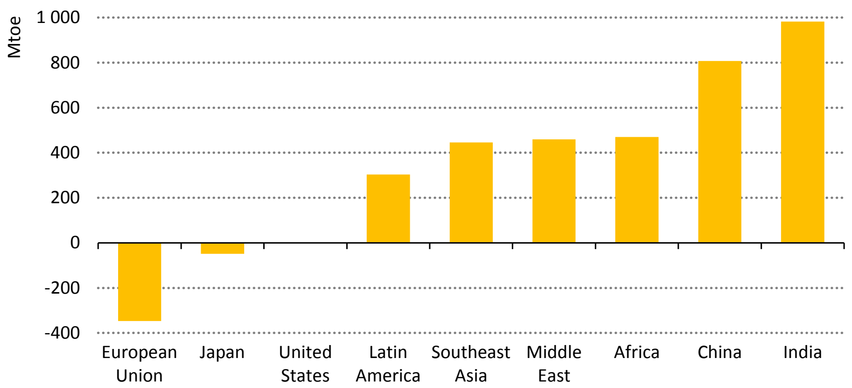
Overview and key findings

Energy policy in a time of transitions

SUMMARY

- In the New Policies Scenario, global primary energy demand expands by over 25% between 2017 and 2040. Without improvements in energy efficiency, the rise would be twice as large. India's energy demand more than doubles to 2040, becoming the single largest source of global growth. China's energy use also grows strongly, but the rate of growth is only one-fifth of that seen from 2000 to 2017. Energy demand remains around today's level in the United States and it falls in Japan and the European Union.

Figure 1.1 ▷ Change in total primary energy demand in selected regions in the New Policies Scenario, 2017-2040



The world is witnessing a major shift in energy demand from advanced to developing economies, with demand growing fastest in India

- Demand for electricity increases by 60% in the New Policies Scenario, the fastest growth among the major energy carriers, and its share in global final consumption reaches one-quarter by 2040. Nearly 90% of the growth in electricity demand occurs in developing economies. On the generation side, declining renewable energy costs, increasing local pollution concerns and climate-related targets are set to reshape the global electricity mix. Coal and renewables switch positions: the share of coal declines from around 40% today to a quarter in 2040 while that of renewables grows from a quarter to around 40% over the same period.
- As the share of wind and solar photovoltaics (PV) grows, so does the need for flexibility to ensure reliable power supply. Available resources for this purpose

double by 2040, with thermal and hydropower plants to the fore, and interconnections, battery storage and demand response all playing increasingly important roles. The transformation of the power sector is pushing electricity security up the policy agenda, part of a broader reappraisal of energy security risks in a changing energy system.

- The pace of oil demand growth slows, and all of the 11.5 million barrels per day (mb/d) increase between 2017 and 2040 takes place in developing economies. Demand growth is consistently strong in the Middle East and India, particularly for trucks and petrochemical feedstocks. But it is China that becomes the world's biggest oil consumer and, by 2040, the largest net oil importer in history.
- Investment in new conventional upstream oil projects is currently well below what would be required to meet demand in the New Policies Scenario. This divergence in trends between strong consumption growth and weak investment in new supply, if left unchecked, points to damaging price spikes in the 2020s. It would be risky to rely on US tight oil production more than tripling from today's level by 2025 in order to offset the absence of new conventional crude oil projects.
- On the back of strong demand growth, revised up since last year's *Outlook*, China soon becomes the world's largest gas-importing country and its imports approach the level of the European Union by 2040. There are signs that the logjam in new liquefaction projects since mid-2016 is being broken, but there is still uncertainty over the business models that will prevail in a changing global gas market.
- Energy-related carbon dioxide (CO_2) emissions resumed growth in 2017 after three years in which they were flat. They remain on a slow but steady upward path in the New Policies Scenario, in line with the trajectory implied by the Nationally Determined Contributions but a long way from the early peak and rapid subsequent decline that would be consistent with the objectives of the Paris Agreement.
- Under current and planned policies, the world is also set to fall short on other energy-related Sustainable Development Goals. The number of people worldwide without access to electricity has dipped below 1 billion for the first time, but by 2030 there are 650 million people still without access in the New Policies Scenario and more than 2 billion globally still cooking with solid fuels. Premature deaths from poor air quality also remain stubbornly high. The Sustainable Development Scenario outlines an integrated path to achieve access, air quality and climate goals, maximising the synergies between them.
- Government policies and preferences will play a crucial role in shaping where we go from here. More than 70% of the $42 trillion in investment in energy supply in the New Policies Scenario, across all domains, is either conducted by state-directed entities or responds to a full or partial revenue guarantee put in place by governments. Only just over a quarter comes from private enterprises responding to prices set on competitive markets.

Introduction

The latest energy data are sending some mixed signals about the pace and direction of change in the global energy system. Electricity generated from renewables now accounts for a quarter of global generation and solar photovoltaics (PV) are cheaper than ever; yet there are signs that near-term deployment of new solar capacity might be slowing. The demise of coal has been widely predicted and consumption fell for two years straight from 2015, but bounced back in 2017. Energy efficiency is a proven way of meeting multiple energy policy goals, but the flow and stringency of new policies appears to be weakening. Nations have expressed a commitment to address climate change, but after three flat years, energy-related carbon dioxide (CO_2) emissions are on the rise again.

These signals point to today's energy transitions as complex, uneven, multi-speed processes in a system that is under pressure to meet rising demand for energy services. Untangling the various strands, the New Policies Scenario provides a measure of the real advances that are being made in many countries around the world, as well as the areas in which the world is falling short of some shared objectives to ensure universal access, cleaner air and reduced emissions – an assessment enabled by comparison with the Sustainable Development Scenario.

The first section of this chapter covers the main results of the scenario projections from different angles, looking at demand, supply, end-use sectors, efficiency, emissions, trade, and investment, and highlighting briefly the main findings. The second part takes up the theme of energy security, how this is evolving in a time of energy transition, and how various vulnerabilities play out in our scenarios to 2040. Drawing on the analysis from across this year's *World Energy Outlook (WEO)*, we highlight seven themes that are critical to a reliable, affordable and sustainable energy future:

- Adapt power systems to the transformation that is underway in the electricity sector, or risk compromising the reliability of electricity supply.
- Realise the full potential of energy efficiency, the one policy instrument that can reliably target all aspects of energy security.
- Reduce emissions from power but do not forget the rest of the energy system, in particular the parts that electricity cannot reach.
- Think strategically about the role of gas infrastructure in meeting long-term energy and environmental goals.
- Watch out for shortfalls in investment across the board, not only in clean energy technologies, but also in traditional elements of supply.
- Seek out gains from co-operation: regional integration and international collaboration can play a major role in improving outcomes.
- Work to bring universal access to modern energy, the lack of which is the most extreme form of energy insecurity.

Figures and tables from this chapter may be downloaded from www.iea.org/weo2018/secure/.

Scenarios

1.1 Overview

Table 1.1 ▷ World primary energy demand by fuel and scenario (Mtoe)

			New Policies		Current Policies		Sustainable Development	
	2000	2017	2025	2040	2025	2040	2025	2040
Coal	2 308	3 750	3 768	3 809	3 998	4 769	3 045	1 597
Oil	3 665	4 435	4 754	4 894	4 902	5 570	4 334	3 156
Gas	2 071	3 107	3 539	4 436	3 616	4 804	3 454	3 433
Nuclear	675	688	805	971	803	951	861	1 293
Renewables	662	1 334	1 855	3 014	1 798	2 642	2 056	4 159
Hydro	225	353	415	531	413	514	431	601
Modern bioenergy	377	727	924	1 260	906	1 181	976	1 427
Other	60	254	516	1 223	479	948	648	2 132
Solid biomass	646	658	666	591	666	591	396	77
Total	**10 027**	**13 972**	**15 388**	**17 715**	**15 782**	**19 328**	**14 146**	**13 715**
Fossil fuel share	*80%*	*81%*	*78%*	*74%*	*79%*	*78%*	*77%*	*60%*
CO_2 emissions (Gt)	**23.1**	**32.6**	**33.9**	**35.9**	**35.5**	**42.5**	**29.5**	**17.6**

Notes: Mtoe = million tonnes of oil equivalent; Gt = gigatonnes. Solid biomass includes its traditional use in three-stone fires and in improved cookstoves.

The overall share of fossil fuels in global primary energy demand has not changed over the last 25 years. Oil, coal and gas remain central to today's global energy system, though energy efficiency has had a significant impact in moderating the growth in energy demand. New contenders are however emerging, led by wind and solar PV, and are helping to push electricity into new parts of the energy system. How they fare depends to a large extent on the level of policy ambition and technology innovation, which will determine to a large extent the trajectory of energy-related emissions.

In the **New Policies Scenario**, global primary energy demand grows by over a quarter between today and 2040. The overarching structural trends that shape demand are population growth, urbanisation and economic growth. Energy policies also play a critical role, notably those relating to energy efficiency, renewable resources, measures to curb air pollution and the phasing-out of fossil fuel subsidies. In the Sustainable Development Scenario, demand is almost flat out to 2040, reflecting in part the continuing potential of energy efficiency to reduce demand. Our scenario-based projections show where policy choices lead the energy sector.

In the **Current Policies Scenario**, continued strong growth among the incumbent fuels leaves only a small amount of headroom for renewables to step in and meet incremental demand. Coal use rises on the back of strong consumption in the developing world. In the absence of significant additional commitments to improve vehicle fuel efficiency, oil demand climbs by 25% to 2040.

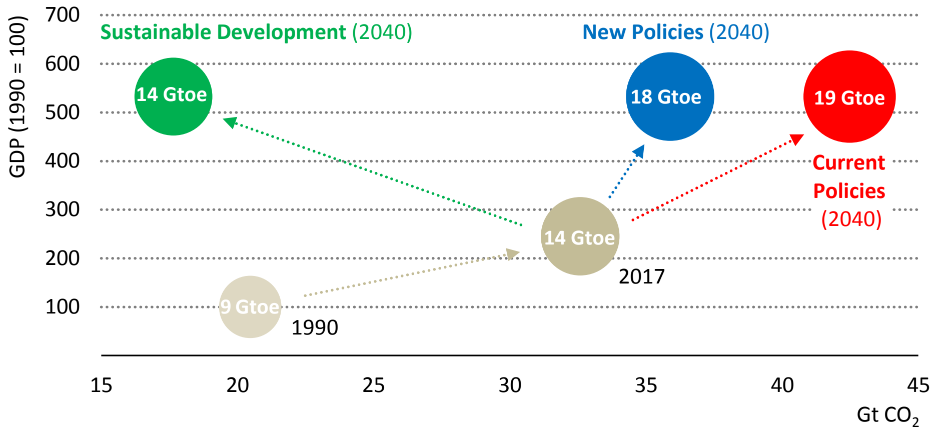
In the New Policies Scenario, coal, and oil to a degree, have to make room for others, not least because of rapid rise in the share of renewables in electricity generation. Strong policy headwinds, including commitments to phase out coal use in some countries, mean that global coal consumption levels off. Oil use in cars also peaks in the 2020s due to advances in fuel efficiency and an increased use of biofuels and electricity. However, trucks, aviation, shipping and petrochemicals continue to push up overall oil use.

In the **Sustainable Development Scenario**, coal moves to the back of the pack: demand of 1 600 million tonnes of oil equivalent (Mtoe) of coal in 2040 is in line with the level of 1975, when the global economy was barely a quarter the size of today. Oil demand reaches a peak and begins to decline.

Natural gas consumption grows in every scenario, underpinned by its versatility and environmental advantages relative to other combustible fuels. Its growth prospects are, however, curtailed in the Sustainable Development Scenario by higher efficiency and the push towards full decarbonisation of the energy system.

There is still a strong link between economic growth and global energy-related CO_2 emissions in the Current Policies Scenario. This is weakened in the New Policies Scenario, but emissions keep rising to almost 36 gigatonnes of carbon dioxide (Gt CO_2) in 2040. In the Sustainable Development Scenario, the share of fossil fuels in the primary energy mix drops to 60% by 2040 and the emissions trend parts company with economic growth (Figure 1.2).

Figure 1.2 ▷ World primary energy demand and energy-related CO_2 emissions by scenario



Achieving sustainable development goals requires a complete reversal of the historic relationship between economic growth, energy demand and emissions

Notes: Bubble size and numbers represent total primary energy demand. Gtoe = gigatonnes of oil equivalent or 1 000 Mtoe; Gt CO_2 = gigatonnes of CO_2.

1.2 Primary energy demand by region

Table 1.2 ▷ Total primary energy demand by region in the New Policies Scenario (Mtoe)

	2000	2017	2025	2030	2035	2040	2017-2040 Change	2017-2040 CAAGR
North America	2 678	2 624	2 675	2 667	2 661	2 693	69	0.1%
United States	2 271	2 148	2 185	2 162	2 139	2 149	1	0.0%
Central and South America	449	667	730	784	847	916	249	1.4%
Brazil	184	285	315	338	363	391	106	1.4%
Europe	2 028	2 008	1 934	1 845	1 779	1 752	-256	-0.6%
European Union	1 693	1 621	1 512	1 404	1 321	1 274	-347	-1.0%
Africa	490	829	980	1 086	1 192	1 299	470	2.0%
South Africa	103	131	133	132	135	138	7	0.2%
Middle East	353	740	846	957	1 085	1 200	460	2.1%
Eurasia	742	911	943	960	986	1 019	108	0.5%
Russia	621	730	745	744	754	769	39	0.2%
Asia Pacific	3 012	5 789	6 803	7 344	7 798	8 201	2 412	1.5%
China	1 143	3 051	3 509	3 684	3 787	3 858	807	1.0%
India	441	898	1 238	1 465	1 683	1 880	982	3.3%
Japan	518	428	415	403	390	379	-48	-0.5%
Southeast Asia	383	664	826	923	1 018	1 110	446	2.3%
International bunkers	274	404	476	525	578	635	231	2.0%
Total	**10 027**	**13 972**	**15 388**	**16 167**	**16 926**	**17 715**	**3 743**	**1.0%**
Current Policies			15 782	16 943	18 125	19 328	5 356	1.4%
Sustainable Development			14 146	13 820	13 688	13 715	-257	-0.1%

Notes: CAAGR = Compound average annual growth rate. International bunkers include both marine and aviation fuels.

