

An energy system under stress

The global energy system is in danger of falling short of the hopes and expectations placed upon it. Turmoil in parts of the Middle East – which remains the only large source of low-cost oil – has rarely been greater since the oil shocks in the 1970s. Conflict between Russia and Ukraine has reignited concerns about gas security. Nuclear power, which for some countries plays a strategic role in energy security (and which is examined in depth in this edition of the *World Energy Outlook [WEO-2014]*), faces an uncertain future. Electricity remains inaccessible to many people, including two out of every three people in sub-Saharan Africa (the regional focus in *WEO-2014*). The point of departure for the climate negotiations, due to reach a climax in 2015, is not encouraging: a continued rise in global greenhouse-gas emissions and stifling air pollution in many of the world's fast-growing cities.

Advances in technology and efficiency give some reasons for optimism, but sustained political efforts will be essential to change energy trends for the better. Signs of stress would be much more serious, were it not for improvements in efficiency and continuous efforts to innovate and reduce the cost of emerging energy technologies, such as solar photovoltaics (PV). But global energy trends are not easily changed and worries over the security and sustainability of energy supply will not resolve themselves. Actions from well-informed policy-makers, industry and other stakeholders are needed. *WEO-2014*, with projections and analysis extended to 2040 for the first time, provides insights that can help to ensure that the energy system is changed by design, rather than just by events.

Energy: the answer to – and the cause of – some urgent problems

Global energy demand is set to grow by 37% by 2040 in our central scenario, but the development path for a growing world population and economy is less energy-intensive than it used to be. In our central scenario, growth in global demand slows markedly, from above 2% per year over the last two decades to 1% per year after 2025; this is a result both of price and policy effects, and a structural shift in the global economy towards services and lighter industrial sectors. The global distribution of energy demand changes more dramatically, with energy use essentially flat in much of Europe, Japan, Korea and North America, and rising consumption concentrated in the rest of Asia (60% of the global total), Africa, the Middle East and Latin America. A landmark is reached in the early 2030s, when China becomes the largest oil-consuming country, crossing paths with the United States, where oil use falls back to levels not seen for decades. But, by this time, it is India, Southeast Asia, the Middle East and sub-Saharan Africa that take over as the engines of global energy demand growth.

By 2040, the world's energy supply mix divides into four almost-equal parts: oil, gas, coal and low-carbon sources. Resources are not a constraint over this period, but each of these four pillars faces a distinct set of challenges. Policy choices and market developments that bring the share of fossil fuels in primary energy demand down to just under three-quarters in 2040 are not enough to stem the rise in energy-related carbon dioxide (CO₂) emissions, which grow by one-fifth. This puts the world on a path consistent with a long-term global average temperature increase of 3.6 °C. The Intergovernmental Panel on Climate Change estimates that in order to limit this temperature increase to 2 °C – the internationally agreed goal to avert the most severe and widespread implications of climate change – the world cannot emit more than around 1 000 gigatonnes of CO₂ from 2014 onwards. This entire budget will be used up by 2040 in our central scenario. Since emissions are not going to drop suddenly to zero once this point is reached, it is clear that the 2 °C objective requires urgent action to steer the energy system on to a safer path. This will be the focus of a *WEO Special Report*, to be released in mid-2015 in advance of the critical UN climate talks in Paris.

Energy security concerns on the rise

The short-term picture of a well-supplied oil market should not disguise the challenges that lie ahead as reliance grows on a relatively small number of producers. Regional oil demand trends are quite distinct: for each barrel of oil no longer used in OECD countries, two barrels more are used in the non-OECD. Increased oil use for transport and petrochemicals drives demand higher, from 90 million barrels per day (mb/d) in 2013 to 104 mb/d in 2040, although high prices and new policy measures gradually constrain the pace of overall consumption growth, bringing it towards a plateau. Investment of some \$900 billion per year in upstream oil and gas development is needed by the 2030s to meet projected demand, but there are many uncertainties over whether this investment will be forthcoming in time – especially once United States tight oil output levels off in the early 2020s and its total production eventually starts to fall back. The complexity and capital-intensity of developing Brazilian deepwater fields, the difficulty of replicating the US tight oil experience at scale outside North America, unresolved questions over the outlook for growth in Canadian oil sands output, the sanctions that restrict Russian access to technologies and capital markets and – above all – the political and security challenges in Iraq could all contribute to a shortfall in investment below the levels required. The situation in the Middle East is a major concern given steadily increasing reliance on this region for oil production growth, especially for Asian countries that are set to import two out of every three barrels of crude traded internationally by 2040.

