Organization of the Petroleum Exporting Countries

2019

World Oil Outlook 2040

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2040

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Acknowledgements

Secretary General, Chairman of the Editorial Board
Mohammad Sanusi Barkindo

Director, Research Division
Ayed S. Al-Qahtani

Head, Energy Studies Department
Abderrezak Benyoucef

Main contributors
Jan Ban, Mohammad Alkazimi, Erfan Vafaie Fard, Julius Walker, Haris Aliefendic, Hans-Peter Messmer, Eleni Kaditi, Moufid Benmerabet, Hend Lutfi, Irene Etiobhio, Mustapha Sungungun, Joerg Spitzy

Other contributors
Adedapo Odulaja, Behrooz Baikalizadeh, Mohamed Mekerba, Hossein Hassani, Mohammad Zarie Zare, Afshin Javan, Imad Al-Khayyat, Hassan Balfakeih, Mohammad Ali Danesh, Hector Hurtado, Tona Ndamba, Yacine Sariahmed, Nadir Guerer, Aziz Yahyai, Pantelis Christodoulides, Douglas Linton, Viveca Hameder, Klaus Stoeger, Mohammad Sattar, Zairul Arifin, Mihni Mihnev, Martin Tallett, Alanna Bock-Butler, Pradeep Kumar

Editor
James Griffin

Editorial support
Anique-Marie Cabardos, Menhal Alamri, Angelika Hauser, Mathew Quinn

Layout and typesetting
Andrea Birnbach

Design & Production Coordinator
Carola Bayer

OPEC's Economic Commission Board **(as of October 2019)**
Achraf Benhassine, Ntika Mbiya Ricardo, José Antonio Cepeda Altamirano, Florencio Oyono Eneme Obono, André-Brice Boumbendje, Mohammad Taeb, Ali Nazar Faeq Al-Shatari, Mohammad Khuder Al-Shatti, Taher M.O. Najah, Mele Kyari, Esam Alkhalifa, Salem Hareb Al Mehairi, Ronny Romero

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Foreword

"The goal is to turn data into information, and information into insight." This pertinent line from Carly Fiorina, former Chief Executive Officer (CEO) of HP, aptly underscores the key linkages between data, research and analysis, and is fitting for the tremendous work undertaken by the research, editorial and design teams at the OPEC Secretariat in compiling this year's **World Oil Outlook (WOO)**. The efforts of all those involved, including the direct collaboration with OPEC Member Countries, should be widely lauded.

This year's publication also comes on the back of the July 2019 endorsement of the **'Charter of Cooperation'**, which provides a longer-term institutional framework for the cooperation between 24 OPEC and non-OPEC partners. It builds on the success of the **'Declaration of Cooperation'** that has done so much to bring more balance to the oil market, more optimism to the industry and help restore sustainable stability.

There is no doubt this historic cooperation between OPEC and non-OPEC producing nations will be vital in the years and decades ahead. Its permanence will not only be beneficial to the 24 countries of the **'Charter'**, but it is also in the interest of producers, consumers and the global economy.

This is apparent in the **WOO 2019**, which emphasizes the linkages between the short-, medium- and long-terms. None can be viewed in isolation; it is vital that all stakeholders have an understanding of our oil and energy futures given the great importance they have to our everyday lives. With much talk of an energy transition, we need to have a better appreciation of what this actually means and look to follow a realistic path that leads us to a **sustainable energy future for all**.

The **WOO 2019** analyzes developments in areas such as the global economy, energy demand, oil supply and demand, both in the upstream and downstream sectors, policy and technology developments, and environment and sustainable development concerns. This forms the basis for the WOO's projections, with breakdowns provided by region, sector and timeframe.

What is clear is that the world will need a great deal more energy in the decades to come. It is easy to appreciate why. The global population is expected to increase by almost **1.6 billion** from around **7.6 billion** in 2018 to a level of **9.2 billion** in 2040. The global economy in 2040 is expected to be double the size it was in 2018. And we should also not forget that energy poverty remains a scourge, with almost **one billion people** still **lacking access to electricity** and **three billion** with **no access to clean fuels** for cooking.

Total primary energy demand is expected to increase by **25%** between **2018 and 2040** with renewables leading the way in terms of growth, but **oil and gas** are still forecast to meet more than **50%** of the world's energy needs by the end of the forecast period. These trends can also be viewed in similar forecasts from other reputable organizations with long-term energy outlooks.

From the perspective of oil demand, given recent signs of stress in the global economy, and the outlook for global growth, at least in the short- and medium-term, the outlook for **global oil demand** has been lowered slightly this year to **110.6 mb/d** by **2040**, but demand expands in every five-year period to the end of the timeframe.

On the supply side, market stability, on the back of the voluntary production adjustments through the **'Declaration of Cooperation'** has generally been maintained over the past year. This is all the more striking and welcome in the face of the considerable risks and uncertainties to the global economy, including threats to global trade, rising debt levels, shaky economies in a number of key countries and Brexit-related worries.

Over the past year, **OPEC Member Countries** have continued to underscore their commitment to **market stability** and remain **dependable**, **reliable** sources of supply for their customers worldwide.

Non-OPEC supply prospects have been revised up sharply, as US tight oil, in particular, has again outperformed expectations. While there continues to be talk of more financial prudence in the tight oil patch, prospects for growth remain given that efficiency and technology gains have further increased. The expectations of a return to growth in some key mature producers, such as Norway, major new field start-ups in Brazil, Guyana and elsewhere, mean that other sources of non-OPEC supply will also likely have a meaningful medium-term impact.

In the long-term, however, it is OPEC that will be expected to meet the majority of oil demand requirements. Demand for OPEC liquids will rise to **44.4 mb/d** by **2040**.

For the downstream sector, the medium-term outlook envisages significant crude distillation capacity additions of around **8 mb/d** between **2019** and **2024**, with over **70%** of the additions in the Asia-Pacific and the Middle East. Moreover, this is close to **50%** of the total capacity additions required in the long-term to **2040**.

In terms of trade, the global crude oil and condensate trade is estimated to remain relatively static at around **38 mb/d** between **2018 and 2025**, before increasing thereafter to around **42 mb/d** by **2040**. While the US & Canada are expected to increase crude and condensate exports in the medium-term, in the long-term the major trade route remains the Middle East to the Asia-Pacific.