Growth in the New Policies Scenario is led by developing economies, where demand increases by some 45% between 2017 and 2040. As recently as 2000, North America and Europe accounted for more than 40% of global energy demand and developing economies in Asia for around 20%. By 2040, this situation is completely reversed. This represents a huge change in the geography of global energy consumption.

India is the largest single source of growth and its demand more than doubles over the outlook period: by 2040, energy demand in India is around half that of China, up from less than 30% today. China cements its position as the world's largest energy consumer. Outside Asia, the Middle East and North Africa see the most rapid growth, with demand more than 60% higher in 2040 than today.

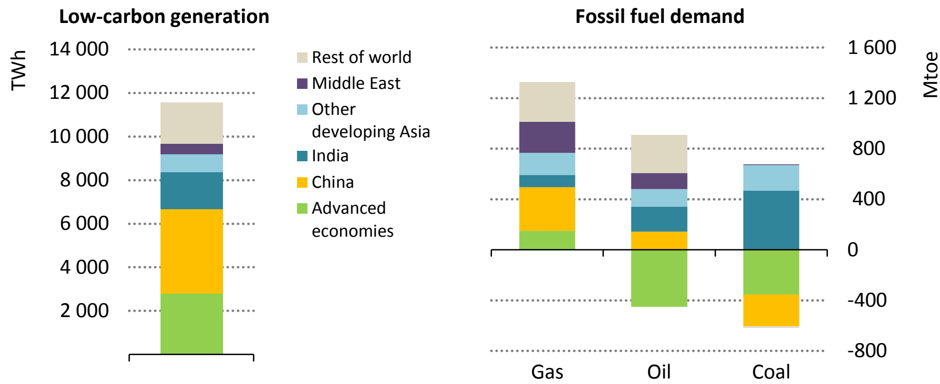
Energy use in Africa as a whole rises by just under 60% and surpasses that of the European Union towards the end of the outlook period, although it remains the lowest consumer of energy on a per-capita basis.

Demand in Central and South America grows less rapidly than in many other developing economies, but still rises by almost 40% by 2040. Demand in Eurasia increases by only just over 10% as robust increases in Caspian countries are mitigated by much more subdued growth in Russia.

The corollary of the rising share of primary energy demand going to developing economies is a reduction in the share accounted for by advanced economies. But a noticeable decline is only visible in the European Union and Japan, where demand falls by 20% and 10% respectively. In North America, demand remains flat throughout the period.

Demand for coal falls in advanced economies and China, which together account for more than half of the global increase in energy from low-carbon technologies and around 40% of the growth in natural gas. In India and most other fast-growing developing Asian economies, demand increases for all fuels and technologies (Figure 1.3).

Figure 1.3 ▷ Change in low-carbon generation and fossil fuel demand by region in the New Policies Scenario, 2017-2040



Demand growth in advanced economies and China is met by low-carbon technologies and gas, while India and other developing Asia mobilise all fuels and technologies

Note: TWh = terawatt-hours; Mtoe = million tonnes of oil equivalent.

Global primary energy demand grows by almost 40% between today and 2040 in the Current Policies Scenario, although existing policies are sufficient to secure a continued decline in energy use in the European Union and Japan (demand has already been falling in these regions since the mid-2000s).

In the Sustainable Development Scenario, demand is essentially flat, underscoring the importance of demand-side measures to achieve an outlook compatible with sustainable development goals. China's demand is on a downward trend by the latter years of this scenario, although India's energy use continues to grow through to 2040.

1.3 Total final consumption and efficiency

Table 1.3 ▷ Total final consumption in the New Policies Scenario (Mtoe)

							2017-2040	
	2000	**2017**	**2025**	**2030**	**2035**	**2040**	**Change**	**CAAGR**
Industry	1 863	2 855	3 265	3 460	3 648	3 833	977	1.3%
Transport	1 958	2 794	3 144	3 313	3 447	3 617	823	1.1%
Buildings	2 450	3 047	3 276	3 439	3 602	3 759	711	0.9%
Other	765	999	1 187	1 260	1 320	1 373	374	1.4%
of which feedstock	439	535	667	720	767	813	278	1.8%
Electricity	1 090	1 846	2 206	2 457	2 717	2 985	1 139	2.1%
District heat	248	289	301	302	303	302	14	0.2%
Direct use of renewables	271	456	583	669	755	844	388	2.7%
of which modern bioenergy	262	408	505	567	625	687	278	2.3%
Gas	1 118	1 503	1 790	1 964	2 139	2 298	795	1.9%
Oil	3 123	3 940	4 297	4 405	4 458	4 541	601	0.6%
Coal	542	1 004	1 029	1 027	1 021	1 020	15	0.1%
Solid biomass	646	658	666	649	624	591	-67	-0.5%
Total	**7 036**	**9 696**	**10 871**	**11 474**	**12 018**	**12 581**	**2 885**	**1.1%**
Current Policies			11 103	11 911	12 704	13 510	3 815	1.5%
Sustainable Development			10 126	10 007	9 946	9 958	262	0.1%

Notes: CAAGR = Compound average annual growth rate; Solid biomass includes its traditional use in three-stone fires and in improved cookstoves.

Developing economies in Asia and the Middle East account for three-quarters of the global growth in total final consumption to 2040 in the New Policies Scenario. The reorientation of China's economy from heavy industrial sectors towards domestic consumption slows growth in China to one-fifth of the pace seen since 2000. In India, final consumption more than doubles to 2040.

Among end-use sectors, industry is the largest contributor to overall growth in final consumption, with gas and electricity accounting for almost 80% of this increase. In the transport sector, oil accounts for less than 50% of the growth in demand, down from a share of nearly 90% for the period since 1990. In the buildings sector, global energy demand growth would have been nearly 40% higher without efficiency improvements, although the New Policies Scenario by no means exhausts the potential for further efficiency gains.

Electricity (40%) and gas (around 30%) underpin the rise in total final consumption in the New Policies Scenario, taking an increasing share of overall end-use consumption at the expense of coal and oil; the share of electricity rises from 19% today to 24% in 2040. Existing and announced efficiency measures avoid over 3 000 Mtoe in final consumption (a quarter of projected energy use) in 2040.

The share of electricity in 2040 reaches 28% in the Sustainable Development Scenario (four percentage points higher than in the New Policies Scenario). Buildings remain the largest consumer of electricity, but consumption in the transport sector is more than double the level in the New Policies Scenario as a result of a much bigger push for electric mobility (Figure 1.4).

Figure 1.4 ▷ Average annual change in total final electricity consumption by scenario and sector, 2017-2025 and 2025-2040

Buildings remain the largest source of growth for electricity demand; the transport sector increases its contribution to growth significantly in the Sustainable Development Scenario

Electricity demand in developing economies expands by more than 90% to 2040 in the New Policies Scenario; industrial motors are the largest source of growth, followed by demand for space cooling and household appliances. Nonetheless, per-capita electricity use in 2040 in developing economies is still only around 40% of the level in advanced economies today. The outlook for electricity demand in advanced economies is much flatter – a rise of just over 15%.

In 2017, more than 50% of total final consumption was used to supply heat. Just over half of all heat was consumed in industry, and almost all of the rest used for space and water heating in the buildings sector. In the New Policies Scenario, the contribution of heat from renewable sources rises from 10% today to 15% of the total by 2040.

Sales of electric cars escalate by over 30% every year for the next five years in the New Policies Scenario and there are 300 million electric cars on the road by 2040; there are also 740 million electric bikes, scooters and tuk-tuks, almost 30 million light- and heavy-duty electric trucks and 4 million electric buses worldwide. In total, these consume nearly 1 200 terawatt-hours (TWh) in 2040 (3% of total electricity demand in 2040).

1.4 Power generation and energy supply

Table 1.4 ▷ World electricity generation by fuel, technology and scenario (TWh)

			New Policies		Current Policies		Sustainable Development	
	2000	2017	2025	2040	2025	2040	2025	2040
Coal	6 001	9 858	9 896	10 335	10 694	13 910	7 193	1 982
Oil	1 212	940	763	527	779	610	605	197
Gas	2 747	5 855	6 829	9 071	7 072	10 295	6 810	5 358
Nuclear	2 591	2 637	3 089	3 726	3 079	3 648	3 303	4 960
Hydro	2 618	4 109	4 821	6 179	4 801	5 973	5 012	6 990
Wind and solar PV	32	1 519	3 766	8 529	3 485	6 635	4 647	14 139
Other renewables	217	722	1 057	2 044	1 031	1 653	1 259	3 456
Total generation	**15 441**	**25 679**	**30 253**	**40 443**	**30 971**	**42 755**	**28 859**	**37 114**
Electricity demand	*13 156*	*22 209*	*26 417*	*35 526*	*26 950*	*37 258*	*25 336*	*33 176*

Notes: TWh = terawatt-hours. Electricity demand equals total generation minus own use (for generation) and transmission and distribution losses. Total generation includes other sources.

Power generation

Global electricity generation increases by some 60% (15 000 TWh) between 2017 and 2040 in the New Policies Scenario. Fossil fuels remain the major source for electricity generation, but their share falls from around two-thirds today to under 50% by 2040.

Coal and renewables switch their position in the power mix. The share of coal declines from around 40% today to a quarter in 2040 while that of renewables grows from a quarter to just over 40% over the same period. The share of natural gas remains steady at over 20%.

Hydropower remains the largest low-carbon source of electricity in the New Policies Scenario, contributing 15% of total generation in 2040. Renewables altogether account for over 70% of the increase in electricity generation. Solar PV costs are projected to fall by more than 40% to 2040, underpinning a ninefold growth in solar PV generation, mainly in China, India and the United States. Low-carbon technologies account for half of the world's electricity generation by 2040.

Output from nuclear plants remains at around 10% of the global power mix. The nuclear fleet in advanced economies is ageing: around two-thirds of the fleet (220 GW) is older than 30 years today. China becomes the country with the largest generation of nuclear-based electricity.

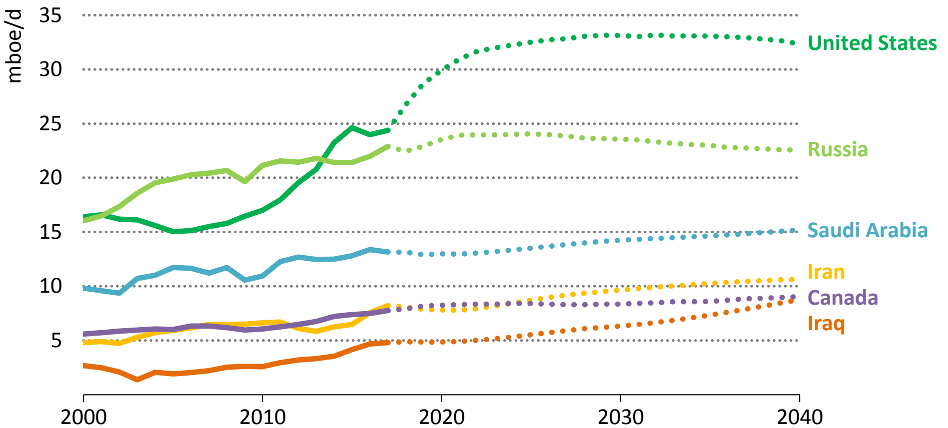
Energy supply

Global oil and natural gas production expands by more than 20% to 2040. Having become the world's largest gas and oil producer in 2015, the United States continues the remarkable growth of recent years, accounting for more than half of global supply increase to 2025 (over 70% for oil and 40% for gas); in 2025, nearly every fifth barrel of oil and every fourth cubic metre of gas in the world is produced in the United States.

After the mid-2020s, shale output from the United States levels off and conventional oil and gas production in the Middle East and unconventional production from a diverse range of countries accelerate to fill the gap. Shale gas and tight oil production outside the United States picks up in the latter part of the projection period, led by Argentina, Canada, China and Mexico. A variety of enhanced oil recovery techniques collectively manage to squeeze an additional 2.4 million barrels per day (mb/d) out of existing oil fields by 2040.

Global conventional crude oil production peaked in 2008 at 69.5 mb/d and has since fallen by around 2.5 mb/d. In the New Policies Scenario, it drops by a further 3 mb/d between 2017 and 2040, and its share in the global oil supply mix falls steadily from 72% today to 62% in 2040. The level of conventional crude oil resources approved for development in recent years is far below the demand requirements of the New Policies Scenario, creating the risk of sharp market tightening in the 2020s.

Figure 1.5 ▷ Oil and gas production for selected countries in the New Policies Scenario



The rise in US production of tight oil and shale gas since 2010 is the largest parallel increase in oil and gas output in history

Note: mboe/d = million barrels of oil equivalent per day.

Coal production in China declines at an average rate of 0.4% per year. India overtakes Australia and the United States in the early 2020s to become the second-largest coal producer.

1.5 Emissions

Table 1.5 ▷ World energy-related CO_2 emissions by fuel and scenario (Mt)

			New Policies		Current Policies		Sustainable Development	
	2000	2017	2025	2040	2025	2040	2025	2040
Coal	8 951	14 448	14 284	14 170	15 207	17 930	11 335	3 855
Oil	9 620	11 339	11 862	11 980	12 303	13 984	10 657	6 886
Gas	4 551	6 794	7 757	9 731	7 945	10 561	7 543	6 906
Total CO_2	**23 123**	**32 580**	**33 902**	**35 881**	**35 454**	**42 475**	**29 535**	**17 647**

Note: Mt = million tonnes.

After plateauing for three years, global energy-related CO_2 emissions rose in 2017 by more than 500 million tonnes (Mt). In the **New Policies Scenario**, total energy-related CO_2 emissions continue to rise, going up by 10% to 36 gigatonnes (Gt) in 2040. Most of the growth comes from gas and oil, reflecting the trends in demand, but coal (with 39% of the total) remains the largest source of emissions in 2040, followed by oil (33%) and gas (27%).

There is little overall change in the projected trajectory for energy-related CO_2 emissions in the New Policies Scenario compared with the *WEO-2017*. The projection remains slightly below the level implied solely by countries' Nationally Determined Contributions submitted as part of the Paris Agreement, meaning that, in aggregate, countries are broadly on course to deliver what they had planned in their international commitments (see Chapter 2). However, these commitments are far from sufficient to set the world on the emissions pathway of the Sustainable Development Scenario.