Demand for natural gas grows by more than half, the fastest rate among the fossil fuels, and increasingly flexible global trade in liquefied natural gas (LNG) offers some protection against the risk of supply disruptions. The main regions that push global gas demand higher are China and the Middle East, but gas also becomes the leading fuel in the OECD energy mix by around 2030, helped by new regulations in the United States limiting power sector emissions. In contrast to oil, gas production increases almost everywhere (Europe is the main exception) and unconventional gas accounts for almost 60% of global

supply growth. The key uncertainty – outside North America – is whether gas can be made available at prices that are attractive to consumers while still offering incentives for the necessary large capital-intensive investments in gas supply; this is an issue of domestic regulation in many of the emerging non-OECD markets, notably in India and across the Middle East, as well as a concern in international trade. Import needs are set to rise across much of Asia as well as in Europe, but concerns about the security of future gas supply are allayed in part by a growing cast of international gas suppliers, a near-tripling of global liquefaction sites and a rising share of LNG that can be re-directed in response to the short-term needs of increasingly interconnected regional markets.

While coal is abundant and its supply secure, its future use is constrained by measures to tackle pollution and reduce CO₂ emissions. Global coal demand grows by 15% to 2040, but almost two-thirds of the increase occurs over the next ten years. Chinese coal demand plateaus at just over 50% of global consumption, before falling back after 2030. Demand declines in the OECD, including the United States, where coal use for electricity generation plunges by more than one-third. India overtakes the United States as the world's second-biggest coal consumer before 2020, and soon after surpasses China as the largest importer. Current low coal prices have put pressure on producers worldwide to cut costs, but the shedding of high-cost capacity and demand growth are expected to support an increase in price sufficient to attract new investment. China, India, Indonesia and Australia alone account for over 70% of global coal output by 2040, underscoring Asia's importance in coal markets. Adoption of high-efficiency coal-fired generation technologies, and of carbon capture and storage in the longer term, can be a prudent strategy to ensure a smooth transition to a low carbon power system, while reducing the risk that capacity is idled before recovering its investment costs.

Prices and policies have to be right to get more efficiency into the mix

Energy efficiency is a critical tool to relieve pressure on energy supply and it can also mitigate in part the competitive impacts of price disparities between regions. A renewed policy focus on efficiency is taking hold in many countries and the transport sector is in the front line. With more than three-quarters of global car sales now subject to efficiency standards, oil transport demand is expected to rise by only one-quarter despite the number of cars and trucks on the world's roads more than doubling by 2040. New efficiency efforts have the effect of suppressing total oil demand growth by an estimated 23 mb/d in 2040 – more than current oil production of Saudi Arabia and Russia combined – and measures mainly in power generation and industry hold the growth in gas demand back by 940 billion cubic metres, more than current gas output in North America. Aside from reducing energy-import bills and environmental impacts, efficiency measures can also help in part to address the concern, felt in some import-dependent regions, that relatively high prices for natural gas and electricity put their energy-intensive industries at a competitive disadvantage. But regional energy price disparities are set to persist and North America, in particular, remains a relatively low-cost region through to 2040: the average amount spent on a unit of energy in the United States is expected even to fall below that of China in the 2020s.

Fossil-fuel subsidies totalled \$550 billion in 2013 – more than four-times those to renewable energy – and are holding back investment in efficiency and renewables. In the Middle East, nearly 2 mb/d of crude oil and oil products are used to generate electricity when, in the absence of subsidies, the main renewable energy technologies would be competitive with oil-fired power plants. In Saudi Arabia, the additional upfront cost of a car twice as fuel-efficient as the current average would, at present, take about 16 years to recover through lower spending on fuel: this payback period would shrink to 3 years if gasoline were not subsidised. Reforming energy subsidies is not easy and there is no single formula for success. However, as our case studies of Egypt, Indonesia and Nigeria show, clarity over the objectives and timetable for reform, careful assessment of the effects and how they can (if necessary) be mitigated, and thorough consultation and good communication at all stages of the process are essential.