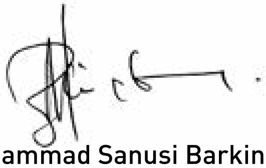
Given this outlook, there is clearly the requirement for major oil industry investment. In the period to **2040**, the WOO sees the need for around **$10.6 trillion of investment** across the upstream, midstream and downstream sectors. OPEC Member Countries are fully committed to making the necessary investments to keep consumers well supplied, and the issue of returning global investments is a core focus of the **'Declaration'** and **'Charter'**.

On the policy front, however, the industry is now concerned about policies that may detrimentally impact investments; for example, those related to climate-related financial disclosures. It is important to stress that **OPEC is fully engaged and supportive of the Paris Agreement**. As responsible citizens, we believe that **there is no Planet B**, and our Member Countries are making significant efforts to diversify their economies and make investments in renewables and energy efficiency measures.

We also believe that the **oil industry** must be **part of the solution** to the **climate change challenge**. The science tells us that we need to reduce emissions; it does not tell us that we need choose one energy over another. Thus, we need to continually look to develop, evolve and adopt cleaner energy technologies across the board; ones that enable us to meet expected future energy demand, in a sustainable and ever more efficient manner and where no-one is left behind.

With OPEC's landmark **60th Anniversary** taking place in 2020, the **WOO 2019** helps establish a platform for discussion in the coming year by laying out possible future oil and energy paths. This year's WOO once again highlights the industry's challenges, as well as its opportunities, and underscores the vital requirement for a serious and thorough evaluation of all the factors, drivers and risks to our common long-term energy future.

We look forward to further broadening our cooperation and dialogues with all industry stakeholders. It is a never-ending process, but one OPEC is fully committed to, in the interests of **producers**, **consumers**, the **global economy**, and **the world as a whole**.



Mohammad Sanusi Barkindo
Secretary General

Executive Summary

The World Oil Outlook (WOO) presents the OPEC Secretariat's medium- to long-term analysis and projections for the global economy, oil and energy demand, liquids supply and oil refining, as well as related matters, such as policies and technology. This includes analysis of the energy industry's various linkages and its shifting dynamics. The detailed review in this Outlook includes breakdowns by region, sector and timeframe and is consistent with the July edition of OPEC's Monthly Oil Market Report (MOMR).

Non-OECD countries to drive global population above 9 billion people by 2040

The global population is expected to increase by around 1.6 billion, from an estimated 7.6 billion in 2018 to 9.2 billion in 2040. The majority of this growth is projected to come from developing countries, particularly from the Middle East & Africa. The population of the Organisation for Economic Co-operation and Development (OECD) countries is forecast to increase by 78 million, mostly in OECD Americas. The overall population growth is set to decelerate throughout the forecast period. While the global working-age population (aged 15–64) is projected to grow by just under 900 million over the long-term, its share of the global population is expected to remain relatively constant, dropping slightly from 65% in 2018 to 64% in 2040. Moreover, the global urbanization rate will increase from 56% in 2018 to 64% in 2040.

Global GDP growth between 2018 and 2040 is projected to average 3.3% p.a., driven primarily by developing countries

Global Gross Domestic Product (GDP) growth will be mainly driven by developing countries, largely due to improving labour productivity. The GDP of non-OECD countries is expected to grow by 4.5% per annum (p.a.) on average in the medium-term, while projected economic growth for the OECD averages 1.8% p.a. In the long-term, this becomes 4.2% and 1.7%, respectively. Global GDP between 2018 and 2040 is expected to increase at a rate of 3.3% on average, with the pace of GDP growth slowing during the forecast period. The projected figures are lower compared to the WOO 2018 due to a drop in expected economic growth in the near- and medium-term, as well as the longer-term trend of emerging economies such as China and India beginning to reach maturity in the latter years of the forecast period.

Continued high GDP growth in Asian countries will shift the centre of economic gravity further east

Based on 2011 purchasing power parity (2011 PPP), global GDP is projected to rise from $117.4 trillion in 2018 to more than $237 trillion in 2040. Together, China and India are forecast to account for 40% of global GDP in 2040, whereas the OECD is expected to account for only 32%, a striking reversal of the current distribution pattern. Despite large regional shifts in terms of the global economic picture, average income per capita is not envisaged to witness significant changes. OECD Americas is anticipated to remain the region with the highest GDP per capita over the entire forecast period, followed by OECD Asia Oceania and OECD Europe. The Middle East & Africa region is likely to have the lowest GDP per capita, and it is expected to be the only region where the average income remains less than $10,000 per capita in 2040.

Energy policies continue to focus on emission reductions despite some divergent signals from policymakers

The Outlook takes into account existing energy policies, whilst recognizing their transitory nature and potential evolution over time. Recently enacted energy policies focus primarily on measures aimed at emission reductions. The substitution of coal by natural gas and renewables in the power generation sector will continue to be at the centre of policy discussions. Several policies are aimed at limiting oil use, especially in the transportation sector. Examples include tightening standards for Corporate Average Fuel Economy (CAFE), carbon dioxide (CO_2) emission performance standards for road transportation vehicles, emissions and efficiency regulations in the maritime and aviation sectors, fuel substitution in the rail sector and taxation policies in many countries.

Technological progress will provide additional options for the global energy system

The rapid evolution of electric mobility technology will lead to a substantial increase in its usage, but internal combustion engines (ICEs) are expected to see further efficiency improvements and remain the main powertrain for the majority of passenger and commercial vehicles during the forecast period. Substantial innovation is expected in the aviation industry, including efficiency leaps for aircraft engines. The increased use of liquefied natural gas (LNG) in maritime transportation will allow for substantially higher fuel efficiency and cleaner emissions. Remarkable progress has been achieved in renewable power generation technology, but photovoltaics (PV) and wind power are likely to continue to suffer low capacity factors. On the supply side, the tight oil boom is making heavy use of rapidly advancing information technology (IT). Moreover, Industry 4.0, combined with highly innovative concepts in data processing and data interpretation via artificial intelligence (AI), will significantly enhance oil industry efficiencies.