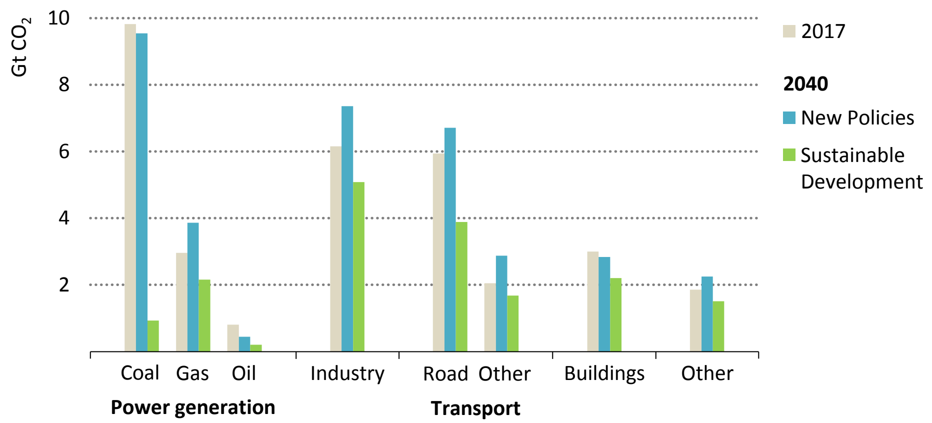
Emissions across advanced economies have fallen by an average of 0.9% each year since 2005, a rate that increases marginally in the New Policies Scenario. Among developing economies, China's emissions are largely flat through to the mid-2020s and then start to decline, projected at around 2% lower in 2040 than today. India's CO_2 emissions are among the lowest in the world on a per-capita basis. India's emissions continue to grow to 2040, but at a slower pace than in the past and its CO_2 emissions intensity halves by 2040.

Direct CO_2 emissions rise by around 20% to 2040 in the industry and transport sectors. Growth from industry comes despite a rise in electricity and gas use, at the expense of coal, that reduces the CO_2 intensity of the sector. Increasing sales of electric cars and improvements in vehicle and logistics efficiency limit CO_2 emissions growth in road transport to less than 15%, but CO_2 emissions in other transport modes rise by more than 40%. The buildings sector sees a slight dip in direct emissions, underpinned by fuel switching to electricity and gas and continued efficiency improvements.

In the power sector, 2040 emissions of CO_2 are only around 2% higher than today despite an increase in electricity consumption of some 60%. The rapid penetration of low-carbon sources of electricity helps to offset the increase in electricity demand, together with improvements in the average efficiency of the global thermal coal and gas fleets.

Emissions of the three major air pollutants – sulfur dioxide (SO_2), nitrogen oxides (NO_X) and fine particulate matter ($PM_{2.5}$) – decline in the New Policies Scenario: SO_2 emissions from the power sector halve by 2040. This helps alleviate some adverse health impacts, but in 2040 there are still more than 6 million premature deaths attributable to air pollution.

Figure 1.6 ▷ World energy-related CO_2 emissions by sector in the New Policies and Sustainable Development scenarios



The industry and transport sectors take a growing share of energy-related CO_2 emissions while the power sector emissions remain broadly constant in the New Policies Scenario

Note: Gt CO_2 = gigatonnes of carbon dioxide.

In the **Sustainable Development Scenario**, energy-related CO_2 emissions are reduced by more than 45% to 17.6 Gt by 2040. The power sector witnesses the most dramatic change, with the share of low-carbon technologies reaching 85% in 2040 (up from 35% today). Emissions from passenger cars halve, despite the number of cars nearly doubling. Transport is the largest emitting sector in 2040 in this scenario, followed by industry. Emissions from the power sector comprise just nearly 20% of total CO_2 emissions in 2040 (down from 42% today) while those from industry rise to nearly 30% (up from 19% today) (Figure 1.6).

The increase in CO_2 emissions caused by achieving universal energy access (which leads to a very slight increase in fossil fuel consumption) is more than offset by reductions in methane emissions from sharp falls in the traditional use of biomass as a cooking fuel.

Emissions of all three major air pollutants decline sharply from today's levels, and power sector emissions of SO_2 are all but eliminated. Emissions of NO_X, which today occur predominantly in the transport sector, drop by nearly half by 2040.

1.6 Trade

Table 1.6 ▷ Net import (shaded) **and export shares by fuel and region in the New Policies Scenario**

	Oil		Natural gas		Coal		Total	
	2017	2040	2017	2040	2017	2040	2017	2040
North America	10%	21%	2%	11%	12%	16%	2%	16%
United States	*30%*	*1%*	*0%*	*14%*	*11%*	*12%*	*7%*	*10%*
Central and South America	18%	32%	7%	7%	45%	39%	24%	26%
Brazil	*15%*	*48%*	*26%*	*22%*	*90%*	*90%*	*19%*	*34%*
Europe	76%	75%	53%	66%	50%	61%	39%	33%
European Union	*88%*	*91%*	*74%*	*89%*	*49%*	*62%*	*47%*	*39%*
Africa	50%	23%	33%	38%	35%	38%	46%	38%
Middle East	76%	71%	22%	24%	77%	90%	61%	53%
Eurasia	71%	65%	34%	41%	42%	48%	48%	47%
Asia Pacific	77%	85%	23%	41%	3%	5%	16%	22%
China	*69%*	*82%*	*42%*	*54%*	*8%*	*3%*	*18%*	*21%*
India	*82%*	*91%*	*46%*	*52%*	*31%*	*23%*	*16%*	*24%*
World trade on production	**46%**	**44%**	**20%**	**24%**	**21%**	**20%**	**25%**	**22%**

Notes: Shaded orange cells indicate net imports; white cells indicate net exports. Import shares for each fuel are calculated as net imports divided by primary demand. Export shares are calculated as net exports divided by production. Total also includes bioenergy, hydropower, nuclear and renewables.

Global energy trade continues to expand over the course of the New Policies Scenario, although not all fuels follow the same pattern. Oil remains the most traded product while natural gas trade grows by 70% between today and 2040. Total coal trade decreases slightly.

Oil trade is underpinned by mounting import needs in developing economies in Asia. Despite flattening demand after 2030, China becomes the world's largest oil importer.

North America switches its role in international oil trade during the projection period, becoming a net exporting region largely thanks to burgeoning tight oil production in the United States. The United States becomes a net oil exporter in the early 2020s.

The Middle East remains the world's largest oil exporter by a wide margin. Crude oil exports represent the majority of its exports today but, as the region's refining activity expands by more than 50% to 2040, the bulk of future export growth comes from oil products.

Natural gas trade increases much faster than the pace of demand growth. Driven by policy efforts to improve air quality, China's net import needs more than triple over the outlook period, and its gas imports rise to the level of the European Union. Russia remains the world's largest natural gas exporter throughout the period, followed by the Middle East and North America.

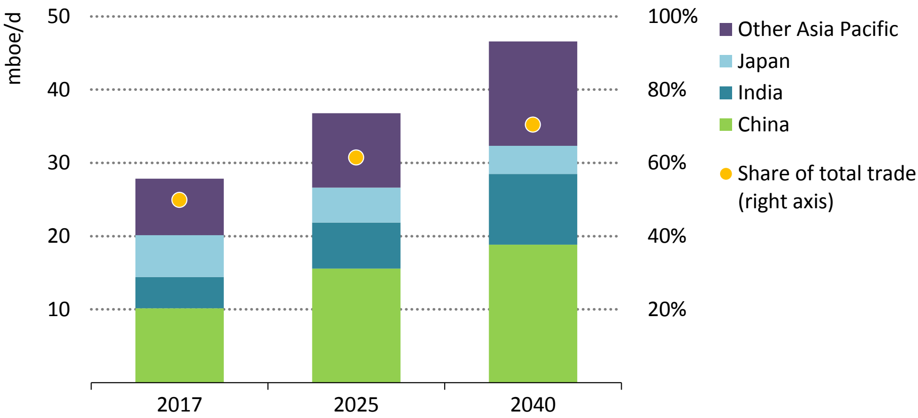
Liquefied natural gas (LNG) represents the bulk of the growth in trade. Global LNG trade more than doubles between 2017 and 2040, increasing its share in global gas trade from around 40% to more than 60% by 2040.

Coal trade is underpinned by two different movements: steam coal trade is affected by weaker demand for power generation and flattens out, while coking coal trade increases at a rate of 1% per year. India becomes the world's largest coal importer, overtaking China.

But uncertainty looms large: small changes in the supply-demand balance in either China or India can quickly have substantial implications for traded coal. Australia continues to be well positioned to serve the Asian markets with low-cost coking coal in a growing international coking coal market. Indonesian exports are affected by surging domestic consumption that limits export potential.

A common trend across all fuels is a growing concentration of trade flows to Asia. Overall, Asia's share of global oil and gas trade rises from around half today to around two-thirds by 2040 (Figure 1.7). China accounts for much of this, and our projections suggest a deepening in energy ties between China and key suppliers in the Middle East, Russia and Central Asia.

Figure 1.7 ▹ Net oil and gas imports by Asian destination in the New Policies Scenario



More than two-thirds of global oil and gas imports flow to Asia by 2040

Aggregate net oil import requirements in developing Asia expand by 80% between today and 2040, and around half of the world's traded gas finds a home in Asia by 2040. Coal imports in developing Asia more than double due to the increasing use of coal for power generation.

1.7 Investment

For the third consecutive year, global energy investment registered a slight decline in 2017, falling to $1.8 trillion. Increases in investment in several sectors, including energy efficiency and upstream oil and gas, were more than offset by a drop in power sector investment.

Nonetheless, the largest share of global investment went to the electricity sector, as it was in 2016, reflecting the growing importance of electricity in the energy system. China was the main destination for energy investment, over one-fifth of the total (IEA, 2018a).

Table 1.7 ▷ Global annual average energy investment by type and scenario ($2017 billion)

		New Policies		Current Policies		Sustainable Development	
	2010-17	2018-25	2026-40	2018-25	2026-40	2018-25	2026-40
Fossil fuels	1 171	967	1 081	1 043	1 407	830	574
Renewables	293	331	380	295	296	467	663
Electricity networks	264	313	387	334	397	286	462
Other	20	61	62	60	57	67	150
Total supply	**1 749**	**1 672**	**1 909**	**1 732**	**2 157**	**1 649**	**1 848**
Fuel supply	*58%*	*52%*	*53%*	*53%*	*60%*	*46%*	*32%*
Power supply	*42%*	*48%*	*47%*	*47%*	*40%*	*54%*	*68%*
Energy efficiency	236	397	666	299	496	505	828
Other end-use	124	148	246	122	143	203	581
Total end-use	**360**	**545**	**912**	**421**	**640**	**708**	**1 409**
Total investment	**2 109**	**2 216**	**2 821**	**2 153**	**2 796**	**2 357**	**3 257**
Cumulative 2018-2040		60 042		59 168		67 713	

Notes: The historical value for energy efficiency includes only 2017. Other includes nuclear, battery storage and carbon capture, utilisation and storage (CCUS) in the power sector. Other end-use includes direct use of renewables in end-use sectors (except biofuels, which are included in supply), electric vehicles and CCUS in industry.

In the **New Policies Scenario**, energy investment amounts to $2.2 trillion each year between 2018 and 2025 on average and $2.8 trillion each year thereafter. A pick-up in oil and gas investment to balance the near-term market, together with a slight rise in costs, mean that spending on fossil fuels regains a larger share in total supply investments than electricity.

Average annual upstream oil and gas spending rises in the New Policies Scenario from $580 billion between today and 2025 to $740 billion each year between 2025 and 2040. The United States accounts for almost 20% of total upstream oil and gas investment globally, followed by the Middle East with almost 15%.

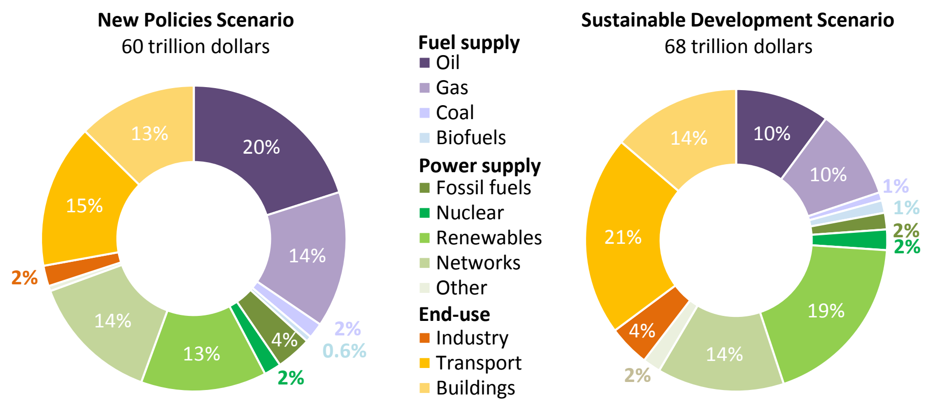
Renewables represent over half of the investment made in power plants since 2010 and continue to take the largest share of investment in the New Policies Scenario, with an average annual spend of $350 billion. Continued declines in costs mean that a constant investment in dollar terms buys a steadily increasing amount of capacity.

Once the wave of global coal-fired capacity currently under construction is completed, total annual investment in coal-fired plants halves in the New Policies Scenario, compared with the average of the last five years.

Energy efficiency investment increases in all end-use sectors in the New Policies Scenario. The buildings sector accounts for almost 40% of cumulative investment in energy efficiency, nearly 60% of which supports more energy-efficient houses, appliances and equipment. More than two-thirds of the investment in the transport sector goes to light-duty vehicles.

The **Sustainable Development Scenario** requires around 15% more capital than the New Policies Scenario, and puts much more emphasis on investment in end-use efficiency and clean energy technologies (Figure 1.8). Electricity demand follows a lower trajectory in the Sustainable Development Scenario owing to increased energy efficiency in all end-use sectors. Continued investment in oil and gas supply, however, remains essential even in the Sustainable Development Scenario to 2040, as decline rates at existing fields leave a substantial gap that needs to be filled with new upstream projects.

