International Energy Agency
Secure Sustainable Together

World Energy Outlook 2016

EXECUTIVE SUMMARY

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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The European Commission also participates in the work of the IEA.

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The Paris Agreement on climate change, which entered into force in November 2016, is at its heart an agreement about energy. Transformative change in the energy sector, the source of at least two-thirds of greenhouse-gas emissions, is essential to reach the objectives of the Agreement. The changes already underway in the energy sector, demonstrating the promise and potential of low-carbon energy, in turn lend credibility to meaningful action on climate change. Growth in energy-related CO_2 emissions stalled completely in 2015. This was mainly due to a 1.8% improvement in the energy intensity of the global economy, a trend bolstered by gains in energy efficiency, as well as the expanded use of cleaner energy sources worldwide, mostly renewables. An increasing slice of the roughly $1.8 trillion of investment each year in the energy sector has been attracted to clean energy, at a time when investment in upstream oil and gas has fallen sharply. The value of fossil-fuel consumption subsidies dropped in 2015 to $325 billion, from almost $500 billion the previous year, reflecting lower fossil-fuel prices but also a subsidy reform process that has gathered momentum in several countries.

The renewables-led transformation of the power sector has given focus to a new debate over power market design and electricity security, while traditional energy security concerns have not gone away. Adding in issues of energy access, affordability, climate change and energy-related air pollution, as well as problems with public acceptance for different types of energy projects, there are many trade-offs, co-benefits and competing priorities that need to be untangled across the energy sector. This is the task that the *World Energy Outlook (WEO)* takes up in different scenarios and case studies, with the additional opportunity in 2016 to provide the first comprehensive examination of the new era opened up by the Paris Agreement. All the Paris climate pledges, covering some 190 countries, have been examined in detail and incorporated into our main scenario. More stringent decarbonisation options examined in *WEO-2016* include not only the 450 Scenario (consistent with a 50% chance of limiting global warming to 2 °C) but also a first examination of pathways that could limit warming further.

The world's energy needs continue to grow, but many millions are left behind

In our main scenario, a 30% rise in global energy demand to 2040 means an increase in consumption for all modern fuels, but the global aggregates mask a multitude of diverse trends and significant switching between fuels. Moreover, hundreds of millions of people are still left in 2040 without basic energy services. Globally, renewable energy – the subject of an in-depth focus in *WEO-2016* – sees by far the fastest growth. Natural gas fares best among the fossil fuels, with consumption rising by 50%. Growth in oil demand slows over the projection period, but tops 103 million barrels per day (mb/d) by 2040. Coal use is hit hard by environmental concerns and, after the rapid expansion of recent years, growth essentially grinds to a halt. The increase in nuclear output is spurred mainly by deployment in China. With total demand in OECD countries on a declining path, the geography of global

energy consumption continues to shift towards industrialising, urbanising India, Southeast Asia and China, as well as parts of Africa, Latin America and the Middle East. China and India see the largest expansion of solar photovoltaics (PV); while by the mid-2030s developing countries in Asia consume more oil than the entire OECD. Yet, despite intensified efforts in many countries, large swathes of the global population are set to remain without modern energy. More than half a billion people, increasingly concentrated in rural areas of sub-Saharan Africa, are still without access to electricity in 2040 (down from 1.2 billion today). Around 1.8 billion remain reliant on solid biomass as a cooking fuel (down by a third on today's 2.7 billion); this means continued exposure to the smoky indoor environments that are currently linked to 3.5 million premature deaths each year.

A new division of capital

A cumulative $44 trillion in investment is needed in global energy supply in our main scenario, 60% of which goes to oil, gas and coal extraction and supply, including power plants using these fuels, and nearly 20% to renewable energies. An extra $23 trillion is required for improvements in energy efficiency. Compared with the period 2000-2015, when close to 70% of total supply investment went to fossil fuels, this represents a significant reallocation of capital, especially given the expectation of continued cost declines for key renewable energy technologies. The main stimulus for upstream oil and gas investment is the decline in production from existing fields. In the case of oil, these are equivalent to losing the current output of Iraq from the global balance every two years. In the power sector, the relationship between electricity supply and generating capacity is changing. A large share of future investment is in renewables-based capacity that tends to run at relatively low utilisation rates, so every additional unit of electricity generated is set to necessitate the provision of 40% more capacity than during the period 1990-2010. The increased share of spending on capital-intensive technologies is balanced in most cases by minimal operational expenditures, e.g. zero fuel costs for wind and solar power.