Global primary energy demand is forecast to increase by 72 mboe/d in the period to 2040

Global demand for energy is forecast to increase from nearly 286 million barrels of oil equivalent a day (mboe/d) in 2018 to more than 357 mboe/d in 2040, with average growth of about 1% p.a. In this period, energy demand in non-OECD countries is expected to increase by almost 75 mboe/d, while demand in the OECD is estimated to drop by around 3 mboe/d. These regional demand growth differences relate to variances in demographics, efficiency levels, climate change policies and other factors that shape the energy mix in various countries and regions. Energy demand growth in India and China alone is expected to account for almost 50% of the energy demand growth in the non-OECD region.

Total primary energy demand by region, 2018–2040

	Levels *mboe/d*				Growth *%p.a.*	Growth *mboe/d*	Share of global energy demand *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	56.0	56.7	56.6	55.3	–0.1	–0.7	19.6	19.3	17.2	15.5
OECD Europe	36.4	36.4	35.7	34.3	–0.3	–2.1	12.7	12.4	10.9	9.6
OECD Asia Oceania	18.2	18.1	18.1	17.9	–0.1	–0.4	6.4	6.2	5.5	5.0
OECD	**110.6**	**111.2**	**110.5**	**107.5**	**–0.1**	**–3.1**	**38.7**	**37.9**	**33.6**	**30.1**
China	63.6	66.1	75.5	81.8	1.1	18.1	22.3	22.5	22.9	22.9
India	18.8	20.2	28.7	37.5	3.2	18.8	6.6	6.9	8.7	10.5
OPEC	20.0	20.4	25.5	29.8	1.8	9.9	7.0	6.9	7.8	8.3
Other non-OECD	49.9	52.0	63.8	74.8	1.9	24.9	17.5	17.7	19.4	20.9
Russia	14.8	15.0	15.5	15.8	0.3	1.0	5.2	5.1	4.7	4.4
Other Eurasia	8.2	8.5	9.5	10.3	1.1	2.1	2.9	2.9	2.9	2.9
Non-OECD	**175.3**	**182.2**	**218.4**	**250.1**	**1.6**	**74.8**	**61.3**	**62.1**	**66.4**	**69.9**
World	**285.9**	**293.4**	**328.9**	**357.5**	**1.0**	**71.7**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Oil will retain the highest share in the energy mix in the period to 2040

In 2018, oil accounted for more than 31% of global energy demand, ahead of coal (27%) and gas (23%). Oil is forecast to remain the largest contributor to the energy mix by 2040, accounting for more than 28%. Between 2018 and 2040, global gas demand is anticipated to rise from 65.5 mboe/d to just above 90 mboe/d. Consequently, natural gas is expected to become the second-largest energy source, reaching a share of 25% in the total primary energy mix in 2040. Demand increases for gas will come primarily from Asia, led by China and India, as well as OPEC Member Countries.

Coal will remain the largest source of global CO_2 emissions despite falling demand after 2030

Despite a declining coal demand trend after 2030, coal is still expected to be the largest source of CO_2 emissions. It is estimated to account for almost 40%, or 14.9 billion tonnes (bt), of total energy-related emissions in 2040. Energy-related emissions will continue to increase to more than 38 bt by 2040, which is more than 4 bt higher than the observed level in 2018. However, the pace of growth is forecast to decelerate significantly over his period.

'Other renewables' will be the fastest growing source of energy in relative terms, while demand for natural gas rises the most in absolute terms

'Other renewables', which includes solar, wind and geothermal power, is expected to be the fastest growing source of energy, expanding on average by 6.9%. Demand for 'other renewables' is seen rising by nearly 18 mboe/d between 2018 and 2040. Nuclear and biomass are expected to see demand growth of approximately 7 mboe/d each, while additional demand for hydropower will be around 3 mboe/d.

Medium-term global oil demand is expected to reach 104.8 mb/d by 2024

Global oil demand is expected to continue growing at relatively healthy rates in the medium-term reaching 104.8 million barrels a day (mb/d) by 2024. This represents an increase of 6.1 mb/d above the 2018 level. The average growth will be about 1 mb/d over the medium-term period, declining from a projected 1.1 mb/d in 2019 to 0.9 mb/d in 2024. Incremental demand is forecast to come primarily from non-OECD countries (+6.6 mb/d). Annual average oil demand growth from non-OECD countries is projected to remain within a relatively narrow range of 1–1.2 mb/d over this period. Oil demand in the OECD is projected to gradually shift from slight growth during the initial years of the medium-term to declining demand after 2020, partially offsetting growth in the non-OECD region.

Impact of IMO regulations is forecast to be less severe than previously expected

The new International Maritime Organization (IMO) regulation limiting sulphur content in marine fuels (0.5% maximum on a weight basis), effective from 1 January 2020, is expected to be a disruptive event, not only for the shipping sector, but also for the global refining system and related refined product supply. However, evolving market conditions and projections in terms of oil demand, liquids supply and oil refining, as well as developments within the shipping industry, have led to slight adjustments to previous IMO-related projections. Recent assessments indicate that the global refining system will have sufficient flexibility to address the changes in the maritime sector's fuel mix. Nevertheless, the impact on high sulphur fuel oil (HSFO) prices, the gasoil/HSFO spread, as well as HSFO-rich crude oil prices, will still be significant, although less severe than previously expected.

Long-term oil demand to rise to 110.6 mb/d in 2040

Long-term global oil demand is expected to increase by about 12 mb/d, rising from 98.7 mb/d in 2018 to 110.6 mb/d in 2040. From a regional perspective, there is a contrast between declining OECD demand and expanding demand in the non-OECD. Driven by an expanding middle class, high population growth rates and stronger economic growth potential, non-OECD oil demand is expected to increase by 21.4 mb/d between 2018 and 2040. India is projected to be the country with the fastest oil demand growth and the largest additional demand. OECD demand is expected to plateau at around 48 mb/d for the next few years, before declining to around 38 mb/d by 2040. At the global level, growth is forecast to slow from a level of 1.4 mb/d in 2018 to around 0.5 mb/d towards the end of the next decade.