Figure 1.8 ▷ Cumulative investment needs by sector in the New Policies and Sustainable Development scenarios, 2018-2040



Total investment in the Sustainable Development Scenario is only about 15% higher than in the New Policies Scenario, but there is a marked difference in capital allocation

Note: Other includes battery storage and carbon capture, utilisation and storage.

Key themes

1.8 Energy policy in a time of transitions

The scenario structure of the *World Energy Outlook* provides a variety of lenses through which to view the long-term components of a secure energy system: reliability, affordability and sustainability.[1] The main concerns about reliability and affordability have traditionally been directed at the adequacy of investment in conventional oil resources and in natural gas, given that these resources are unevenly distributed around the world. The question of who supplies this energy and on what terms remains a very important strand of the energy security debate, even if it has been substantially reshaped by the rise of shale in the United States.

However, as analysed in detail in Part B of this year's *Outlook*, questions of electricity security are rising up the policy agenda worldwide. Moreover, the investments required to buttress long-term energy security are also inseparable from questions of sustainability, especially as countries step up their response to a range of environmental challenges. The risks from a changing climate are a strong motivating force, especially given that energy-related CO_2 emissions resumed growth in 2017. But for policy makers in many countries (and not only developing countries), a near-term priority is to reduce the health impacts caused by poor air quality. More than 5 million premature deaths each year are attributable to air pollution. Most of these deaths are from outdoor pollution in cities, with the remainder from smoky indoor environments due to cooking over open fires using solid biomass. The challenge for energy policy in a time of transitions is therefore twofold: to accelerate and broaden investment in cleaner, smarter and more efficient energy technologies, while ensuring at the same time that all the key elements of energy supply, including electricity networks, remain reliable and robust.

Two energy revolutions

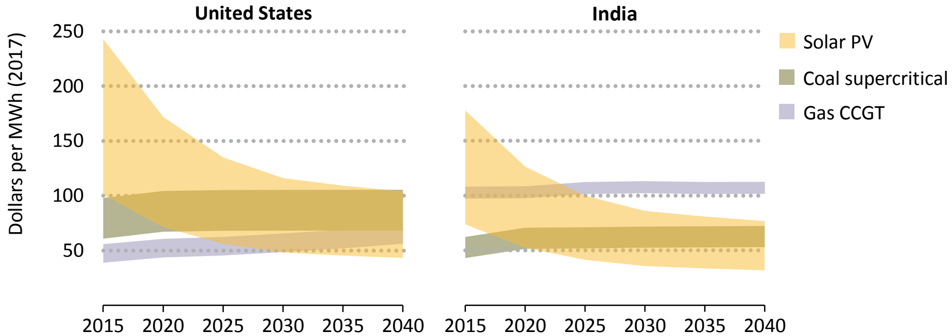
Two energy revolutions are having a major influence on this picture: the rise of shale in the United States and the transformation of the global power sector.

The shale revolution, which has brought a rise of oil and gas production in the United States that is unparalleled in the history of the hydrocarbons industry, has eased traditional concerns for importing countries related to the concentration of conventional resources. But it has also raised new questions over how major hydrocarbon-dependent economies will fare in the face of increased uncertainty over their long-term oil and gas revenues (the focus of *Outlook for Producer Economies*, a special report in the *WEO-2018* series [IEA, 2018b]). Uncertainty about the direction of long-term policy and technology has

1. Energy security also has an important short-term component, related to the resilience of the energy system and its ability to react promptly to sudden changes in the supply-demand balance. The focus here is on longer term security, which mainly deals with timely investments to supply energy in line with economic development and environmental needs.

also embedded an increasing preference for shorter cycle investments in the strategies of many oil and gas companies, and the limited appetite for large, capital-intensive projects is becoming an important element in the debate about future supply.

Figure 1.9 ▷ Levelised costs of selected new sources of electricity generation in selected countries in the New Policies Scenario



Cost reductions for solar PV put it on track to be among the cheapest options for new generation in many countries around the world

Notes: WACC = weighted average cost of capital. CCGT = combined cycle gas turbine. Costs for renewable energy are discussed in more detail in Chapter 8.

The impacts of the renewable energy revolution and the upheaval underway in the electricity sector have been no less far-reaching. In many countries (as the examples of the United States and India illustrate in Figure 1.9), solar PV is becoming among the least expensive options to produce electricity – especially if projects have access to relatively inexpensive financing. Pairing solar PV with storage raises the levelised costs, but also increases its value by easing its integration into power systems.[2] These developments have undercut the case for new investment in thermal generation in some countries, especially in coal-fired power: final investment decisions in new coal plants in 2017 were at one-third of the level seen in 2010, and the fall in China has been particularly abrupt. Our projections in the New Policies Scenario suggest that investment in coal-fired generation will not return to the peak level seen in 2015.

The accessibility and cost-competitiveness of wind and solar PV mean that some arguments often heard in favour of incumbent fuels, focusing on their affordability and their role in providing energy access, no longer hold as much water as they once did. Of those gaining

2. A full evaluation of the competitiveness of different generation options requires consideration of both the costs and value, discussed in Chapter 8.

access to electricity since 2000, most have done so through grids with generation from fossil fuels, primarily coal. But this balance is changing. The most common route for those gaining access in our projections to 2030 is via renewable energy sources, and off-grid and mini-grid systems provide a mode of delivery much better adapted than grids to the rural areas where the access problem is increasingly concentrated. Access to modern energy is indispensable for social and economic welfare, and low-cost renewables are making an important contribution to development in many of the world's poorest countries.

Choice of scenario

How these different elements play out, and how potential vulnerabilities evolve, depends on which scenario the world follows. The Current Policies Scenario provides the clearest illustration of the hazards that lie ahead: a business-as-usual approach that heads into increasingly perilous territory for all aspects of energy security. The New Policies Scenario paints a much more nuanced picture: a concerted effort to move to cleaner and more efficient technologies, with the power sector in the vanguard of change, and a large and expanding role for natural gas, with LNG underpinning the emergence of an increasingly competitive global gas market. But there remains a significant gap between the outcomes in the New Policies Scenario and those in the Sustainable Development Scenario; this is gradually narrowing, but at nowhere near the pace required (Box 1.1).

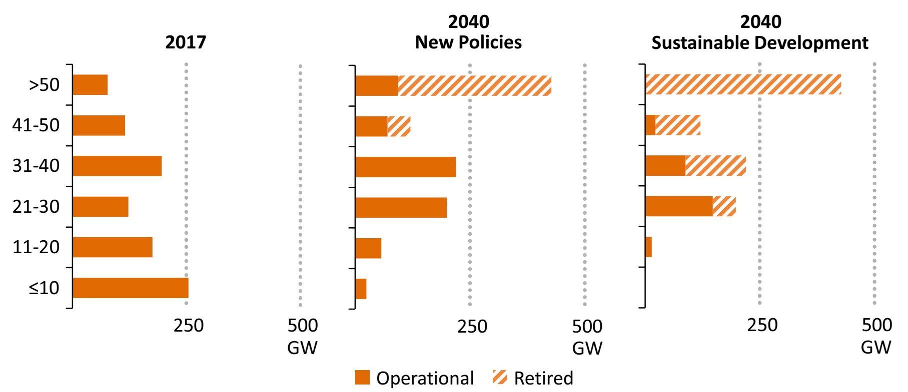
Box 1.1 ▷ Do we have one foot on the bridge?

In 2015, a *WEO Special Report* (IEA, 2015) identified five cost-effective opportunities for countries to reach an early peak in energy-related greenhouse gas (GHG) emissions. While not sufficient on their own to avoid severe impacts from climate change, these measures – if implemented in full – nonetheless could keep the door open for further action later and provide a bridge (hence the name "Bridge Scenario") to an emissions trajectory consistent with long-term decarbonisation goals. A few years later, we can assess progress in these five areas. Overall, the rise in global emissions in 2017 has started to open a gap between the world's emissions trajectory and what would be needed to stay with the Bridge Scenario.

- **Increasing energy efficiency** in the industry, buildings and transport sectors. The coverage and stringency of energy efficiency policies have increased in recent years, but two-thirds of final energy use is still not covered by mandatory efficiency standards, and the pace of global improvement in energy efficiency slowed down in 2017.
- **Increasing investment in renewable energy technologies.** This is the brightest spot. Investment in renewable power fell in monetary terms in 2017 to $300 billion, but that brought in more than 175 GW of new capacity worldwide. Deployment of solar PV and offshore wind remain on a rising trend, although annual additions of onshore wind have been falling.

- **Removing inefficient fossil fuel subsidies**. We estimate that artificially low prices for fossil fuels for end-users around the world involved subsidies totalling just over $300 billion in 2017. This is lower than in 2015, thanks in part to pricing reforms in many countries, but these reforms are coming under pressure as oil prices rise.
- **Reducing methane emissions** from oil and gas production. As highlighted in last year's *Outlook*, there is an opportunity here for action that is still not being taken up at scale. We estimate that worldwide methane leaks from oil and gas supply chains are still on the rise.
- **Phasing out the least-efficient coal-fired power plants**. Investment in new coal plants has slowed sharply, especially for the least-efficient subcritical coal technologies. However, 60% of today's operating coal plants are subcritical and almost half are under 20 years old, locking in emissions for the future (Figure 1.10).

Figure 1.10 ▷ Subcritical coal-fired capacity by age and scenario



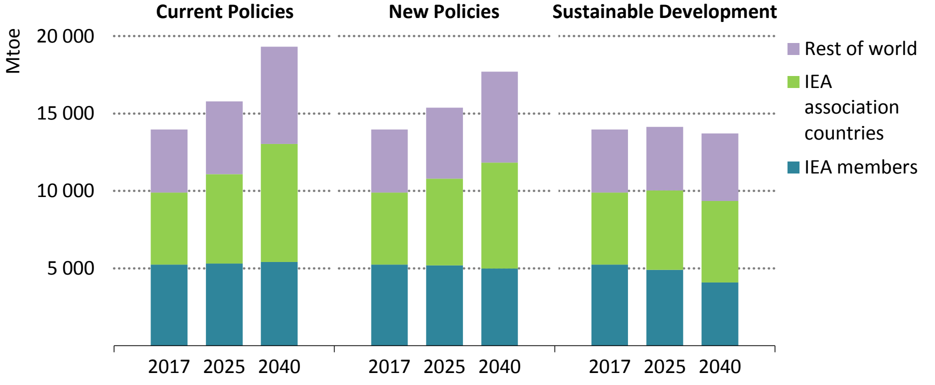
Half of the subcritical coal-fired fleet in operation today is less than 20 years old; without strong policy action, they are unlikely to close before reaching 40-50 years old

This is a mixed picture and more progress would be needed to get a firm foothold on the "bridge". Our analysis suggests that emissions are tracking the levels implied by their Nationally Determined Contributions, submitted under the Paris Agreement (see Chapter 2). In aggregate, countries are doing roughly what they had promised; the problem is that this still leaves them a long way from where they might wish to end up.

Shifting sources of global growth

The extent, composition and geography of global demand growth are crucial variables in determining the evolving nature of energy security challenges. Our projections in the *World Energy Outlook* vary widely by scenario, but a common denominator is that growth in energy demand is overwhelmingly concentrated in the developing economies of Asia. Furthermore, our projections consistently show that, within Asia, sources of growth are moving away from China (where the huge rise in energy demand in recent years slows in all scenarios) and towards India and other countries in South and Southeast Asia. This growth in demand is the main reason why the International Energy Agency (IEA) is putting strong emphasis on "opening its doors" to key emerging economies and working with them on clean energy transitions.

Figure 1.11 ▷ IEA member and association countries in world primary energy demand by scenario



IEA member and association countries now account for over two-thirds of global energy demand

Note: Since November 2015, eight countries have joined the IEA as association countries: Brazil, China, India, Indonesia, Morocco, Singapore, South Africa and Thailand.

To the extent that future demand growth continues the patterns of the past, the stage looks set for a return to some traditional strains in the system, especially in oil markets. Since 2015, oil consumption has been growing at a rate well over 1 mb/d per year: the Current Policies Scenario sees this continuing and the world becoming reliant on unprecedented volumes from the main conventional resource-holders in the Middle East, even though higher prices encourage non-OPEC supply. Production in Saudi Arabia pushes up to 15 mb/d in 2040, and Iran and Iraq each produce around 7 mb/d. This scenario reminds us that, although eclipsed today by other concerns, we may not have heard the last of the peak oil supply debate.

However, new policies and the pace of technological change mean that past trends are unlikely to be a good guide to the future. In the New Policies Scenario, demand growth is restrained by the increasing coverage and strength of energy efficiency policies, and renewables and natural gas account for 80% of the growth in energy demand to 2040. The position of coal erodes in the face of strong policy headwinds, meaning that its share in the global energy mix falls behind that of natural gas by 2030. And the hold of oil over the energy mix weakens, with its share falling from 32% in 2017 to 28% in 2040, even without a projected peak in demand.

Changing face of energy

China is emblematic of the changing face of global energy use. Even as it overtakes the United States to become the single largest consumer of oil globally in the 2030s, a combination of industrial strategy, rising import dependence and concerns about air quality mean that oil consumption is set to plateau in China at around 4 barrels per capita per year, far below the levels reached historically in Europe or North America. China is already a leader in electric mobility, accounting for more than half of global electric car sales in 2017 and an even higher share of electric buses and two-wheelers. Oil demand growth in China almost comes to a halt by the 2030s as oil use in road transport starts to fall, and coal use declines by some 15% to 2040, but natural gas demand rises very strongly – almost to the level of the United States today – and China also leads the global deployment of renewables and nuclear. In the electricity sector, with far and away the largest roll-out of smart meters worldwide, China is taking the lead in applying many of the digital technologies that are playing an increasing role in the energy sector (Box 1.2).

Box 1.2 ▷ Digitalization: the next big thing, for better or worse

The increased application of digital technologies is set to be a transformative shift for the energy sector, although it cannot be taken for granted that all of the changes set in motion by these technologies push in the direction of a more secure and sustainable energy system. As ever, which face of digitalization we end up seeing – the good or the bad – will largely depend on whether policy makers are able to get ahead of the curve with regulation and oversight that adapts to the types of innovations that are coming into play.