Climate pledges and climate goals

Countries are generally on track to achieve, and even exceed in some instances, many of the targets set in their Paris Agreement pledges; this is sufficient to slow the projected rise in global energy-related CO_2 emissions, but not nearly enough to limit warming to less than 2 °C. China's transition to an economic model oriented towards domestic consumption and services plays a critical role in shaping global trends. The build-up of China's infrastructure in recent decades relied heavily on energy-intensive industrial sectors, notably steel and cement. However, energy demand from these sectors is now past its high point, with the projected decline to 2040 bringing down China's industrial coal use in its wake. Almost all the growth in China's power generation comes from sources other than coal, whose share in the power mix falls from almost three-quarters today to less than 45% in 2040. China's energy-related CO_2 emissions plateau, only slightly above current levels. In India, coal's share in the power mix drops from 75% to 55% over the period to 2040, a major shift in a country that sees electricity demand more than triple

(compared with a "mere" 85% rise in China). Among the main developed economies, the United States, the European Union and Japan look to be broadly on track to meet their climate pledges, although delivering on further improvements in energy efficiency will be vital. With a continued focus on full and timely implementation, the pledges are sufficient in aggregate to limit the increase in global CO_2 emissions to an annual average of 160 million tonnes. This is a marked reduction compared with the average annual rise of 650 million tonnes seen since 2000. But continued growth in energy-related CO_2 emissions, to 36 gigatonnes in 2040, self-evidently means that these pledges do not deliver the Paris Agreement's goal to reach a peak in emissions as soon as possible.

Efficiency is the motor of change

A step-change in the pace of decarbonisation and efficiency improvement is required in the 450 Scenario, underlining the importance of the five-year review mechanism, built into the Paris Agreement, for countries to increase the ambition of their climate pledges. The frontlines for additional emissions reductions are in the power sector, via accelerated deployment of renewables, nuclear power (where politically acceptable) and carbon capture and storage; a strong push for greater electrification and efficiency across all end-uses; and a robust and concerted clean energy research and development effort by governments and companies. With regard to efficiency, we highlight in *WEO-2016* the potential for further improvement in the performance of electric motor systems, which account for more than half of today's electricity consumption in a range of end-use applications (e.g. fans, compressors, pumps, vehicles, refrigerators). In the industrial sector alone, additional cumulative investment of around $300 billion in the 450 Scenario reduces 2040 global electricity demand by about 5% and avoids $450 billion in investment in power generation. Capturing these energy savings requires a system-wide approach that encompasses not only strict regulation of motors and motor-driven devices, but also larger uptake of variable speed drives and the implementation by operators of other measures to enhance the efficiency of the system as a whole, such as predictive maintenance.

Electric vehicles ready to move

Electricity takes an ever-larger share of the growth in final energy consumption: from just over one-quarter over the last 25 years, electricity accounts for almost 40% of additional consumption to 2040 in our main scenario and for two-thirds in the 450 Scenario. Non-OECD countries account for more than 85% of the increase in electricity use in both scenarios, but this is also one of the few energy carriers that gains ground within the OECD. Although a small factor in total power demand, the projected rise of electricity consumption in road transport is emblematic of the broader trend, as electric cars gain consumer appeal, more models appear on the market and the cost gap with conventional vehicles continues to narrow. The worldwide stock of electric cars reached 1.3 million in 2015, a near-doubling on 2014 levels. In our main scenario, this figure rises to more than 30 million by 2025 and exceeds 150 million in 2040, reducing 2040 oil demand by around 1.3 mb/d. Although battery costs continue to fall, supportive policies – which are far from

universal for the moment – are still critical to encourage more consumers to choose electric over conventional vehicles. If these policies, including tighter fuel-economy and emissions regulations as well as financial incentives, become stronger and more widespread, as they do in the 450 Scenario, the effect is to have some 715 million electric cars on the road by 2040, displacing 6 mb/d of oil demand.

Renewables break free

The electricity sector is the focus of many Paris pledges: nearly 60% of all new power generation capacity to 2040 in our main scenario comes from renewables and, by 2040, the majority of renewables-based generation is competitive without any subsidies. Rapid deployment brings lower costs: solar PV is expected to see its average cost cut by a further 40-70% by 2040 and onshore wind by an additional 10-25%. Subsidies per unit of new solar PV in China drop by three-quarters by 2025 and solar projects in India are competitive without any support well before 2030. Subsidies to renewables are around $150 billion today, some 80% of which are directed to the power sector, 18% to transport and around 1% to heat. With declining costs and an anticipated rise in end-user electricity prices, by the 2030s global subsidies to renewables are on a declining trend from a peak of $240 billion. Renewables also gain ground in providing heat, the largest component of global energy service demand, meeting half of the growth to 2040. This is mainly in the form of bioenergy for industrial heat in emerging economies in Asia; and solar thermal applications for water heating, already an established choice in many countries, including China, South Africa, Israel and Turkey.

