil use for passenger vehicles (even though the global car fleet doubles from today to reach 2 billion by 2040). Powerful impetus from other sectors

is enough to keep oil demand on a rising trajectory to 105 mb/d by 2040: oil use to produce petrochemicals is the largest source of growth, closely followed by rising consumption for trucks (fuel-efficiency policies cover 80% of global car sales today, but only 50% of global truck sales), for aviation and for shipping. Once US tight oil plateaus in the late 2020s and non-OPEC production as a whole falls back, the market becomes increasingly reliant on the Middle East to balance the market. There is a continued large-scale need for investment to develop a total of 670 billion barrels of new resources to 2040, mostly to make up for declines at existing fields rather than to meet the increase in demand. This puts steady upward pressure on costs and prices in the New Policies Scenario, as supply and services markets tighten and companies have to move on to more complex new projects.

**Even greater upside for US tight oil and a more rapid switch to electric cars would keep oil prices lower for longer.** We explore this possibility in a Low Oil Price Case, in which a doubling of the estimate for tight oil resources, to more than 200 billion barrels, boosts US supply and more widespread application of digital technologies helps to keep a lid on upstream costs around the globe. Extra policy and infrastructure support pushes a much more rapid expansion in the global electric car fleet, which approaches 900 million cars by 2040. Along with a favourable assumption about the ability of the main oil-producing regions to weather the storm of lower hydrocarbon revenues, this is enough to keep prices within a \$50-70/barrel range to 2040. However, it is not sufficient to trigger a major turnaround in global oil use. Even with a rapid transformation of the passenger car fleet, reaching a peak in global demand would require stronger policy action in other sectors. Otherwise, in a lower oil price world, consumers have few economic incentives to make the switch away from oil or to use it more efficiently. Meanwhile, with projected demand growth appearing robust, at least for the near term, a third straight year in 2017 of low investment in new conventional projects remains a worrying indicator for the future market balance, creating a substantial risk of a shortfall of new supply in the 2020s.

### *LNG ushers in a new order for global gas markets*

**Natural gas, the fuel focus in *WEO-2017*, grows to account for a quarter of global energy demand in the New Policies Scenario by 2040, becoming the second-largest fuel in the global mix after oil.** In resource-rich regions, such as the Middle East, the case for expanding gas use is relatively straightforward, especially when it can substitute for oil. In the United States, plentiful supplies maintain a strong share of gas-fired power in electricity generation through to 2040, even without national policies limiting the use of coal. But 80% of the projected growth in gas demand takes place in developing economies, led by China, India and other countries in Asia, where much of the gas needs to be imported (and so transportation costs are significant) and infrastructure is often not yet in place. This reflects the fact that gas looks a good fit for policy priorities in this region, generating heat, power and mobility with fewer carbon-dioxide (CO<sub>2</sub>) and pollutant emissions than other fossil fuels, helping to address widespread concerns over air quality. But the competitive landscape is formidable, not just due to coal but also to renewables, which in some countries become a cheaper form of new power generation than gas by the mid-2020s,

pushing gas-fired plants towards a balancing rather than a baseload role. Efficiency policies also play a part in constraining gas use: while the electricity generated from gas grows by more than half to 2040, related gas use rises by only one-third, due to more reliance on highly efficient plants.

**A new gas order is emerging, with US LNG helping to accelerate a shift towards a more flexible, liquid, global market. Ensuring that gas remains affordable and secure, beyond the current period of ample supply and lower prices, is critical for its long-term prospects.**

LNG accounts for almost 90% of the projected growth in long-distance gas trade to 2040: with few exceptions, most notably the route that opens up between Russia and China, major new pipelines struggle in a world that prizes the optionality of LNG. The transformation in gas markets is advanced by market liberalisation in Japan and other Asian economies and by the rise of portfolio players – large companies with a range of supply assets. New buyers, often smaller scale, are appearing: the number of LNG-importing countries has risen from 15 in 2005 to 40 today. Gas supply also becomes more diverse: the amount of liquefaction sites worldwide doubles to 2040, with the main additions coming from the United States and Australia, followed by Russia, Qatar, Mozambique and Canada. Price formation is based increasingly on competition between various sources of gas, rather than indexation to oil. With destination flexibility, hub-based pricing and spot availability, US LNG acts as a catalyst for many of the anticipated changes in the wider gas market. The new gas order can bring dividends for gas security, although there is the risk of a hard landing for gas markets in the 2020s if uncertainty over the pace or direction of change deters new investments. Over the longer term, a larger and more liquid LNG market can compensate for reduced flexibility elsewhere in the energy system (for example, lower fuel-switching capacity in some countries as coal-fired generation is retired). We estimate that, in 2040, it would take around ten days for major importing regions to raise their import levels by 10%, a week less than it might take today in Europe, Japan and Korea.

### ***Access, air pollution and greenhouse-gas emissions: the world falls short***

**Universal access to electricity remains elusive, and scaling up access to clean cooking facilities is even more challenging.** There are some positive signs: over 100 million people per year have gained access to electricity since 2012 compared with around 60 million per year from 2000 to 2012. Progress in India and Indonesia has been particularly impressive, and in sub-Saharan Africa electrification efforts outpaced population growth for the first time in 2014. But, despite this momentum, in the New Policies Scenario around 675 million people – 90% of them in sub-Saharan Africa – remain without access to electricity in 2030 (down from 1.1 billion today), and 2.3 billion continue to rely on biomass, coal or kerosene for cooking (from 2.8 billion today). Household air pollution from these sources is currently linked to 2.8 million premature deaths per year, and several billion hours are spent collecting firewood for cooking, mostly by women, that could be put to more productive uses.