Long-term oil demand by region, 2018–2040

mb/d

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	25.5	25.9	25.6	24.3	22.8	21.1	–4.5
OECD Europe	14.3	14.3	13.9	13.1	12.2	11.3	–3.0
OECD Asia Oceania	8.0	7.9	7.5	7.0	6.4	5.9	–2.1
OECD	**47.8**	**48.1**	**46.9**	**44.4**	**41.5**	**38.3**	**–9.6**
Latin America	5.9	6.0	6.4	6.8	7.0	7.3	1.4
Middle East & Africa	4.2	4.4	5.0	5.6	6.2	6.8	2.6
India	4.7	5.1	6.2	7.4	8.8	10.2	5.4
China	12.7	13.4	14.7	15.7	16.5	17.1	4.4
Other Asia	9.0	9.3	10.3	11.2	12.1	12.8	3.8
OPEC	8.8	9.0	10.0	10.9	11.5	11.8	3.0
Russia	3.6	3.7	3.9	3.9	3.9	3.8	0.3
Other Eurasia	2.0	2.1	2.3	2.4	2.4	2.5	0.5
Non-OECD	**50.9**	**52.9**	**58.6**	**63.9**	**68.5**	**72.3**	**21.4**
World	**98.7**	**101.0**	**105.6**	**108.3**	**109.9**	**110.6**	**11.9**

Source: OPEC.

Petrochemical sector will be the leading long-term source of incremental demand

The largest incremental demand growth (+4.1 mb/d) is expected to come from the petrochemical sector, although road transportation will remain the largest demand sector in terms of absolute volumes. For road transportation, despite an overall increase of close to 3 mb/d, its overall share is forecast to drop by 2%. Significant demand growth is also expected in the aviation sector, which is projected to be the fastest growing sector, with oil demand expanding on average by 1.5% p.a. Some growth is also projected in the marine sector, as well as in rail and domestic waterways.

Oil demand in road transportation is set to plateau in the 2030-2040 forecast period

Road transportation is estimated to account for 43% of total demand by 2040. However, this sector is forecast to witness a strong decoupling between oil demand, transport services and the number of vehicles on the road. This will primarily be a result of efficiency improvements driven by technological developments, a tightening of energy policies, and the increasing penetration of alternative fuelled vehicles (electric vehicles (EVs), natural gas and to some extent hydrogen). The total vehicle fleet is estimated to grow by more than 1 billion between 2018 and 2040, reaching 2.4 billion. The large majority of this increase (953 million) comes from non-OECD countries. EVs (including battery electric vehicles (BEVs) and plug-in hybrids) are estimated to reach around 320 million units in 2040, equivalent to a share of 13% of the global fleet. The majority of EVs are expected to be passenger cars (305 million). In relative terms, this represents 15% of all passenger cars in 2040.

Strong medium-term non-OPEC supply growth driven mainly by US tight oil

Non-OPEC total liquids supply is projected to grow by 9.9 mb/d between 2018 and 2024, reaching 72.2 mb/d. This is mainly driven by the return of modest increases in upstream investment and healthy demand. US tight oil is forecast to continue to expand at a strong pace, contributing just over 60% of this medium-term non-OPEC supply growth. In addition, a cyclical recovery elsewhere sees meaningful contributions from Brazil, Norway and Canada, in addition to expected barrels from newcomer Guyana.

Long-term non-OPEC supply prospects are more modest

US tight oil supply will expand sharply by 6.7 mb/d in the medium-term, before slowing thereafter, showing only modest increases. US tight oil supply is expected to peak at 17.4 mb/d in 2029. Tight oil production elsewhere has potential, but it is estimated to remain at relatively modest volumes. US total liquids are forecast to peak at 22.8 mb/d in the mid-2020s. Total non-OPEC supply is forecast to reach 72.6 mb/d in 2026, but gradually decline thereafter to a level of 66.4 mb/d by 2040. Beyond the mid-2020s, only two non-OPEC countries are expected to show meaningful output growth, namely Brazil and Kazakhstan. Virtually all other non-OPEC producers are anticipated to see a decline in long-term liquids production.

Long-term global liquids supply outlook

mb/d

	2018	2019	2020	2025	2030	2035	2040	Change 2018–2040
US	16.7	18.6	20.3	22.8	22.2	20.5	18.5	1.8
of which: tight oil	*10.2*	*12.0*	*13.8*	*17.0*	*17.3*	*16.3*	*14.5*	*4.4*
OECD	**28.2**	**30.0**	**31.9**	**35.3**	**34.1**	**32.1**	**29.7**	**1.4**
Latin America	5.2	5.4	5.8	7.2	7.6	7.7	7.5	2.3
Middle East	3.2	3.2	3.2	3.6	4.0	4.1	4.1	0.9
Africa	1.5	1.6	1.6	1.7	1.5	1.4	1.3	–0.2
China	4.0	4.1	4.1	4.0	3.9	3.7	3.6	–0.4
Non–OECD, excl. OPEC	**31.9**	**32.2**	**32.7**	**34.6**	**34.8**	**34.4**	**33.8**	**1.9**
Processing gains	**2.3**	**2.3**	**2.4**	**2.5**	**2.7**	**2.8**	**3.0**	**0.7**
Non-OPEC	**62.4**	**64.4**	**66.9**	**72.4**	**71.5**	**69.3**	**66.4**	**4.0**
Crude	*44.0*	*45.5*	*47.2*	*50.6*	*48.0*	*44.7*	*41.0*	*–3.0*
NGLs	*9.9*	*10.4*	*10.9*	*11.9*	*12.8*	*13.2*	*13.3*	*3.4*
Global biofuels	*2.5*	*2.5*	*2.6*	*2.9*	*3.3*	*3.5*	*3.8*	*1.3*
Other liquids	*3.7*	*3.7*	*3.8*	*4.4*	*4.8*	*5.1*	*5.3*	*1.6*
Total OPEC liquids	**36.6**	**35.0**	**34.4**	**33.4**	**37.0**	**40.8**	**44.4**	**7.8**
Stock change	**0.3**	**–0.5**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	
World	**99.0**	**99.4**	**101.3**	**105.8**	**108.5**	**110.2**	**110.8**	**11.8**

Source: OPEC.

Medium-term distillation capacity additions are estimated at almost 8 mb/d, mostly in the Middle East and Asia-Pacific

Almost 70% of distillation capacity additions are projected to occur in the first three years of the forecast period, with an average annual additions estimated at around 1.8 mb/d in the period 2019–2021. However, the rate of capacity additions is expected to level off in the years thereafter, dropping to only 0.4 mb/d. The majority of expansions are seen in the Asia-Pacific and the Middle East (5.7 mb/d or more than 70% of global additions) driven predominantly by oil demand growth, but also efforts to increase refined product exports, mostly in the Middle East. Significant additions (0.8 mb/d) are also expected in Africa with one large project in Nigeria accounting for the largest share.