Digitalization is influencing trends all across the energy sector (for example, it is widely seen as the next frontier for cost reductions in upstream oil and gas), but is likely to have the largest impact in electricity. On the demand side, it is pushing up electricity use while also making demand smarter and more flexible. As billions more connected devices and machines enter the market over the coming years, they not only draw electricity at the plug, but also push up growth in demand for data centre and data transmission network services. So far, efficiency gains from improvements of servers, storage devices, network switches and data centre infrastructure, as well as a shift to much higher shares of highly efficient cloud and hyper-scale data centres, have kept demand from this sector in check. But demand growth looks set to continue to rise relentlessly: connected devices account for 20% of the growth in buildings sector electricity consumption through to 2040 in the New Policies Scenario.

There is even greater uncertainty over potential growth areas for electricity consumption like bitcoin mining and autonomous vehicles. Bitcoin's contribution to today's electricity demand is subject to a wide range of estimates. For the moment the range is still small on a global scale (0.1-0.3% of global electricity use), but this source of demand is fast becoming a concern in regions, including parts of China, Georgia, Iceland and Quebec (Canada), that are key bitcoin mining centres. In Iceland, for example, electricity use from bitcoin mining could soon exceed the entire country's household electricity consumption. Autonomous vehicles could potentially reduce costs while improving the safety, accessibility and convenience of road transport. But the consequences of automation on long-term energy demand and emissions could go in different directions, depending on the combined effect of changes in technological progress, vehicle technology, policy intervention and consumer behaviour.

Digitalization is already starting to enable demand to become more responsive to supply signals through smart metering. As our special focus on electricity makes clear, digitalization also presents a huge opportunity to improve the operational flexibility, efficiency and stability of power systems, by optimising performance across a range of equipment, appliances and sources of generation and storage. Investment in smart grid technologies such as improved monitoring, control and automation technologies reached $13 billion in 2017. However, increasing digitalization could raise digital security risks, both in terms of the grid's vulnerability to cyber-attacks as well as concerns around data privacy and ownership for consumers.

Digitalization is bringing new players and business models into play, especially in the electricity sector where demand aggregators, virtual power plants[3], energy service companies and other third parties are blurring traditional distinctions between generators, networks, retailers and consumers. Software companies and international oil and gas companies are also appearing as investors in the power sector. Meanwhile there has been a huge change in the composition of the world's largest electricity companies. Fifteen years ago, the *World Energy Investment Outlook* (IEA, 2003) provided a list of the ten-largest power companies in the world, ranked by installed capacity. European utilities dominated the list. This year we repeated the exercise, and Chinese-owned utilities now occupy six of the top-ten places, with EDF the only European company in the top-five rank.

3. Virtual power plants (VPP) are networks of distributed energy resources (behind-the-meter storage, rooftop PV, demand-side response resources) that are aggregated and connected to markets and services to which they might not otherwise have access. Virtual power plants can provide bulk electricity, system services such as adequacy, capacity or power quality like their physical counterparts, by aggregating through digital technologies a multitude of small resources. In 2017 there were 18 GW of VPP in Europe.

If the future is electric, then there are new resources in play

In 2016, the power sector became the principal destination for global investment in energy supply for the first time. It happened again in 2017, with global investment in electricity generation, networks and storage reaching $750 billion, 5% more than investment in oil and gas (IEA, 2018a). This is in part a reflection of the precipitous fall in upstream spending on new hydrocarbon projects, which – even if offset in part by lower costs – is raising the spectre of a new boom and bust cycle in oil (see below and Chapter 3). But it also points to a longer term shift in the balance of investment flows towards electricity and clean energy technologies that needs to accelerate very rapidly in the Sustainable Development Scenario. In this scenario, the global power sector accounts for two-thirds of all capital flows into new energy supply and nearly $20 trillion is spent on clean energy technologies as a whole, bringing a new set of energy resources and investment uncertainties into play (Spotlight).

S P O T L I G H T

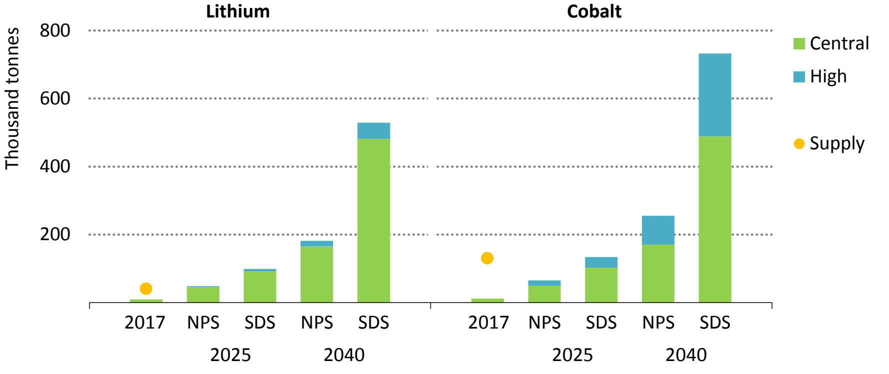
A new brand of resource politics?

The faster the energy economy changes, the more it requires new conversations about resources. The rise of clean energy technologies is leading to significant growth in demand for a wide range of minerals and metals, such as aluminium, copper, lead, cobalt, lithium, manganese, nickel, silver, iron ore, zinc and rare earth minerals. Rapid growth in electric vehicles in particular is bringing the energy sector closer to other commodity sectors that are subject to volatility and, in some cases, strong concentrations of resource ownership. Lithium and cobalt are both essential components of batteries for electric vehicles. More than half of cobalt production and reserves are in a single country, the Democratic Republic of Congo. China has 60% of the refining capacity for cobalt, up from only 3% in 2000, and has a strong position in production and reserve levels in practically every key mineral and metal required under low-carbon scenarios.

The growth in electric vehicles projected in the New Policies Scenario, and even more so in the Sustainable Development Scenario, represents a level of demand for lithium and cobalt that is considerably higher than today's supply. This means large investment to open new mining operations and expand production capacity. Today's market prices offer a substantial incentive to do so. However, given that it takes several years to bring new mine capacity online, the risk remains that bottlenecks in the supply chain will lead to tight supply and price spikes in the early 2020s. This would have implications along the value chain, as raw material costs make up around 20% of the total battery pack cost, and as the cost of the battery is the main determinant of the price of an electric vehicle.

Pressures on primary production could be eased over the longer term by recovering material from existing batteries, or re-using old batteries for stationary storage, even though current recycling rates are low. If there are serious constraints on supply, any shortage would also create strong incentives to innovate and find alternative technological solutions; there is a lot of current research on different battery chemistries that could alleviate potential shortages of cobalt. Whichever way things evolve, the energy sector needs to widen its discussions about energy resources.

Figure 1.12 ▷ Lithium and cobalt requirements for electric vehicle batteries in the New Policies and Sustainable Development scenarios



Major new supplies of lithium and cobalt will be needed as the number of electric vehicles expands

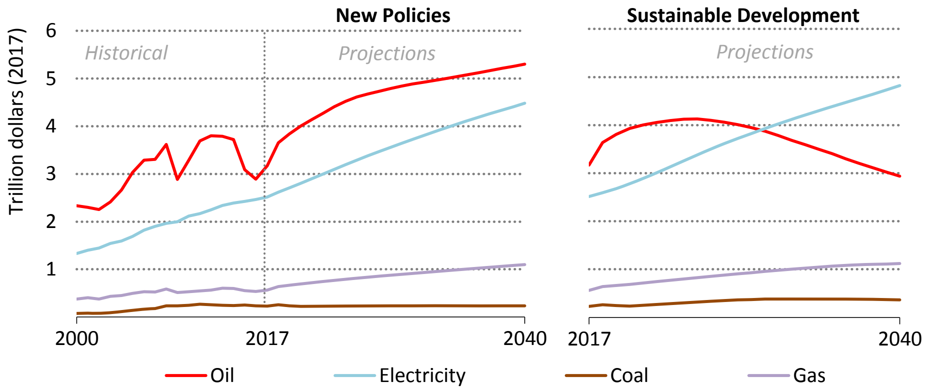
Notes: The range between the central and high variant in each year depends on the chemistry of the batteries being produced. NPS = New Policies Scenario; SDS = Sustainable Development Scenario.

The broader picture

The affordability of energy remains a major element of long-term energy security, and the level and composition of consumer spending on energy varies substantially between scenarios. Generating sufficient supply to meet demand in the Current Policies Scenario requires high prices, making affordability a key concern. In the New Policies Scenario, end-user spending on oil products remains the largest single component of the total. Even though the oil intensity of the global economy has been decreasing steadily with time, this suggests that both the absolute level and the volatility of oil prices are set to remain a central concern of consumers and policy makers in this scenario (Figure 1.13). The likelihood of oil price volatility does not diminish in the Sustainable Development Scenario (arguably the opposite is the case), but the decline in oil demand that starts in the 2020s means that, by 2030, electricity has become the largest element in consumer energy spending.

A critical element of the broader picture is the implications of our projections for global emissions. In the New Policies Scenario, emissions of all the major air pollutants decline, but premature deaths attributable to poor air quality remain stubbornly high; a much more sustained effort on both urban air quality and clean cooking would be required to bring these numbers down. Today the world is already around 1 °C warmer than in pre-industrial times. The rise in energy-related CO_2 emissions in the New Policies Scenario together with emissions of other GHGs (including those from outside the energy sector) would put the world on course for a global mean temperature rise of roughly 2.7 °C by 2100, as against the rise of between a 1.7-1.8 °C which is consistent with the Sustainable Development Scenario.[4]

Figure 1.13 ▷ Global end-user energy spending by fuel and scenario



In the Sustainable Development Scenario, electricity takes over from oil as the main element of consumer spending on energy

The implications of the difference between these two outcomes are huge. Quantifying the changes in physical hazards is subject to a large degree of uncertainty, but the higher the temperature rise, the greater the risks of extreme weather events such as heat waves, droughts, river and coastal floods and crop failures. Limiting the average global surface temperature rise to 1.7 °C would already lead to an increase in the risks of extreme weather events from today's levels. But risks are amplified for every increment in the temperature. For example, between 1981 and 2010 the global average chance of a place experiencing an extreme heat wave was around 5%.[5] With an average temperature increase of 1.7 °C, this rises to 40%; with a 2.7 °C increase it rises further to 67%. Similarly, a major river flood is, on average, nearly twice as likely to occur with a 1.7 °C temperature rise than was the case on average between 1981 and 2010 and is two-and-half times more likely under a 2.7 °C rise (Arnell et al., 2018).

4. Post-2040 emissions trends are not modelled in detail here, but by comparing trends to 2040 with other long-term emissions scenarios, the Sustainable Development Scenario puts the energy sector on a trajectory towards a long-term temperature rise of between 1.7 and 1.8 °C above pre-industrial levels (see Chapter 2). These temperature rises refer to the average increase globally; in reality, the temperature rise in some regions would be much higher than in others.

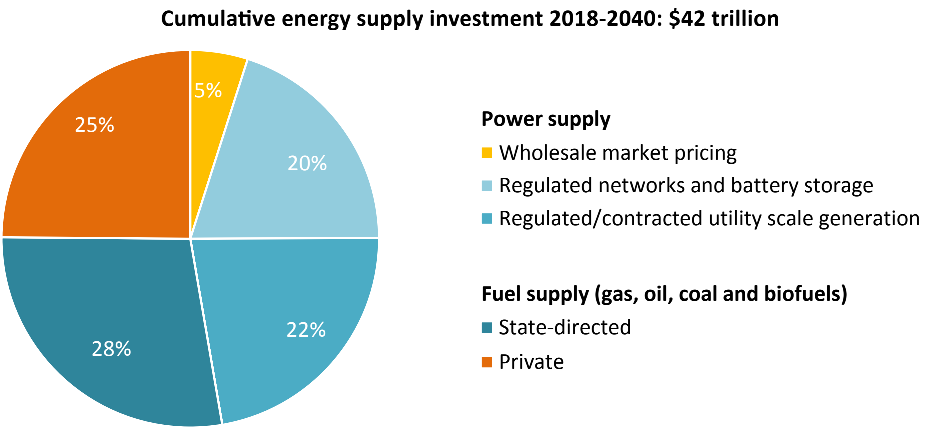
5. A heat wave is defined here as at least four days when the temperature is higher than the 99th percentile of the warm season temperature in that region.

Aside from the broader impacts on society and welfare, these changes would also amplify some of the challenges facing the energy sector, which would have to contend with the sudden and destructive effect of more frequent extreme weather events on energy infrastructure, as well as the more gradual impacts of changes to heating and cooling demand, and the effect of shifting weather patterns on hydropower.

Policies will determine which way investment flows

How government policies evolve remains an important key to future developments. In the power sector, for example, over 95% of global investment is made in areas where revenues are fully regulated or affected by mechanisms to manage the risk associated with variable prices on competitive wholesale markets (IEA, 2018a). In many areas of fuel supply, investments are made by companies in which the state is the sole or the majority shareholder. Of the cumulative $42 trillion in investment in energy supply required to 2040 in the New Policies Scenario, we estimate that more than 70% is made either by state-directed entities or where revenues are fully or partially guaranteed by regulation (Figure 1.14).

Figure 1.14 ▷ Cumulative energy supply investment by type in the New Policies Scenario



More than 70% of investments in energy supply are either made by state-directed entities or respond to a regulatory or other incentive

Against this backdrop, we highlight seven areas from the *WEO-2018* analysis where choices made by policy makers play a crucial role in determining the future reliability, affordability and sustainability of the energy system.