In the 450 Scenario, nearly 60% of the power generated in 2040 is projected to come from renewables, almost half of this from wind and solar PV. The power sector is largely decarbonised in this scenario: the average emissions intensity of electricity generation drops to 80 grammes of CO_2 per kWh in 2040, compared with 335 g CO_2/kWh in our main scenario, and 515 g CO_2/kWh today. In the four largest power markets (China, the United States, the European Union and India), variable renewables become the largest source of generation, around 2030 in Europe and around 2035 in the other three countries. A 40% increase in generation from renewables, compared with our main scenario, comes with only a 15% increase in cumulative subsidies and at little extra cost to consumers: household electricity bills in the 450 Scenario are virtually unchanged from those in our main scenario, thanks also to more efficient energy use.

The policy focus shifts to integration

Cost reductions for renewables, on their own, will not be enough to secure an efficient decarbonisation of electricity supply. Structural changes to the design and operation of the power system are needed to ensure adequate incentives for investment and to integrate high shares of variable wind and solar power. The rapid deployment of technologies with low short-run costs, such as most renewables, increases the likelihood of sustained periods of very low wholesale electricity prices. A careful review of market rules and structures is required to ensure that generators have ways to recover their costs, and that the power system is able to operate with the necessary degree of flexibility. Strengthening the grid,

incentivising system-friendly deployment of wind and solar, and ensuring the availability of power plants ready to dispatch at short notice can efficiently accommodate the variability of wind and solar output, up until they reach a share of around one-quarter in the power mix. After this point, demand response and energy storage become essential to avoid wind and solar installations having their operations curtailed in times of abundant generation. In the absence of these additional measures, by the end of the *Outlook* period in the 450 Scenario curtailment could occur for up to one-third of the time in Europe and around 20% in the United States and India, potentially idling the equivalent of up to 30% of the investment in new wind and solar plants. The timely deployment in this scenario of cost-effective demand-side and storage measures, as part of a suite of system integration tools, limits curtailment to below 2.5% of annual wind and solar output and paves the way for deep decarbonisation of the power sector.

The 2 °C pathway is very tough: the road to 1.5 °C goes through uncharted territory

The challenges to achieve the 450 Scenario are immense, requiring a major reallocation of investment capital going to the energy sector. The division of the $40 trillion in cumulative energy supply investment in the 450 Scenario (some $4 trillion less than in our main scenario) moves away from fossil fuels and towards renewables and other low-carbon investments in nuclear and carbon capture and storage. By 2040, the share going to fossil fuels drops towards one-third. In addition, $35 trillion is needed for improvements in energy efficiency (an extra $12 trillion, compared with our main scenario). The 450 Scenario puts the energy sector on course to reach a point, before the end of this century, when all residual emissions from fuel combustion are either captured and stored, or offset by technologies that remove carbon from the atmosphere. The more ambitious the target for limiting global warming, the earlier this point of net-zero emissions has to be reached. The transformation required for a reasonable chance of remaining within the temperature goal of 1.5 °C is stark. It would require net-zero emissions at some point between 2040 and 2060 (even if negative emissions technologies can be deployed at scale), thus requiring radical near-term reductions in energy sector CO_2 emissions, employing every known technological, societal and regulatory decarbonisation option.

Fossil fuels and the risks from the low-carbon transition

For the moment, the collective signal sent by governments in their climate pledges (and therefore reflected in our main scenario) is that fossil fuels, in particular natural gas and oil, will continue to be a bedrock of the global energy system for many decades to come, but the fossil-fuel industry cannot afford to ignore the risks that might arise from a sharper transition. While all fossil fuels see continued growth in our main scenario, by 2040 oil demand returns to the levels of the late 1990s in the 450 Scenario, at under 75 mb/d; coal use falls back to levels last seen in the mid-1980s, at under 3 000 million tonnes of coal equivalent per year; only gas sees an increase relative to today's consumption level. A fully fledged policy drive to decarbonise the energy system will have important consequences for future revenues of fossil-fuel companies and exporting countries, but the exposure