Medium-term outlook points at significant excess refining capacity

Potential incremental medium-term crude throughput is estimated at a surplus of almost 4 mb/d relative to the incremental refined product demand by 2024. While the gap is still moderate in 2019, it widens gradually from 2020 onwards, illustrating a rising surplus of distillation capacity at the global level. The largest surplus is expected for the Middle East, US & Canada, Europe and China. This may lead to more downstream competition post-2020 and potentially refinery closures. Refinery closures amounting to 2.1 mb/d are expected in the medium-term due to lower demand in several regions, as well as additions of highly competitive new refinery units. Consequently, the majority of closures are expected for the US & Canada and Europe, with limited closures in other regions. The only region with a projected medium-term deficit is Latin America.

Long-term distillation capacity additions projected at around 16.5 mb/d

Total crude distillation capacity additions are projected to reach 16.5 mb/d by 2040, mostly in developing countries (Asia-Pacific, Middle East, Africa and Latin America). Refinery additions required through 2040 are heavily 'front-loaded' with major implications for a slowdown in projects and investment after the medium-term period. Projections for secondary capacity additions indicate the need to add some 8.8 mb/d of conversion units, 18 mb/d for desulphurization and 5 mb/d of octane units in the period to 2040. The majority of these additions are expected to materialize before 2030, in line with demand growth and the implementation of stricter product specifications.

Required long-term investments are estimated at around $10.6 trillion

Projected global upstream investments required to sustain production according to this Outlook are estimated to be $8.1 trillion ($2019) over the period to 2019–2040. Another $1 trillion is seen as required in the midstream sector. Global downstream investments are estimated at around or slightly above $1.4 trillion. Combined, this indicates that nearly $10.6 trillion of investment will be needed globally over the long-term to sustain projected oil supply requirements.

After a medium-term dip, global crude exports are expected to grow in the long-term, driven by additional Middle East exports to the Asia-Pacific

In the medium-term, overall crude trade is seen relatively stable near 38 mb/d. In terms of regional exports, the biggest change is the significant increase in crude exports from the US & Canada, which are expected to climb to a level just under 5 mb/d in 2025, up by around 3 mb/d from 2018. In the long-term, the outlook changes fundamentally, with exports rising by 4.5 mb/d from 2025–2040 to reach almost 42 mb/d. Export flows from the US & Canada are projected to drop to around 3 mb/d by 2040. Total Middle East exports are set to increase by around 7 mb/d between 2025 and 2040 to reach levels of around 23 mb/d.

Energy-exporting developing countries disproportionately affected by the impact of implementation measures taken in response to climate change

For energy-exporting developing countries the imperative to re-orient their economies is due to a stringent regulatory framework on climate change action and the associated adverse impacts of response measures. Achieving diversification is considered vital for their long-term socio-economic sustainability. A diversified portfolio could help such economies to increase their resilience, while taking into consideration the importance of local and regional contexts in policymaking. Energy-exporting developing countries could use their comparative advantage and diversify even within the energy sector. Policymakers could also pursue actions and measures that extend existing capabilities into industries of higher value added and complexity. Governments could play a vital role in the economic and structural reforms needed to achieve diversification. International cooperation could contribute to the identification and sharing of not only best practices but also ways in which the international community could facilitate increased trade, foreign investment, and support in the form of technology transfer and finance.

Introduction

The World Oil Outlook (WOO), now in its 13th edition, aims to highlight possible future developments in the oil and energy sectors, as well as identify the main challenges and opportunities for the sector in the years to come. It presents an in-depth view of the OPEC Secretariat's medium- to long-term projections and analysis for the global oil and energy industries over the first eight chapters of the publication.

This includes analysis of the energy industry's various linkages and its shifting dynamics, providing insights into population and demographic trends, the global economy, policy and technology developments, energy and oil demand, oil supply and refining, environmental concerns and sustainable development. The detailed analysis includes breakdowns by region, sector and timeframe.

New to the WOO this year is a section focused on economic diversification in energy-exporting developing countries with a special emphasis on OPEC Member Countries. This can be found in Chapter 9: Energy and sustainable development, alongside analysis regarding the potential impacts of a below 2°C-compatible scenario.

On a technical note, it should be mentioned that this publication reflects the current 2019 membership status of OPEC, as well as other international bodies. Since the WOO 2018 was published last year, Lithuania has acceded to full OECD membership and is now part of the OECD Europe regional group, while Qatar has withdrawn its membership in OPEC. Therefore, throughout the publication, when OPEC is referred to, it only includes the current 14 Member Countries.

It has once again been a challenging year for energy markets since the publication of the WOO 2018. Signs of stress have appeared in the global economy, and the outlook for global growth, at least in the short- and medium-term, has been revised down repeatedly over the past year. As a result, this year's WOO has lowered its outlook numbers for global oil demand growth, to 104.8 mb/d by 2024, and 110.6 mb/d by 2040.

At the same time, non-OPEC supply prospects have been revised up, as US tight oil, in particular, has again outperformed expectations. Prospects for growth are undimmed, given that efficiency and technology gains, as well as investments, have further increased. Furthermore, supermajors, including ExxonMobil and Chevron, are moving deeper into this space, reducing some of the fears regarding investment, as these companies can re-invest cash flow from other projects, and offset lower prices through vertical integration.

The prospects of a return to growth in some key producers, such as Norway, as well as projected start-ups in various major new fields in Brazil, Guyana and elsewhere, mean that other sources of non-OPEC supply will again become increasingly important. In the long-term to 2040, OPEC Member Countries will prove to be significant contributors to meeting oil demand requirements, accounting for 40% of global supply.

Oil prices, after topping $80/b around the time of publishing the WOO 2018, fell sharply toward the end of 2018, bottoming out at around $50/b. The market then saw a more stable environment over the first half of 2019, largely due to the re-affirmed commitment to sustainable market stability by OPEC and its cooperating non-OPEC partners in the historic 'Declaration of Cooperation'.