1.9 How can policy makers enhance long-term energy security?

Adapt power systems to the transformation that is underway

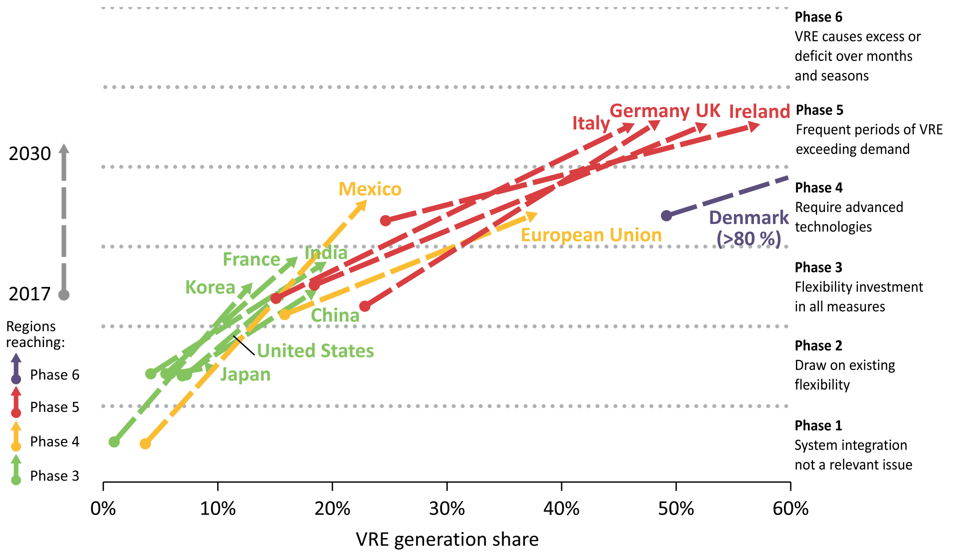
Power systems have always needed flexibility: electricity supply needs to balance demand at all times, and demand patterns have always changed hourly, daily, weekly and seasonally. But the flexibility needs of future power systems are rising, in some cases quite rapidly, due to the rapid emergence of non-dispatchable sources of generation such as wind and solar PV. The number of countries with a share of wind and solar PV above 5% of total electricity generation has increased from less than 10 in 2010 to more than 40 in 2017. Countries in the 10-20% range include Austria, Belgium, Greece, Italy, Netherlands, Sweden and United Kingdom. Germany, Ireland, Portugal and Spain are all at shares of more than 20%; Denmark was up to a share of around 50% in 2017.

The IEA categorises the integration of variable renewables into six distinct phases which are intended to assist in the identification and prioritisation of integration measures. These cover all possible levels of variable renewable penetration from a first phase – where deployment of the first tranche of wind and solar power plants has no noticeable impact at the system level – to an energy system relying on variable renewables as the dominant source of generation (IEA, 2018c).

There are four main sources of flexibility to balance electricity systems: the remainder of the power generation fleet; the interconnection of electricity grids to allow for balancing over a wider area; flexibility on the demand side; and energy storage. In the special focus on electricity in Part B of this *WEO*, we look in detail at both the increasing demand for flexibility in power systems in our scenarios, and how this can most cost effectively be provided. At present, the ability of thermal and hydropower plants to ramp up and down their own generation provides more than 85% of the flexibility available to power systems: interconnections provide around another 5%, and pumped storage a further 4%. Digitalization is unlocking new, small and more distributed sources of flexibility, especially in terms of demand-side response, and battery storage has grown quickly, especially behind-the-meter, but the contribution of these new forms of flexibility currently accounts for only around 1% of the total.

In the New Policies Scenario, the composition of the global power plant fleet changes fast. Within a decade, gas-fired capacity takes the lead from coal. Solar PV's rapid rise pushes it past wind capacity in the near term, and then past hydropower around 2030 and coal just before 2040. The evolution of the generation mix differs widely by country, but overall the share of wind power in global generation grows strongly from 4% to 12%, overtaking nuclear as the second-largest low-carbon source of electricity behind hydropower. Solar PV provided only around 2% of global generation in 2017, but widespread deployment and falling costs boost its global share to almost 10% by 2040. Battery storage costs are also set to decline rapidly, and global battery storage capacity reaches 220 GW by 2040, challenging the role of oil and gas-fired peaking plants.

Figure 1.15 ▷ Evolving flexibility needs in the power sector in the New Policies Scenario



The need for extra flexibility in power systems rises substantially as new wind and solar PV resources are added

Note: VRE = variable renewable energy sources.

In all markets, the need for electricity system flexibility increases as the share of variable renewables rises (Figure 1.15). Available resources for the provision of flexibility double by 2040, with power plants remaining the cornerstone of system flexibility, but contributions from interconnections, storage and demand response all increasing. The speed at which countries climb through different integration phases varies, depending not just on the shares of variable renewables in the system but also on the specific characteristics of the system itself. For instance, where there is a good match between the output of VRE and demand, as is the case in many countries with solar PV and cooling demand, their integration is less challenging than in other cases. In the New Policies Scenario, Mexico and India make large leaps in the need to draw upon flexibility, while countries with high penetrations at present (primarily in Europe) reach levels where no country is today. Without the provision of adequate flexibility, the low-carbon transformation of the power sector may well become associated with risks to electricity security, a development that would not only be disruptive for economies, but also put the brakes on the pace of change.

Realise the full potential of energy efficiency

Global energy intensity, the ratio of primary energy supply to gross domestic product, fell by 1.7% in 2017 – the smallest annual decline since 2012. Improvements in energy efficiency are the main instrument to bring down global energy intensity, and offer one of the few ways of simultaneously addressing all aspects of energy security. Global energy intensity would need to fall by an annual average of 3.4% to be consistent with the Sustainable Development Scenario, but there are indications that the flow of effective new efficiency policies may have waned in recent years, linked in part to lower international oil and gas prices.

The contest between efficiency, technological innovation and the rise of alternative fuels on the one hand and economic and population growth on the other is at the heart of the debate surrounding the future of oil demand in road transport. The rise of electric vehicles is often seen as the key variable, and indeed their rapid growth has a significant influence on overall fuel use for passenger cars, but our analysis suggests that changes in the fuel efficiency of the traditional fleet are set to have a much greater influence. Many of these savings do not require technological breakthroughs: if the fuel efficiency of the global car fleet was in line with that of cars in the European Union today (7.3 litres/100 km), this would already reduce global oil consumption by almost 6 mb/d.

Road transport – encompassing cars, trucks, two/three-wheelers and buses – is the largest segment of global oil demand today, accounting for 41 mb/d out of the current 95 mb/d of total consumption. In the absence of any additional efficiency measures or growth in the use of alternative fuels, rising demand for road transport services in the New Policies Scenario would theoretically lead to an increase of about 28 mb/d of oil demand between 2017 and 2040. Yet our projections show growth of less than 4 mb/d, with fuel use in cars around the same as today and all of the increase coming from the freight sector.

How can we explain this 24 mb/d of "missing" oil demand, and all that this implies for reduced local air pollution, global emissions, consumer spending and oil import bills? By far the largest contribution comes from more stringent fuel-economy and emissions standards, and from improvements in engines and hybrid technologies; this avoids around 15 mb/d of potential oil demand. Another 4 mb/d is displaced by biofuels and natural gas. As well, in the New Policies Scenario there are around 300 million electric cars on the road in 2040, 740 million electric bikes, scooters and tuk-tuks, 30 million electric light- and heavy-duty trucks and 4 million electric buses: taken together, these displace over 5 mb/d in 2040.

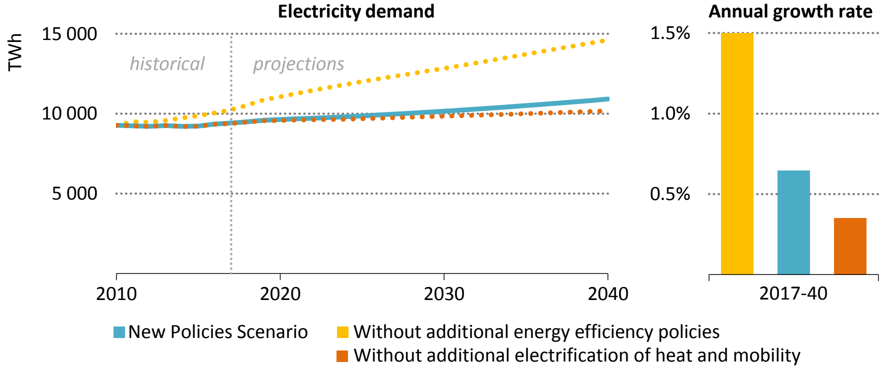
Efficiency also plays a major role in shaping our outlook for electricity. More than 90% of global electricity demand today is concentrated in the buildings and industry sectors, and here too there is a huge volume of potential consumption that is avoided because of efficiency gains through to 2040. In the industry sector, efficiency measures (mostly for motor systems) help to avoid nearly 3 600 TWh of additional electricity consumption by 2040, cutting industrial electricity demand growth in the New Policies Scenario by nearly half. In the buildings sector, an additional 4 000 TWh is saved by 2040, mostly due to more stringent implementation of minimum energy performance standards for appliances and cooling equipment. The improvements seen in the New Policies Scenario by no means exhaust the global potential in this area; but the 7 600 TWh avoided in these two areas already amounts to more than one-third of today's global electricity demand. In advanced economies, efficiency improvements are largely responsible for breaking the link between rising incomes and rising electricity consumption (Box 1.3).

Box 1.3 ▷ The mysterious case of the IEA's disappearing electricity demand

Electricity is at the heart of modern life, but in many advanced economies you would not necessarily know it from the data. Eighteen out of the thirty IEA member economies have seen declines in their electricity demand since 2010 and, in the rest, demand growth has slowed considerably. There is much debate about the causes: structural changes in the economy are often cited. But a detailed decomposition of trends, conducted as part of this year's *WEO* special focus on electricity, highlights that improvements in energy efficiency are the main underlying factor.

Efficiency improvements, typically because of strict minimum energy performance standards, have reined in growth in electricity demand. Without them, electricity demand among IEA member countries since 2010 would have grown at 1.5% per year; with them, it has crawled up by an average of 0.2% per year (Figure 1.16). Total energy use by certain classes of appliances has already peaked: energy use for refrigerators (98% of which are covered by performance standards) is well below the high point reached in 2009, and energy use for lighting has also declined. The world may be electrifying, but – for the moment at least – that does not necessarily mean that advanced economies are using much more electricity.

Figure 1.16 ▷ Electricity demand in IEA member countries and demand without efficiency policies or without new electricity uses



Electricity demand in IEA member countries has been essentially flat since 2010; energy efficiency improvements continue to subdue growth through to 2040

Electricity demand collectively edges higher in IEA countries in the New Policies Scenario, mainly because electricity is in demand for new uses such as electric cars, connected devices and space heating. Of the 1 500 TWh in demand growth in IEA countries from today to 2040 in the New Policies Scenario, around 40% comes from the electrification of mobility and heat.

Reduce emissions from power, but don't forget the rest

In the New Policies Scenario, electricity generation increases by 60%, but global CO_2 emissions from power generation are essentially flat. This means a reduction by one-third in the carbon intensity of electricity generation, largely due to the rapid increase in the contribution of renewables to power generation, but also because of some coal-to-gas switching and continued efficiency improvements in coal and gas-fired power plants. It puts the power sector firmly in the vanguard of change in the energy sector, although an even greater pace would be required to meet the emissions reductions objectives of the Paris Agreement and other sustainable development goals.

By 2040, the share of the power sector in global energy-related CO_2 emissions falls below 40%. But what about the rest of the energy sector? With power sector emissions flat, the reason why total emissions continue to rise in the New Policies Scenario lies elsewhere, primarily in industry and transport (emissions from the buildings sector, which consumes more electricity than any other end-use sector, do not rise). A central pillar of most low-emissions strategies is to couple the future of these sectors as much as possible to a decarbonising power sector, by increasing the electrification of end-uses. In the Future is Electric Scenario, part of the special focus on electricity in this *WEO*, we explore the potential – and the limits – of such an approach.

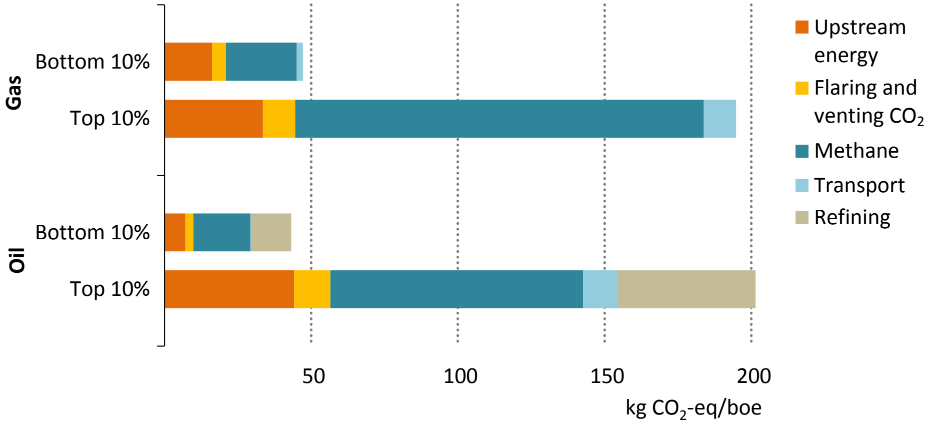
At present, electricity accounts for just under 20% of global final consumption. This share has been steadily increasing, and it rises further to 24% in the New Policies Scenario, and to 28% in the Sustainable Development Scenario. In the Future is Electric Scenario, we assume that a range of electric technologies are widely taken up as soon as they become cost-competitive by removing any constraints related to infrastructure, supply chains or consumer preference for existing technologies. We also accelerate the pace at which universal access to electricity is achieved. As a result, the share of electricity in final consumption rises to 31% by 2040. This is mainly thanks to a much more rapid adoption of heat pumps in buildings and for the provision of low-temperature heat in industry, and a swift transformation in the transport sector that puts almost a billion electric cars on the road by 2040.

This is an impressive result and implies wholesale changes to the energy system, although it would not in itself bring major reductions in global emissions unless accompanied by additional new measures to decarbonise electricity supply. But some 70% of final consumption would still be met by other sources, primarily by oil and gas. Even if the complete technical potential for electrification were deployed, there would still be sectors requiring other energy sources (given today's technologies), with most of the world's shipping, aviation and certain industrial processes not yet "electric-ready".

Finding solutions for these sectors requires a different approach, including further clean technology research and development spending and much more attention to areas such as carbon capture, utilisation and storage (CCUS). In this *WEO*, on the basis of a unique global assessment of the lifecycle emissions intensity of all sources of oil and gas, we also find that there is much more that could be done to make the provision of liquid fuels and gases compatible with a low-emissions future, or at least to lessen their contribution to the emissions that are causing climate change.

There is a broad range of emissions intensities for the oil and gas delivered to consumers today, taking into account all the energy use and emissions during their production, transportation and processing, including methane leaks to the atmosphere. For all but the very worst cases, this does not change our conclusion from the *WEO-2017* that natural gas brings environmental gains compared with coal (especially in relation to air pollutants, where the advantages of gas are undisputed), but there is ample scope to reinforce these benefits by further reducing emissions, not least since the most emissions-intensive sources of oil and gas produce around four-times more emissions than the least-emitting sources (Figure 1.17).