Power sector is leading the transformation of global energy

Electricity is the fastest-growing final form of energy, yet the power sector contributes more than any other to the reduction in the share of fossil fuels in the global energy mix. In total, some 7 200 gigawatts (GW) of capacity needs to be built to keep pace with increasing electricity demand while also replacing existing power plants due to retire by 2040 (around 40% of the current fleet). The strong growth of renewables in many countries raises their share in global power generation to one-third by 2040. Adequate price signals will be needed to ensure timely investments in the new thermal generation capacity, which is necessary, alongside investment in renewables, to maintain the reliability of electricity supply. This will require reforms to market design or electricity pricing in some cases. The shift towards more capital-intensive technologies and high fossil fuel prices lead to increasing average electricity supply costs and end-user prices in most countries in the world. However, end-use efficiency gains help reduce the proportion of household income spent on electricity.

Renewable energy technologies, a critical element of the low-carbon pillar of global energy supply, are rapidly gaining ground, helped by global subsidies amounting to \$120 billion in 2013. With rapid cost reductions and continued support, renewables account for almost half of the increase in total electricity generation to 2040, while use of biofuels more than triples to 4.6 mb/d and the use of renewables for heat more than doubles. The share of renewables in power generation increases most in OECD countries, reaching 37%, and their growth is equivalent to the entire net increase in OECD electricity supply. However, generation from renewables grows more than twice as much in non-OECD countries, led by China, India, Latin America and Africa. Globally, wind power accounts for the largest share of growth in renewables-based generation (34%), followed by hydropower (30%) and solar technologies (18%). As the share of wind and solar PV in the world's power mix quadruples, their integration both from a technical and market perspective becomes more challenging, with wind reaching 20% of total electricity generation in the European Union and solar PV accounting for 37% of summer peak demand in Japan.

A complex set of elements in decision-making on nuclear power

Policies concerning nuclear power will remain an essential feature of national energy strategies, even in countries which are committed to phasing out the technology and that must provide for alternatives. Global nuclear power capacity increases by almost 60% in our central scenario, from 392 GW in 2013 to over 620 GW in 2040. However, its share of global electricity generation, which peaked almost two decades ago, rises by just one percentage point to 12%. This pattern of growth reflects the challenges facing all types of new thermal generation capacity in competitive power markets and the specific suite of other economic, technical and political challenges that nuclear power has to overcome. Growth is concentrated in markets where electricity is supplied at regulated prices, utilities have state backing or governments act to facilitate private investment. Of the growth in nuclear generation to 2040, China accounts for 45% while India, Korea and Russia collectively make up a further 30%. Generation increases by 16% in the United States, rebounds in Japan (although not to the levels prior to the accident at Fukushima Daiichi) and falls by 10% in the European Union.

Despite the challenges it currently faces, nuclear power has specific characteristics that underpin the commitment of some countries to maintain it as a future option. Nuclear plants can contribute to the reliability of the power system where they increase the diversity of power generation technologies in the system. For countries that import energy, it can reduce their dependence on foreign supplies and limit their exposure to fuel price movements in international markets. In a Low Nuclear Case – in which global capacity drops by 7% compared with today – indicators of energy security tend to deteriorate in countries that utilise nuclear power. For example, the share of energy demand met from domestic sources is reduced in Japan (by 13 percentage points), Korea (by six) and the European Union (by four) relative to our central scenario.

Nuclear power is one of the few options available at scale to reduce carbon-dioxide emissions while providing or displacing other forms of baseload generation. It has avoided the release of an estimated 56 gigatonnes of CO₂ since 1971, or almost two years of total global emissions at current rates. Annual emissions avoided in 2040 due to nuclear power (as a share of projected emissions at that time) reach almost 50% in Korea, 12% in Japan, 10% in the United States, 9% in the European Union and 8% in China. The average cost of avoiding emissions through new nuclear capacity depends on the mix and the costs of the fuels it displaces, and therefore ranges from very low levels to over \$80/tonne.