to risk varies across fuels and across different parts of the value chain. For example, the capital at risk in the coal sector is concentrated in coal-fired power stations (for which carbon capture and storage becomes an important asset protection strategy); the key risk in the mining sector, which is much less capital-intensive, is to employment. Exporting countries can take steps to reduce vulnerabilities by limiting their dependence on fossil-fuel revenue, as Saudi Arabia is doing with its sweeping "Vision 2030" reform programme. In the case of oil, we find no reason to assume widespread stranding of upstream oil assets in the 450 Scenario, as long as governments give clear signals of their intent and pursue consistent policies to that end. Investment in developing new upstream projects is an important component of a least-cost transition, as the decline in output from existing fields is much larger than the anticipated fall in demand. But the risks would increase sharply in the event of sudden policy shifts, stop-and-go policy cycles or other circumstances that lead companies to invest for demand that does not materialise.

Oil markets could be in for another bumpy ride

A near-term risk to oil markets could arise from the opposite direction – a shortfall of new projects – if the cuts in upstream spending in 2015-2016 are prolonged for another year. In 2015, the volume of conventional crude oil resources that received development approval fell to its lowest level since the 1950s and the data available for 2016 show no sign of a rebound. A lot of attention is focused on the remarkable resilience of US tight oil output through the current downturn and its potential ability, because of a short investment cycle, to respond in a matter of months to movements in price. But there is a threat on the horizon to the "baseload" of oil output, the conventional projects that operate on a different rhythm, with lead times of three to six years from investment decision to first oil. We estimate that, if new project approvals remain low for a third year in a row in 2017, then it becomes increasingly unlikely that demand (as projected in our main scenario) and supply can be matched in the early 2020s without the start of a new boom/bust cycle for the industry.

Over the longer term, oil demand in our main scenario concentrates in freight, aviation and petrochemicals, areas where alternatives are scarce, while oil supply – despite a strong outlook for US tight oil – increasingly concentrates in the Middle East. There are few substitutes for oil products as a fuel for trucks and planes and as a feedstock for the chemicals industry; these three sectors account for all of the growth in global oil consumption. Total demand from OECD countries falls by almost 12 mb/d to 2040, but this reduction is more than offset by increases elsewhere. India, the largest source of future demand growth, sees oil consumption rise by 6 mb/d. On the supply side, projected US tight oil output has been revised upwards, remaining higher for longer than in last year's *Outlook*, although non-OPEC production as a whole still goes into retreat from the early 2020s. OPEC is presumed to return to a policy of active market management, but nonetheless sees its share of global production rising towards 50% by 2040. The world becomes increasingly reliant on expansion in Iran (which reaches 6 mb/d in 2040) and Iraq (7 mb/d in 2040) to balance the market. The focus for oil trade shifts decisively to Asia: the United States all but eliminates net imports of oil by 2040.

A truly global gas market is coming into view

A 1.5% annual rate of growth in natural gas demand to 2040 is healthy compared with the other fossil fuels, but markets, business models and pricing arrangements are all in flux. A more flexible global market, linked by a doubling of trade in liquefied natural gas (LNG), supports an expanded role for gas in the global mix. Gas consumption increases almost everywhere, with the main exception of Japan where it falls back as nuclear power is reintroduced. China (where consumption grows by more than 400 billion cubic metres) and the Middle East are the largest sources of growth. But questions abound about how quickly a market currently awash with gas can rebalance, especially with another 130 bcm of liquefaction capacity under construction, primarily in the United States and Australia. Our *Outlook* assumes a marked change from the previous system of strong, fixed-term relationships between suppliers and a defined group of customers, in favour of more competitive and flexible arrangements, including greater reliance on prices set by gas-to-gas competition. This shift is catalysed by the increasing availability of footloose US LNG cargoes and the arrival in the 2020s of other new exporters, notably in East Africa, as well as the diversity brought to global supply by the continued, if uneven, spread of the unconventional gas revolution. Floating storage and regasification units help to unlock new and smaller markets for LNG, whose overall share in long-distance gas trade grows from 42% in 2014 to 53% in 2040. But uncertainty over the direction of this commercial transition could delay decisions on new upstream and transportation projects, posing the risk of a hard landing for markets once the current oversupply is absorbed. Export-oriented producers have to work hard to control costs in the face of strong competition from other fuels, especially in the power sector. In the mid-2020s, in gas-importing countries in Asia, new gas plants would be a cheaper option than new coal plants for baseload generation only if coal prices were $150/tonne (double the anticipated 2025 price). The space for gas-fired generation is also squeezed by the rising deployment and falling costs of renewables.