Figure 1.17 ▷ Emissions intensity of the supply of the least- and most-emitting sources of oil and gas worldwide



Emissions from producing, processing and transporting the most emissions-intensive sources of oil and gas are around four-times larger than those from the cleanest sources

Note: kg CO_2-eq/boe = kilogrammes of CO_2 equivalent per barrel of oil equivalent.

Oil and gas supply chains generate around 9% of today's global CO_2 emissions, and this share is set to rise slightly in the New Policies Scenario, despite enhanced efficiency efforts. We therefore explore various "game-changing" options that could have a more fundamental impact, including the use of CO_2 to support enhanced oil recovery, increased use of low-carbon electricity to support operations, and the potential to expand the role of zero-emissions (or "green") hydrogen in the energy system (Box 1.4). We find that the application of measures that would be economic with a $50 per tonne of carbon dioxide (t CO_2) price would cut CO_2 emissions from the oil and gas supply chains in 2040 by nearly 30%. Deploying these technologies would also yield indirect benefits. If the oil and gas industry were to mobilise the vast knowledge, institutional and capital resources at its disposal to support the development of zero-carbon technologies, this would provide a major boost to energy transitions.

Box 1.4 ▷ Is hydrogen heading back to the future?

Interest in hydrogen as a solution to the world's energy and environmental problems has ebbed and flowed over the years, but it is again on an upward path. Japan is accelerating efforts aimed at promoting hydrogen alongside renewable energy, and a number of countries in Europe are actively exploring the injection of hydrogen into their gas networks. The case for hydrogen is straightforward: it can be deployed in nearly all end-use sectors and used for electricity generation; it can be stored; it releases no GHG emissions or air pollutants when used. But it remains relatively costly and has yet to gain a durable foothold in the energy system.

Around 60 Mt of hydrogen is produced today: it is central to many processes in oil refineries, in chemicals manufacturing, and in the production of iron and steel. Nearly all of this hydrogen is produced today through the reformation of natural gas or via coal gasification. There are various options to produce low-carbon hydrogen, either by adding CCUS to the main fossil fuel-based methods used today, or by using zero-carbon electricity in electrolysers to break down water (electrolysis). The latter option could be particularly promising for renewables-rich locations that are far from any existing electricity demand centres; producing hydrogen remotely and then transporting it to consumers (either in liquefied form, as with LNG, or as a hydrogen-rich fuel) offers one of the few ways to exploit this remote renewables potential.

If costs come down, and CO_2 prices go up, a number of possible uses for hydrogen come into view. A first target for green hydrogen would be to replace the existing feedstock used in the chemicals and refining sectors. In the shipping sector, hydrogen has emerged as one of the few fuel options able to achieve the International Maritime Organization agreement to reduce CO_2 emissions at least by 50% by 2050 from 2008 levels. The Sustainable Development Scenario therefore now includes the use of hydrogen-based fuels in the shipping sector and by 2040 this is on a rising trend, in anticipation of the 2050 deadline. To help decarbonise the buildings and industry sectors, hydrogen could be injected into existing gas networks (current regulatory blending limits are relatively low, but up to 20% of hydrogen could be injected into natural gas networks).[6] In the power sector, with increasing levels of renewables deployed, hydrogen is one option to provide sizeable seasonal storage to help manage mismatches between supply and demand. If large-scale, dedicated hydrogen networks were to be established, hydrogen could also be used as a fuel in road and rail (hydrogen vehicles benefit from shorter refuelling times and longer ranges than electric vehicles) as well as in buildings and industry.

6. A 20% blend of hydrogen in the European natural gas grid today would reduce CO_2 emissions by around 60 Mt (a 7% reduction).

With multiple possible roles in the future energy system, low-carbon hydrogen could provide the answer to a variety of questions. But much greater effort is needed if the potential of hydrogen is to be realised. Stepping up policy support for research, development and deployment, and the creation of new market-based instruments would be essential to make a shift towards green hydrogen a more attractive proposition.

Think strategically about gas infrastructure

Consumption of natural gas rises strongly in the New Policies Scenario: the projected increase of 45% to 2040 is above that in last year's *Outlook*, mainly on the back of lower prices (thanks to another upward revision in the resource estimates for shale gas in the United States) and higher projected demand in China.

Changes in the way natural gas markets operate also play strongly into our analysis. A period of ample availability of LNG, driven largely by new liquefaction capacity in Australia and the United States, has deepened market liquidity and the ability to procure gas on a short-term basis. New projects and exporters are increasing the range of potential suppliers and competition for customers. Destination-flexible US exports are reducing the rigidity of LNG trade. More gas is being priced on the basis of benchmarks that reflect the supply-demand balance for natural gas, rather than the price of alternative fuels. The contours of a new, more globalised gas market are becoming visible, in which gas takes on more of the features of a standard commodity market.

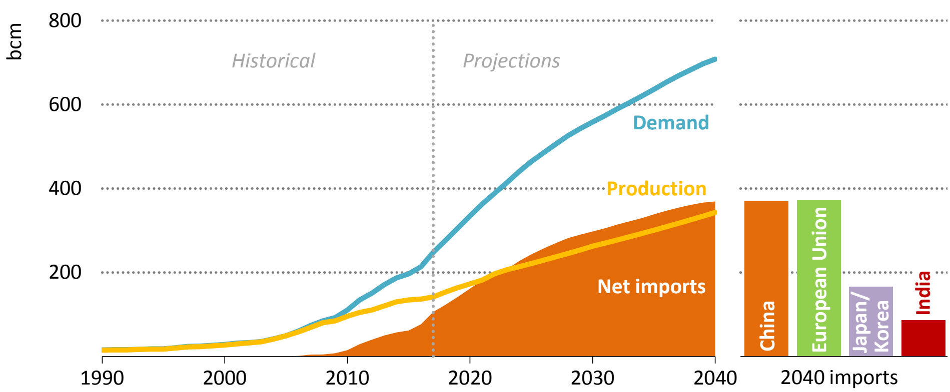
But even if more natural gas is traded on spot markets, the reliance of gas on capital-intensive infrastructure means that the gas business always requires a long-term horizon. Whereas oil and coal can both find ways to market relatively easily, dedicated transportation infrastructure is a pre-requisite for natural gas. Iraq, for example, is producing associated gas along with its oil and has an urgent need to increase the reliability of electricity provision, but pending the long-awaited addition of gas gathering and transmission pipelines it continues to flare large quantities of gas (an estimated 18 bcm [billion cubic metres] in 2017).

In the New Policies Scenario, around half of global gas demand growth comes from developing Asian economies where gas consumption is often relatively low today. Much of this gas will need to be imported and midstream infrastructure is today quite limited: building up infrastructure (especially given the relative abundance of coal and renewable resources across the region) requires conscious choices in favour of natural gas. This cannot be taken for granted.

Such a conscious choice has already been made in China. Gas occupies only a 7% share of China's primary energy mix today, but the potential for growth is increasingly being tapped. Demand grew by an astonishing 16% in 2017, and the indications for 2018 look similarly strong. This is mainly attributable to the strong policy push for coal-to-gas switching in industry and buildings as part of the drive to "turn China's skies blue again" and improve air quality. In 2017, the government set targets for clean winter heating in Beijing, Tianjin and 26 other cities and announced medium-term targets for the whole of northern China. The continued push for cleaner sources of heat is set to have a huge impact on demand for gas, and also for electricity, at the expense of coal. China has also introduced incentives to use compressed natural gas for passenger vehicles and LNG for trucks.

As a result, in the New Policies Scenario gas makes strong inroads in every sector in China, taking total demand in China to 710 bcm by 2040 (three-times higher than today, and 14% of total energy demand in 2040) (Figure 1.18). Despite steady projected growth in domestic production, China's gas imports almost reach the level of those into the European Union by 2040. Securing affordable and reliable supply of gas, ensuring supplier diversification, and building infrastructure in a timely way (this has already proved a constraint, as shown by a winter gas shortage in 2017-18) become critical challenges for Chinese policy makers.

Figure 1.18 ▷ China natural gas balance in the New Policies Scenario



China started gas import at scale barely ten years ago, but is already on the verge of becoming the world's largest gas-importing country

The need for strategic choices about infrastructure applies also to countries with existing gas networks, especially if – as in Europe – efforts to promote efficiency and to electrify end-uses start to push gas demand down. In our projections, EU gas consumption enters a gradual decline from the mid-2020s, reaching 410 bcm in 2040 (compared with a peak in 2010 of 545 bcm, and a level of 480 bcm in 2017). The issue for policy makers is that, although the average utilisation of Europe's gas infrastructure declines, this infrastructure still fulfils an indispensable seasonal role in ensuring security of supply. Gas might be needed less in aggregate, but when it is needed during the winter months (especially during any period when wind power output is low), there is no obvious, cost-effective alternative way to ensure that homes are kept warm and lights kept on: the amount of energy that gas delivers to the European system in winter is almost double the current consumption of electricity. What is more, the importance of this function and the difficulty of maintaining it both increase the further that Europe proceeds with decarbonisation: that is why there is increasing interest in the potential for alternative gases, such as biomethane or hydrogen, to fill at least part of the role played by natural gas today.

Against this backdrop, there are two imperatives for exporters and suppliers. The first is to ensure that adequate and cost-effective investment in new supply keeps gas as competitive as possible with other fuels. In the near term, this requires ways to match buyers' expectations of more flexible contractual terms with what sellers require to underpin major new infrastructure projects: the flow of new investment decisions on LNG plants may have picked up in the latter part of 2018, but there is continued uncertainty on the commercial models that can bridge this gap. The second is to burnish the environmental credentials of gas through concerted and visible action to reduce methane emissions, and through serious exploration of the possibilities to further decarbonise gas supply in the future (see Chapter 11).

Over the longer term, greater liquidity in international gas markets helps to increase confidence in the reliability and affordability of gas supply. International gas markets are evolving in a way that allocates traded volumes much more efficiently than in the past. However, there are some caveats. On the supply side, the high cost of putting gas infrastructure in place means that there are few incentives to build slack into the system: it is difficult to see Russia's current (and, in all likelihood, temporary) surplus of production capacity in the Yamal peninsula as an analogue to the spare capacity held in oil markets. So there is no guarantee that a significant shortfall in a gas-importing region can quickly or economically be replaced by calling on extra international supply.

The demand side, too, may become less responsive to price as the balance of consumption moves gradually away from power generation and towards the industry and the buildings sectors; fuel switching possibilities in power are also diminishing in many advanced economies as coal capacity is retired. The largest and most price-responsive element of demand may ultimately be the power sector in Asia. The extent to which this emerges as a new buffer in the system will depend not only on investment choices, but also on the progress made in developing well-functioning gas and electricity markets, so as to allow price signals from international markets to feed through into decisions further down the chain.

Watch out for shortfalls in investment across the board

One of the greatest threats to long-term energy security is a mismatch between the investment required to meet energy service demand and actual investments in the system: this *WEO* highlights a number of areas of potential concern. This applies not only to investment in clean energy technologies and energy efficiency, which would need to be stepped up dramatically in order to reach sustainability goals, but also to some "traditional" aspects of energy supply. In electricity markets, the challenges differ according to the type of system, but we find that there are difficulties on the horizon in many liberalised markets as well as in regulated ones. In oil, there is a growing divergence between robust demand growth in the near term and the pipeline of new conventional projects being approved for development; if this situation persists, there is a substantial risk of volatility and price spikes in the 2020s, with damaging consequences for the global economy.

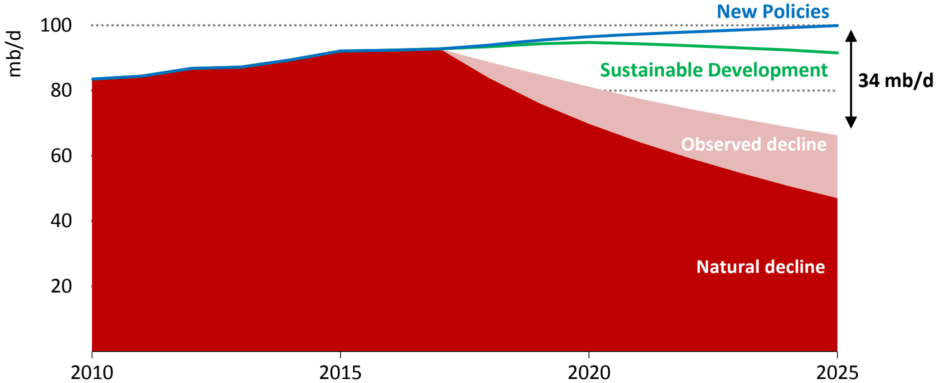
In many competitive electricity markets, power generators are struggling to manage a widening deficit between revenue from electricity sales and total generation costs. In the European Union, for example, this gap rose from 23% in 2010 to 45% in 2017, and is projected to grow to 55% in 2030. The considerations vary by country, but key factors have been increased volumes of generation from renewables and lower natural gas prices together putting downward pressure on wholesale electricity prices; the growth of distributed generation is also disrupting the traditional utility model in some cases. Periods of reduced profitability are a natural part of competitive markets, but declining revenue in lean systems – which we see in some markets today – signals the potential need to re-evaluate market designs to ensure their ability to deliver investment. Scarcity pricing can provide a signal for investment in new power plants and energy storage capacity, but it may also be both necessary and desirable to create new non-energy revenues for market participants in the form of payments for the provision of system or ancillary services or a variety of capacity remuneration mechanisms.

The situation in many regulated markets is quite different. Although demand is growing more quickly, the concern here is the impact of over investment in new electricity supply. Where investment outpaces the needs of the system, there are negative impacts on affordability and the profitability of the power plant fleet, undermining the financial health of the sector. Our analysis suggests that excess capacity, already substantial today in many countries in the Middle East, North Africa and developing Asia, is set to increase in the near term. If this over-build were to persist, additional supply costs could total $400 billion to 2040, or an extra $15 per household per year. The centralised power afforded to authorities in regulated markets enables them to address recognised market failures directly. They have the tools at their disposal to temper investment, improve the accuracy of demand projections and develop flexible power sector development plans.