Almost 200 reactors (of the 434 operational at the end of 2013) are retired in the period to 2040, with the vast majority in Europe, the United States, Russia and Japan; the challenge to replace the shortfall in generation is especially acute in Europe. Utilities need to start planning either to develop alternative capacity or to continue operating existing plants years in advance of nuclear plants reaching the end of their current licence periods. To facilitate this process, governments need to provide clarity on their approach to licence extensions and details of the regulatory steps involved well ahead of possible plant closures. We estimate the cost of decommissioning nuclear plants that are retired in the period

to 2040 at more than \$100 billion. Considerable uncertainties remain about these costs, reflecting the relatively limited experience to date in dismantling and decontaminating reactors and restoring sites for other uses. Regulators and utilities need to continue to ensure adequate funds are set aside to cover these future expenses.

Public concerns about nuclear power must be heard and addressed. Recent experience has shown how public views on nuclear power can quickly shift and play a determining role in its future in some markets. Safety is the dominant concern, particularly in relation to operating reactors, managing radioactive waste and preventing the proliferation of nuclear weapons. Confidence in the competence and independence of regulatory oversight is essential, especially as nuclear power spreads: in our central scenario, the number of economies operating reactors rises from 31 to 36 as newcomers outnumber those that phase out nuclear power. The cumulative total of spent nuclear fuel doubles to more than 700 thousand tonnes over the projection period, but, to date, no country has opened a permanent disposal facility to isolate the most long-lived and highly radioactive waste produced by commercial reactors. All countries that have ever produced radioactive waste should have an obligation to develop a solution for permanent disposal.

Power to shape the future in sub-Saharan Africa

Those who have no access to modern energy suffer from the most extreme form of energy insecurity. An estimated 620 million people in sub-Saharan Africa do not have access to electricity, and for those that do have it, supply is often insufficient, unreliable and among the most costly in the world. Around 730 million people in the region rely on solid biomass for cooking, which – when used indoors with inefficient cookstoves – causes air pollution that results in nearly 600 000 premature deaths in Africa each year. Sub-Saharan Africa accounts for 13% of the global population, but only 4% of global energy demand (more than half of which is solid biomass). The region is rich in energy resources, but they are largely undeveloped. Almost 30% of global oil and gas discoveries made over the last five years were in the region, and it is also endowed with huge renewable energy resources, especially solar and hydro, as well as wind and geothermal.

The sub-Saharan energy system is set to expand rapidly but, even so, many of the existing energy challenges will be only partly overcome. By 2040, the region's economy quadruples in size, the population nearly doubles and energy demand grows by around 80%. Power generation capacity quadruples and almost half of the growth in generation comes from renewables, which also increasingly provide the source of power for mini- and off-grid systems in rural areas. Overall, nearly one billion people gain access to electricity, but more than half a billion still remain without it in 2040. Output from Nigeria, Angola and a host of smaller producers means that sub-Saharan Africa remains an important centre of global oil supply – although an increasing share of output is consumed within the region. The region emerges also as an important player in gas, as development of the major east coast discoveries off Mozambique and Tanzania accompanies increased production in Nigeria and elsewhere.

Sub-Saharan Africa's energy sector can do more to support inclusive growth. In an “African Century Case”, three actions in the energy sector – if accompanied by more general governance reforms – boost the sub-Saharan economy by a further 30% in 2040, delivering an extra decade's worth of growth in per-capita incomes:

- An upgraded power sector: additional investment that reduces power outages by half and achieves universal electricity access in urban areas.
- Deeper regional co-operation: expanding markets and unlocking a greater share of the continent's hydropower potential.
- Better management of energy resources and revenues: more efficiency and transparency in financing essential improvements to Africa's infrastructure.

A modern and integrated energy system allows for more efficient use of resources and brings energy to a greater share of the poorest parts of sub-Saharan Africa. Concerted action to improve the functioning of the energy sector is essential if the 21st is to become an African century.