Coal: a rock in a hard place

With no global upturn in demand in sight for coal, the search for market equilibrium depends on cuts to supply capacity, mainly in China and the United States. There are stark regional contrasts in the coal demand outlook. Some higher income economies, often with flat or declining overall energy needs, make large strides in displacing coal with lower-carbon alternatives. Coal demand in the European Union and the United States (which together account for around one-sixth of today's global coal use) falls by over 60% and 40%, respectively, over the period to 2040. Meanwhile, lower income economies, notably India and countries in Southeast Asia, need to mobilise multiple sources of energy to meet fast growth in consumption; as such they cannot afford, for the moment, to neglect a low-cost source of energy even as they pursue others in parallel. China is in the process of moving from the latter group of countries to the former, resulting in a decline of almost 15% in its coal demand over the *Outlook* period. China is also instrumental to the way that the coal market finds a new equilibrium, after the abrupt end to the coal boom of the 2000s. China is administering a number of measures to cut mining capacity, a move

that has already pushed coal prices higher in 2016 (after four straight years of decline). If, however, the social costs of this transition prove too high, China could ease the pace of supply cuts, raising the possibility of China becoming a coal exporter in order to get rid of surplus output: this would prolong the slump in the international market. Alongside measures to increase coal-plant efficiency and reduce pollutant emissions, the long-term future of coal is increasingly tied to the commercial availability of carbon capture and storage, as only abated coal use is compatible with deep decarbonisation.

Energy and water: one doesn't flow without the other

The inter-dependencies between energy and water are set to intensify in the coming years, as the water needs of the energy sector – and the energy needs of the water sector – both rise. Water is essential for all phases of energy production: the energy sector is responsible for 10% of global water withdrawals, mainly for power plant operation as well as for production of fossil fuels and biofuels. These requirements grow over the period to 2040, especially for water that is consumed (i.e. that is withdrawn but not returned to a source). In the power sector there is a switch to advanced cooling technologies that withdraw less water, but consume more. A rise in biofuels demand pushes up water use and greater deployment of nuclear power increases both withdrawal and consumption levels. On the other side of the energy-water equation, the *WEO* analysis provides a first systematic global estimate of the amount of energy used to supply water to consumers. In 2014, some 4% of global electricity consumption was used to extract, distribute and treat water and wastewater, along with 50 million tonnes of oil equivalent of thermal energy, mostly diesel used for irrigation pumps and gas in desalination plants. Over the period to 2040, the amount of energy used in the water sector is projected to more than double. Desalination capacity rises sharply in the Middle East and North Africa and demand for wastewater treatment (and higher levels of treatment) grows, especially in emerging economies. By 2040, 16% of electricity consumption in the Middle East is related to water supply.

Managing energy-water linkages is pivotal to the prospects for successful realisation of a range of development and climate goals. There are several connections between the new United Nations Sustainable Development Goals (SDG) on clean water and sanitation (SDG 6) and affordable and clean energy (SDG 7) that, if managed well, can help with the attainment of both sets of goals. There are also many economically viable opportunities for energy and water savings that can relieve pressures on both systems, if considered in an integrated manner. Efforts to tackle climate change can exacerbate water stress in some cases, or be limited by water availability. Some low-carbon technologies, such as wind and solar PV, require very little water; but the more a decarbonisation pathway relies on biofuels, concentrating solar power, carbon capture or nuclear power, the more water it consumes. As a result, despite lower energy demand, water consumption in 2040 in the 450 Scenario is slightly higher than in our main scenario.


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World Energy Outlook 2016

The landmark **Paris Agreement** on climate change will transform the global energy system for decades to come.

The latest ***World Energy Outlook*** offers the most comprehensive analysis of what this transformation of the energy sector might look like, thanks to its **energy projections** to 2040. It reviews the key opportunities and challenges ahead for **renewable energy**, the central pillar of the low-carbon energy transition, as well as the critical role for **energy efficiency**.

WEO-2016 examines how a post-Paris world redefines the idea of **energy security**, particularly in the power sector, the frontline in the fight against climate change. The report explores how **oil, natural gas and coal** are adjusting to today's market conditions and assesses the risks that lie ahead, from under-investment in essential supply to stranded assets.

WEO-2016 looks at individual **country pledges** and examines how close – or far – nations are from reaching their goals. It outlines a course that would limit the rise in global temperature to below 2 °C and also plots possible pathways for meeting even more ambitious goals.

This year, ***WEO-2016*** also devotes a special chapter to the critical interplay between **water and energy**, with an emphasis on the stress points that arise as the linkages between these two sectors intensify.

For more information, please visit:
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