Market stability is all the more desirable in the face of the considerable risks and uncertainties to the global economy. Protectionism and populism are on the rise, hurting global trade, the lifeblood of the world's prosperity. Fragile economies in a number of key countries remain a concern.

In 2018, sales of new passenger cars dropped for the first time since 2009, when the global economy was just recovering from the global financial crisis. Meanwhile, EVs (including BEVs and plug-in hybrids) are rarely out of the news, with sales passing the two million mark for the first time in 2018 – still a very small share of sales and the global fleet, but nonetheless they are gaining momentum.

More and more cities are making headlines with diesel bans in inner-city areas, even while boosting public transport infrastructure. Sweden recently announced a total ban on new ICE car registrations by 2030, while Estonia's capital Tallinn and the European country of Luxembourg have plans to make all public transport free. It is also interesting to note that EV pioneer, the city of Oslo, has been forced to stop providing free recharging for EVs due to a lack of infrastructure and strong demand.

On the renewables front, there is evidently a significant degree of optimism regarding the role they (and smart technology) can play in the coming energy transition, despite signs that the rate of investment growth in renewables could, at least temporarily, slow.

It is also important to note that there is a growing trend for companies, including energy and oil companies, to factor climate change concerns into their long-term planning and strategy. Moreover, the rise of public awareness on climate change issues is also becoming more apparent. This is taking place despite some divergent signals from policymakers, resulting in some countries looking to move away from multilateralism.

All of these developments and concerns make the requirement for a serious and thorough evaluation of all the factors, drivers and risks to our common long-term energy future ever more important. OPEC firmly believes in the need to achieve equitable economic development in a sustainable way. The WOO 2019 is the latest endeavour by the OPEC Secretariat to help map out a possible pathway for oil and energy in the future.

Key assumptions

Key takeaways

- The global population is expected to increase by almost 1.6 billion people, from around 7.6 billion in 2018 to a level of 9.2 billion in 2040.
- The majority of this growth is forecast in developing countries (more than 90%), particularly in the Middle East & Africa (41%), whereas Other Asia, India and OPEC are expected to contribute around 15% each.
- The global urbanization rate is forecast to increase from 56% in 2018 to 64% in 2040.
- The working-age population (age 15–64) is estimated to grow by almost 900 million over the long-term forecast period. The relative share of this global working age population in the world's total is expected to remain relatively steady, dropping slightly from 65% in 2018 to 64% in 2040.
- A slow recovery in GDP growth over the medium-term is expected to see global economic growth rise back to 3.4% by 2024, led by non-OECD countries, mainly India and China.
- Global GDP growth between 2018 and 2040 is anticipated to increase at an average rate of 3.3%, slightly lower than the WOO 2018's assumption. Increasing labour productivity will be the key driver behind much of the growth in large non-OECD economies, such as China and Russia.
- This Outlook takes into account currently-enacted energy policies whilst also recognizing the transitory nature of policies.
- Road transportation is challenged with stringent regulatory emissions limits. India and China are setting rigorous fuel emission standards. Contrarily, the US is relaxing its Corporate Average Fuel Economy (CAFE) standards. Other sectors are also generally seeing policies focused on reducing emissions and on increasing energy efficiency.
- This Outlook assumes an evolutionary development of existing technology, while also paying attention to the development of new technology for the global energy business.
- In road transportation, internal combustion engines (ICEs) will remain the major powertrain technology for the foreseeable future, although various powertrain electrification technologies are gaining in importance.
- Conventional power generation sources remain dominant in the energy supply mix. Renewed urgency to secure supply from a diverse range of energy sources is driving the growth in the rising share of renewables in power generation.

This Chapter lays out the key assumptions underlying the projections that make up the WOO Reference Case presented in Chapters 2 through 9. It covers the changes expected to take place in population and demographic trends, economic growth and energy-related policy trends. Furthermore, it discusses potential technology developments that could have repercussions for energy supply and demand.

1.1 Population and demographics

The world is experiencing slowing population growth, and according to a recent United Nations (UN) report, the world's population could stop growing around the end of the century. Population trends are not homogeneous across regions, and various countries are at different stages of a demographic transition. The Organisation for Economic Co-operation and Development (OECD) region and some developing countries are already seeing ageing populations in line with longer life expectancy and lower birth rates, but in many other regions, the transition is only expected to begin sometime in the near future. The major demographic elements, consisting of population growth rates, working population, urbanization and immigration, have been analyzed in detail for this publication.

Based on projections extracted from the UN Population Division's 2019 Revision of World Population Prospects, the global population is expected to rise from an estimated 7.6 billion people in 2018 to 9.2 billion in 2040, an increase of 1.6 billion (Table 1.1).

The majority of this growth is seen coming from developing countries (more than 90%), particularly from the Middle East & Africa (41% excluding OPEC countries), while populations in Other Asia, India and OPEC countries are each expected to grow by approximately 15% by 2040. Notably, according to the UN's 2019 Prospects using the same regional groupings as for the Sustainable

Table 1.1
Population by region

millions

	Levels						Growth
	2018	2020	2025	2030	2035	2040	2018–2040
OECD Americas	513	520	538	554	570	583	71
OECD Europe	577	581	585	587	589	589	13
OECD Asia Oceania	216	217	217	215	213	210	–6
OECD	**1,306**	**1,317**	**1,339**	**1,357**	**1,372**	**1,383**	**78**
Latin America	448	457	474	489	502	512	64
Middle East & Africa	1,068	1,121	1,261	1,408	1,562	1,721	653
India	1,353	1,380	1,445	1,504	1,554	1,593	240
China	1,428	1,439	1,458	1,464	1,461	1,449	21
Other Asia	1,189	1,218	1,288	1,351	1,407	1,455	266
OPEC	498	518	573	628	684	742	244
Russia	146	146	145	143	141	139	–7
Other Eurasia	197	198	201	203	204	205	8
Non-OECD	**6,326**	**6,477**	**6,846**	**7,192**	**7,515**	**7,816**	**1,490**
World	**7,631**	**7,795**	**8,184**	**8,548**	**8,888**	**9,199**	**1,568**