**Policy attention to air quality is rising and global emissions of all the major pollutants fall in our projections, but their health impacts remain severe.** Ageing populations in many industrialised societies become more vulnerable to the effects of air pollution

and urbanisation can also increase exposure to pollutants from traffic. Premature deaths worldwide from outdoor air pollution rise from 3 million today to more than 4 million in 2040 in the New Policies Scenario, even though pollution control technologies are applied more widely and other emissions are avoided because energy services are provided more efficiently or (as with wind and solar) without fuel combustion.

**Despite their recent flattening, global energy-related CO<sub>2</sub> emissions increase slightly to 2040 in the New Policies Scenario.** This outcome is far from enough to avoid severe impacts of climate change, but there are a few positive signs. Projected 2040 emissions in the New Policies Scenario are lower by 600 million tonnes than in last year's *Outlook* (35.7 gigatonnes [Gt] versus 36.3 Gt). In China, CO<sub>2</sub> emissions are projected to plateau at 9.2 Gt (only slightly above current levels) by 2030 before starting to fall back. Worldwide emissions from the power sector are limited to a 5% increase between now and 2040, even though electricity demand grows by 60% and global GDP by 125%. However, the speed of change in the power sector is not matched elsewhere: CO<sub>2</sub> emissions from oil use in transport almost catch up with those from coal-fired power plants (which are flat) by 2040, and there is also a 20% rise in emissions from industry.

### ***An integrated approach can close the gap with the Sustainable Development Goals***

**The Sustainable Development Scenario offers an integrated way to achieve a range of energy-related goals crucial for sustainable economic development: climate stabilisation, cleaner air and universal access to modern energy, while also reducing energy security risks.** This scenario starts from a set of desired outcomes and considers what would be necessary to deliver them. Central to these outcomes is the achievement of an early peak in CO<sub>2</sub> emissions and a subsequent rapid decline, consistent with the Paris Agreement. A key finding is that universal access to electricity and clean cooking can be reached without making this task any more challenging. We also investigate, in a Faster Transition Scenario, how policies could push an even more rapid and steeper decline in CO<sub>2</sub> emissions and limit climate risks further.

**In the Sustainable Development Scenario, low-carbon sources double their share in the energy mix to 40% in 2040, all avenues to improve efficiency are pursued, coal demand goes into an immediate decline and oil consumption peaks soon thereafter.** Power generation is all but decarbonised, relying by 2040 on generation from renewables (over 60%), nuclear power (15%) as well as a contribution from carbon capture and storage (6%) – a technology that plays an equally significant role in cutting emissions from the industry sector. Electric cars move into the mainstream quickly, but decarbonising the transport sector also requires much more stringent efficiency measures across the board, notably for road freight. The 2030 targets for renewables and efficiency that are defined in the Sustainable Development agenda are met or exceeded in this scenario; renewables and efficiency are the key mechanisms to drive forward the low-carbon transition and reduce pollutant emissions. Considering the inter-linkages between them and aligning policy and

market frameworks – notably in the residential sector – is essential to ensure cost-efficient outcomes. The provision of highly efficient appliances, combined with decentralised renewables, also play a major role in extending full access to electricity and clean cooking, especially in rural communities and isolated settlements that are hard to reach with the grid.

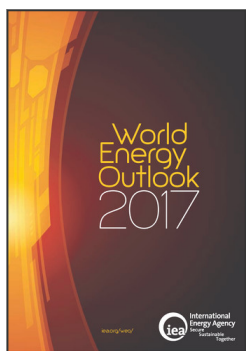
### *Natural gas can help clean energy transitions, but has homework to do*

**As oil and coal fall back and renewables ramp up strongly, natural gas becomes the largest single fuel in the global mix in the Sustainable Development Scenario. Securing clear climate benefits from gas use depends on credible action to minimise leaks of methane – a potent greenhouse gas – to the atmosphere.** Consumption of natural gas rises by nearly 20% to 2030 in the Sustainable Development Scenario and remains broadly at this level to 2040. The contribution of gas varies widely across regions, between sectors and over time in this scenario. In energy systems heavily reliant on coal (as in China and India), where renewable alternatives are less readily available (notably in some industrial sectors), or where seasonal flexibility is required to integrate high shares of variable renewables, gas plays an important role. Stepping up action to tackle methane leaks along the oil and gas value chain is essential to bolster the environmental case for gas: these emissions are not the only anthropogenic emissions of methane, but they are likely to be among the cheapest to abate. We present the first global analysis of the costs of abating the estimated 76 million tonnes of methane emitted worldwide each year in oil and gas operations, which suggest that 40-50% of these emissions can be mitigated at no net cost, because the value of the captured methane could cover the abatement measures. Implementing these measures in the New Policies Scenario would have the same impact on reducing the average global surface temperature rise in 2100 as shutting all existing coal-fired power plants in China.

### *Investment, guided by policy, can write a different story about the future*

**The large-scale shifts in global energy that characterise our WEO-2017 projections also reshape the outlook for energy investment.** Electricity accounts for nearly half of total energy supply investment in the New Policies Scenario and almost two-thirds in the Sustainable Development Scenario, up from an average of 40% in recent years. Clean energy technologies and energy efficiency likewise take an increasing share of the \$60 trillion in cumulative investment in supply and end-uses in the New Policies Scenario, and the bulk of the \$69 trillion in the Sustainable Development Scenario. Nonetheless, upstream oil and gas investment remains a major component of a secure energy system, even in the carbon-constrained world of the Sustainable Development Scenario. Getting pricing signals and policy frameworks right would include phasing out subsidies that promote wasteful consumption of fossil fuels (at an estimated \$260 billion in 2016, these are almost double the subsidies currently going to renewables). Along with a proliferation of community, municipal and private sector initiatives, well-designed policy remains essential to pursue a brighter energy future.





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