In oil markets, the key underlying driver for new investment is declining output from existing fields. If no new fields were to enter operation and there were to be no capital expenditure as of 2018 in all current sources of supply, then oil production would fall by more than 8% per year to 2025 (the "natural" decline rate). In practice, companies do invest in their current sources of supply and this slows the aggregate drop in production to the observed decline rate of just over 4% (Figure 1.19). If no new fields were to enter operation in the meantime, by 2025 there would be 34 mb/d difference between demand and supply. There would likewise be a substantial gap even in the much more constrained demand outlook of the Sustainable Development Scenario.

A looming gap between demand and supply, caused by declining output from existing fields, is not in itself a cause for concern; it is a permanent feature of oil markets. Some 20 mb/d of the 34 mb/d gap in the New Policies Scenario looks likely to be filled by projects that are currently under development as well as by growth in tight oil production, natural gas liquids and other unconventional sources of oil. But what does cause concern is the relative paucity of new conventional project approvals to fill the remaining 13 mb/d gap by 2025.

Figure 1.19 ▷ Declines in current oil production and demand in the New Policies and Sustainable Development scenarios



Observed and natural declines in oil production are much faster than the drop in demand in the Sustainable Development Scenario: new upstream investment remains crucial

We estimate that around 16 billion barrels of new conventional crude oil resources would need to be approved each year between now and 2025 to avoid any potential "mismatch" between supply and demand. However, the average annual level of new resources approved in the three years since the oil price fall in 2014 was around 8 billion barrels (approvals picked up slightly in 2017, but still remained well below the levels seen in the early 2010s). The level of conventional crude oil approvals therefore needs to double if there is to be a smooth matching between supply and demand.

There is a real risk that this level of approvals will not materialise. Many national oil companies are facing constrained capital budgets, which limit their ability to invest in new projects. In Russia, while investment levels did not drop as fast as in many other regions after the oil price crash, companies are largely focusing on how to reduce decline rates in mature West Siberian fields rather than embarking on major new greenfield development programmes. Major international oil companies are currently placing much greater emphasis on cost management and executing projects with short pay-back periods than on seeking to expand their conventional reserve base.

One possibility would be for US tight oil to grow at a higher rate than is projected in the New Policies Scenario (which reaches a plateau around 2025 at about 9 mb/d). If annual approvals of conventional projects were to stay at today's level, then tight oil in the United States would need to grow by an additional 6 mb/d between now and 2025, reaching around 15 mb/d in 2025. With a sufficiently large resource base (much larger than we assume in the New Policies Scenario), this level of tight oil production could be possible. However growth in tight oil production from the Permian Basin was recently held back because of bottlenecks in the necessary distribution infrastructure. Against this backdrop, it would appear risky to rely on US tight oil production more than tripling from today's level by 2025 in order to offset the absence of new conventional crude oil projects.

A supply crunch, if it were to occur, would clearly have potential energy security implications for many importing economies and would be bad news for affordability. Some argue that it might contain some silver lining for sustainable energy transitions in the form of accelerated efficiency improvements and fuel switching. Demand destruction would certainly be a possible outcome, but it is not axiomatic that the supply side consequences would benefit low-carbon energy. In practice, as the 2010-14 period shows, a period of higher prices presents an opportunity to bring some higher cost oil down the cost curve. Moreover, while record high LNG prices during this period did contribute to improving efficiency and the competitiveness of renewables, they also resulted in an upswing in coal use.

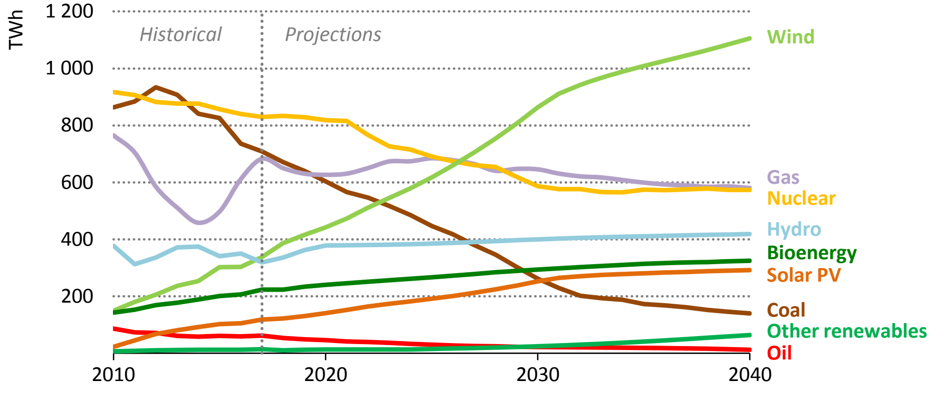
It is not just the upstream sector where there are potential imbalances on the horizon. A new regulation from the International Maritime Organization to limit the sulfur content in marine fuels to no more than 0.5%, due to come into force in 2020, is providing an illustration of how changes in product demand can send ripples through the refining industry and then through the wider energy economy. Compliance with this regulation is set to entail a large increase in the use of marine gasoil (similar to diesel) that could easily lead to a spike in diesel prices. Similar pressures could emerge in the future because of other shifts in oil product demand, for example if innovation and policy action were concentrated narrowly on passenger vehicles while other sectors of oil – such as trucks, aviation, shipping and petrochemicals – were left relatively untouched. In such a case, even if some naphtha was diverted to the petrochemicals sector, it would be difficult to avoid a glut of gasoline on the market once demand started to fall back. As a result, efforts to curb oil use in passenger vehicles would face much stronger headwinds because cheap gasoline would hinder efficiency improvements and electrification. Anticipating and mitigating these feedbacks from the supply side needs to be a larger element of the discussion about orderly energy transitions.

Seek out gains from co-operation

Regional co-operation and integration can ease many of the strains facing the energy sector today. There are many actual or potential examples of this, from Southeast Asia to the Southern Cone in Latin America. In this *WEO*, we include detailed analysis of what Europe's "Energy Union" could mean for the electricity and gas outlook across the continent in light of the new 2030 targets for renewables and energy efficiency, and the revisions to the EU's Emission Trading System.[7]

Our projections in the New Policies Scenario illustrate the scale of the transformation underway in Europe's power generation mix, much of which is driven by policy choices. The two largest sources of generation today, nuclear power and coal, both decline; the drop in coal-fired generation is particularly sharp. Wind power, bolstered by the rapid growth of offshore wind, is set to become the first source of electricity generation within a decade, and overall generation from renewables reaches 55% in 2030 (and 63% in 2040). The share of variable renewables increases to 40% by 2040.

Figure 1.20 ▷ Electricity generation by source in the European Union in the New Policies Scenario



A wholesale transformation of Europe's electricity generation pushes wind out in front, while gas and hydropower become the main sources of flexibility

Alongside other sources of flexibility, cross-border electricity transmission infrastructure among European countries remains a key asset to ensure reliability of the power system. National electricity systems are gradually integrating into regional power pools with increasing trade volumes and converging wholesale prices. In the New Policies Scenario, assumed implementation of the Energy Union framework includes timely and adequate expansion of physical infrastructure to avoid network congestion; new interconnection lines and better use of existing links between power pools; and deployment of demand-side response and storage to meet system flexibility requirements. A counterfactual case, in which there are more limited physical interconnections and a lack of proper investment

7. Several international initiatives, in which European Union countries feature strongly, also play strongly into our projections; 26 countries have committed to stop building new unabated coal capacity by 2020 and 14 of them have joined the "Power Past Coal Alliance" to close existing traditional coal-fired power plants over the coming decades.

signals for new flexible power plants, exhibits disruptions to electricity supply in some zones, higher curtailment of available renewable production, electricity price spikes and significant cross-border network congestion.

In the case of natural gas, a key consideration in the Energy Union is to promote security and diversity of supply, given the EU's high reliance on imported gas. As noted, overall gas consumption is projected to decline to 2040, but import needs remain substantial – not least because of a more pronounced fall in the EU's own gas production. A well-functioning internal gas market, alongside some strengthening of gas interconnections, can ensure that all parts of Europe have access to multiple sources of gas, allowing competition for markets among various sources of pipeline gas and LNG. As with the analysis of electricity, we also modelled a counterfactual case in which gas cannot move as easily across the internal market, due to a combination of infrastructure and regulatory constraints. In this case, some countries in central and southeastern Europe, in particular, would have less scope to procure gas on competitive terms and would also be more vulnerable in case of any interruptions to supply.

Overall, the analysis underlines the potential for an Energy Union to boost energy security, bring down underlying costs and lead to a more efficient allocation of resources. It also highlights the interactions across different aspects of European policy, and the importance of good policy co-ordination to avoid unintended consequences. For example, meeting the 32% renewables target in gross final consumption[8] leads in our projections to a 60% reduction in power sector CO_2 emissions by 2030 (compared with 2005, the reference year for the EU emissions trading system). To the extent that this is not counterbalanced by the newly created Market Stability Reserve of the Emissions Trading System, this could lead in turn to a lower CO_2 price signal that would be insufficient on its own to incentivise coal-to-gas switching.

Work to bring universal access to modern energy

The most extreme form of energy insecurity is faced by those that lack access to any form of modern energy. *WEO's Energy Access Outlook* (IEA, 2017) mapped a path to universal access to modern, sustainable energy for all by 2030, an ambition included as part of the UN Sustainable Development Goals. In this year's *WEO*, we update our assessment of progress towards this goal, with cautious optimism about some of the trends on electrification and even a glint of better news about access to clean cooking, an area that has lagged behind.

On electrification, the number of people without access to electricity fell below one billion for the first time in 2017,[9] helped by growing policy attention to the challenge. India has been the star performer: in April 2018, the government announced that all villages in the country had an electricity connection, a huge step towards universal household access. Other Asian countries have delivered similarly impressive results. In Bangladesh,

8. Calculated according to specific provisions of the European Directive 2009/28/EC.

9. Country level data for 2017 and projections to 2030 on energy access can be found at: iea.org/sdg.

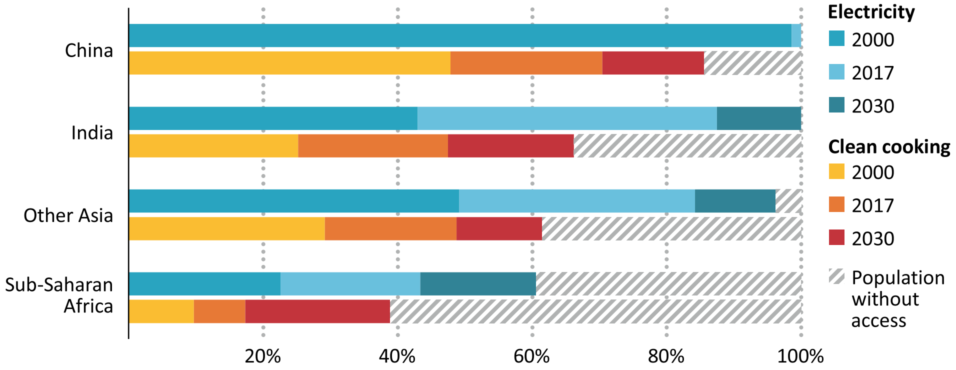
electricity now reaches 80% of the population, from 20% in 2000, while electricity reaches nearly 95% of the population in Indonesia. Progress typically slows as a country nears full electrification, as the last communities or households without access are those that are hardest to reach or comprise the poorest households, making the issue of affordability particularly acute. For comparison, it took China around two decades to reach the last 10% of population without electricity access. But trends across much of developing Asia are encouraging. Rapid expansion of the grid has underpinned much of the progress thus far, but there is also significant momentum in the mini-grid and off-grid sector due to the falling cost of decentralised renewable options.

Progress with electrification has been slower in sub-Saharan Africa. Even though the overall electrification rate in this region has almost doubled since 2000, rising by 20 percentage points to 43%, population growth has meant that the absolute number without access has still grown by some 80 million people over this period. More than 600 million people in sub-Saharan Africa remain without electricity today. And the progress in recent years has been very uneven: more than half of those gaining access since 2011 are concentrated in just four countries: Kenya, Ethiopia, Tanzania and Nigeria.

Some 2.7 billion people, half the population in developing countries, still rely primarily on biomass, coal and kerosene for their main household cooking needs, and this dependence that has serious health consequences. The estimated 2.6 million premature deaths from indoor pollution each year are greater than the number of deaths caused by HIV/AIDS and malaria combined. The more hopeful development is that, there has been a gradual decline in recent years in the global number of people without clean cooking access. As with electricity, progress across countries has been highly uneven, with China and India accounting for nearly three-quarters of those who have gained clean cooking access since 2011, while in sub-Saharan Africa the picture is still deteriorating and there are now over 270 million more people without access than there were in 2000.

The lack of access to modern fuels in the home has many damaging consequences, in particular for women. This is not only because they are more exposed to the negative health effects of polluting fuels, but also because the time and labour that is typically required to support households in the absence of modern fuels limits prospects for productive activity outside the home. Growth in economic productivity in advanced economies over the course of the 20th century was linked in large measure to women entering the workforce, which was enabled in turn by modern energy and cooking fuels and by appliances that depend on modern energy: energy development, economic growth and gender equality are very much intertwined. There are also important linkages between energy and other sustainable development goals, including access to clean water and sanitation (covered in detail in Chapter 2).

Figure 1.21 ▷ Access to electricity and clean cooking in the New Policies Scenario



The population without access to electricity in 2030 is increasingly concentrated in sub-Saharan Africa

Based on today's trends and access policies, the New Policies Scenario projects a continued decline in the global population without access to electricity to 650 million in 2030. The remaining population without access becomes increasingly concentrated in sub-Saharan Africa as developing countries in Asia reach a 99% electrification rate, with universal access achieved by the mid-2020s in India and Indonesia (Figure 1.21). The number of people without access to clean cooking falls, but only to 2.2 billion by 2030. So even though there are some encouraging signs, our projections suggest that the world is still well off-track to meet its 2030 objectives. As outlined in the Sustainable Development Scenario, there are strategies and technologies to close this gap and to ensure that every household has access to a reliable supply of electricity and a clean and environmentally sustainable cooking fuel (see Chapter 2). Progress in these areas is fully compatible with attaining climate goals and improving air quality.