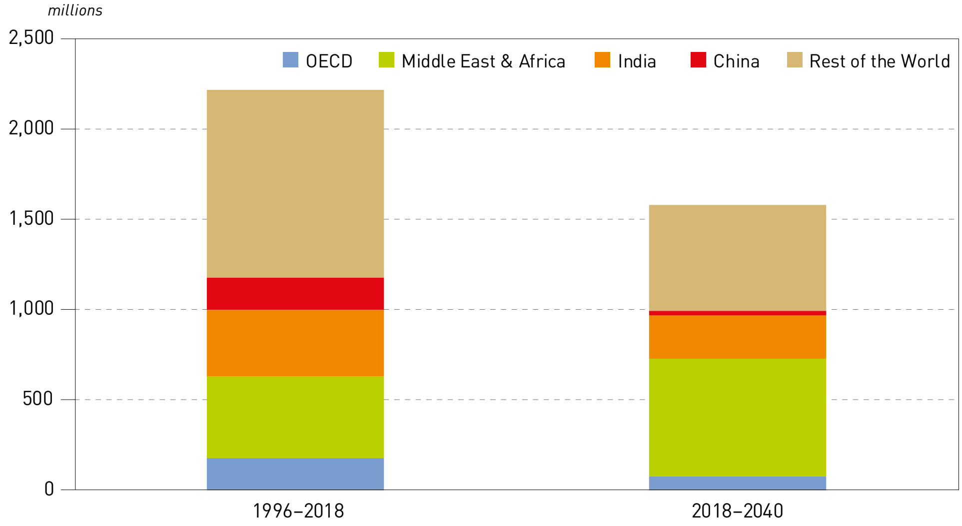
Source: United Nations (UN), OPEC.

Development Goals (SDG), more than 90% of the growth will come from Africa and Asia, with the largest share from Sub-Saharan Africa, Northern Africa and Western Asia.

In the OECD region, the population is expected to rise by 76 million people in the period to 2040, mostly in OECD Americas. This is 22 million fewer compared to the UN's revision from 2017 and is also a significant change in growth pattern from the previous 22-year period, when the population rose by 175 million people. Eurasia's population is projected to marginally increase to 344 million people. Russia is expected to see its population contract by 5 million, while Other Eurasia is anticipated to see an increase of 6 million by 2040.

The population growth dynamics are shown in Figure 1.1. China's population is forecast to grow by 21 million over the next 22 years, whereas the observed growth for the past 22 years was 176 million. This is the most pronounced slowdown in population growth among emerging economies. India, which added 370 million people to the global population over the past 22 years, is expected to see its growth contribution shrink to 240 million for the period from 2018–2040.

Figure 1.1
World population growth, 1996–2018 *versus* 2018–2040

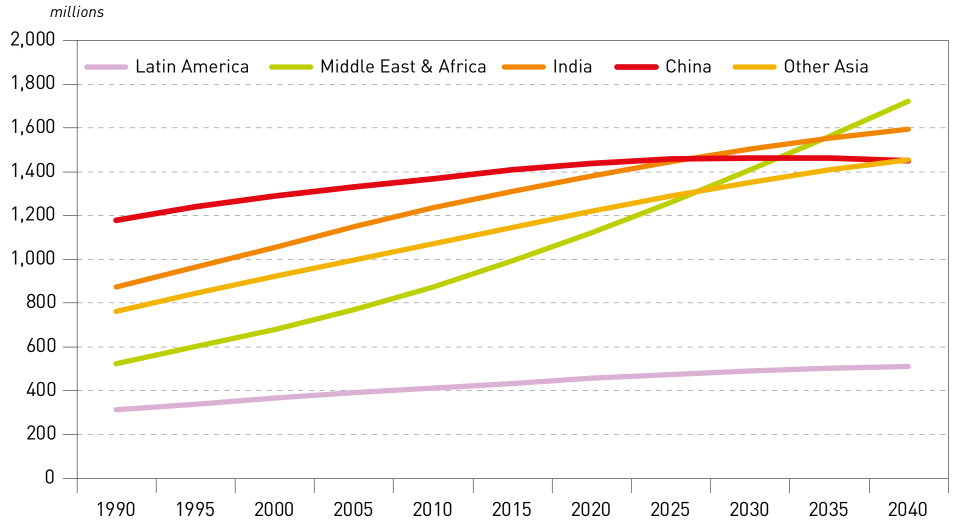


Source: United Nations, OPEC.

The Middle East & Africa (excluding OPEC) region is currently witnessing rapid population growth, and this trend is expected to continue until the end of the projection period. This is, in fact, the only region where population growth is expected to accelerate, adding 653 million people in the period between 2018 and 2040, compared to the 452 million added from 1996–2018.

Looking at historical and projected trends spanning from 1990 to 2040 (Figure 1.2), India's population is forecast to surpass that of China in 2024. The combined populations of the Middle East & Africa are expected to overtake India only towards the middle of the 2030s. The same occurrence can be observed in the share of working-age population. In absolute terms, the Middle East & Africa (excluding OPEC) will see the fastest population growth, the largest population, as well as the largest working-age population (Table 1.2) in the long-term.

Figure 1.2
Population trends in selected regions and countries, 1990–2040



Source: UN, OPEC.

The global working-age population, that is people aged 15–64, is estimated to grow by almost 900 million people over the long-term. The relative share of this global working age population to the world total population is estimated to remain relatively steady, dropping slightly from 65% in 2018 to 64% in 2040. However, there are variations in this trend at the regional and country level. Notably, China's working-age population is expected to decline by 125 million people, consistent with China's observed growth dynamics.

Table 1.2
Working population (age 15–64) by region *millions*

	2018	2020	2025	2030	2035	2040	2018–2040
OECD Americas	340	344	352	358	366	373	33
OECD Europe	372	372	368	362	355	348	–24
OECD Asia Oceania	137	136	133	130	126	120	–17
OECD	**850**	**852**	**854**	**850**	**847**	**842**	**–8**
Latin America	303	309	321	329	335	338	35
Middle East & Africa	610	645	740	844	954	1,069	458
India	899	925	983	1,029	1,068	1,098	198
China	1,007	1,002	996	974	928	882	–125
Other Asia	780	801	849	891	926	955	175
OPEC	304	317	352	391	429	467	163
Russia	97	95	91	89	89	87	–10
Other Eurasia	131	130	130	131	132	132	1
Non-OECD	**4,133**	**4,225**	**4,462**	**4,678**	**4,862**	**5,028**	**895**
World	**4,983**	**5,078**	**5,315**	**5,528**	**5,709**	**5,870**	**887**

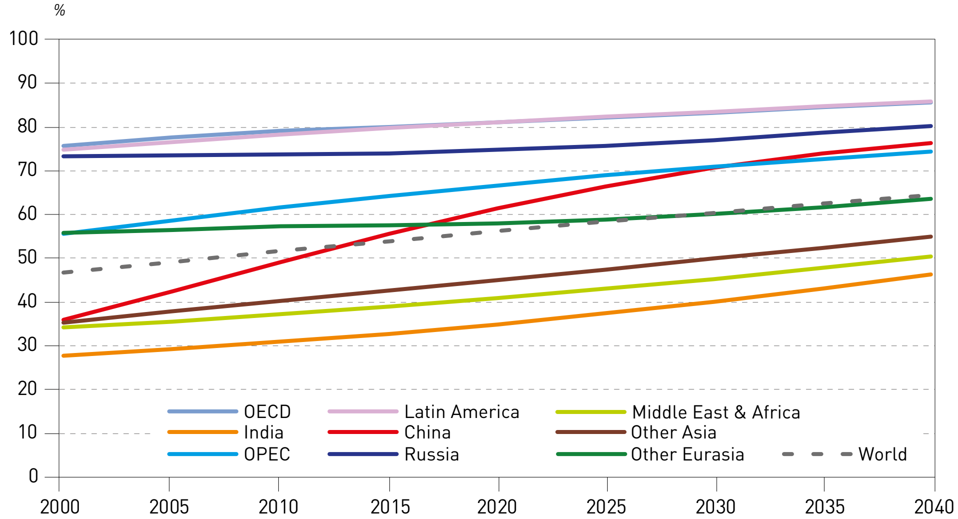
Source: World Bank, OPEC.

The exceptions to the trend of a steady-to-shrinking working-age population are the Middle East & Africa and India. In the Middle East & Africa, around 458 million additional working-age people are expected in 2040 *versus* current levels, and India is forecast to see an addition of around 198 million.

It is also important to take urbanization trends into account, as these have profound implications for economic development, social issues and energy consumption. Moreover, urbanization is closely linked with better access to energy and is a factor in energy poverty alleviation. Urbanization in the WOO is considered as the percentage of the total population living in urban areas. Globally, more people live in urban areas than in rural areas, with almost 55 % of the world's population residing in urban areas in 2018. In 1950, 30% of the world's population was urban, and by 2050, 68% of the world's population is projected to live in urban areas.

Historical trends in the urbanization rate (Figure 1.3) reveal that the OECD region is the most urbanized region with more than 80% of its population living in urban areas. Currently, the most urbanized regions include North America (with 82% of its population living in urban areas in 2018), Latin America and the Caribbean (81%), Europe (74%) and Oceania (68%). OPEC Member Countries also stand above the current average global level at close to 75%. The level of urbanization in Asia is now approaching 50%.

Figure 1.3
Urbanization rate for selected regions, 2000–2040



Source: UN, OPEC.

In contrast, Africa remains mostly rural, with 43% of its population living in urban areas, although this is expected to continue rising steadily, as will also be the case in the wider Middle East & Africa region. The urbanization rate in Other Asia is also on an ascending trend, with expectations for a significant expansion in urbanization levels in the coming decades. India's urbanization rate has been the lowest in the region, and although it is set to rise considerably in the coming decades, it is expected to remain the lowest in 2040. A look at China's historical data reveals that the country has witnessed a dramatic change in urbanization. Urbanization used to be at a similar level to that of India before 1990, but since then it has experienced significant growth. Moreover, urbanization is expected to continue rising, albeit at a decelerating pace.

Migration is another major aspect of demographic change. Table 1.3 depicts net migration, as measured by estimates based on scenarios in the UN's 2019 Revision of the World Population Prospects. The OECD is expected to witness a high inflow of migrants through to 2040, whereas the non-OECD region is expected to see an outflow of its population (negative rate). In Eurasia, net migration is expected to be close to zero, with people moving largely within this region, predominantly to Russia and to only a minor extent outside Eurasia.

Table 1.3
Net migration by region

% of regional population

	2018	2020	2025	2030	2035	2040
OECD Americas	0.8	1.0	1.0	2.2	3.6	5.0
OECD Europe	–0.4	–0.5	0.4	0.9	1.6	2.4
OECD Asia Oceania	0.0	0.1	0.6	1.2	2.0	2.8
OECD	**0.1**	**0.2**	**0.7**	**1.5**	**2.5**	**3.6**
Latin America	0.4	0.2	–0.4	–0.7	–0.9	–1.1
Middle East & Africa	1.2	1.2	0.0	–0.1	–0.3	–0.4
India	0.1	0.2	–0.2	–0.3	–0.5	–0.7
China	–0.9	–1.0	–0.1	–0.3	–0.4	–0.6
Other Asia	–0.5	–0.6	–0.3	–0.7	–1.1	–1.5
OPEC	0.8	0.9	0.3	0.4	0.3	0.2
Russia	–1.2	–1.5	0.3	0.7	1.2	1.7
Other Eurasia	–0.2	–0.2	–0.3	–0.5	–0.8	–1.1
Non-OECD	**–0.2**	**0.0**	**–0.1**	**–0.3**	**–0.5**	**–0.7**

Source: UN, OPEC.

1.2 Economic growth

1.2.1 Current situation and short-term growth

Global economic growth slowed in the second half of 2018, a trend that has carried over into 2019. This downward trend has brought the global growth forecast to a level of 3.2%, compared to last year's growth estimate of 3.6%. In particular, growth in OECD economies has slowed relatively significantly. However, China and India are also forecast to show lower growth in 2019, compared to 2018, although GDP growth remains at considerably high levels. While the recent slowing in global economic growth appears to have stabilized to some extent, underlying risks remain and may further hinder 2019 global growth levels.

Continued trade issues, ongoing challenges in several emerging and developing economies and high debt levels in several important economies remain risks to growth. Moreover, Brexit, fiscal issues in some European Union (EU) Member Country economies and Japan's slowdown, as well as the fading US fiscal stimulus, pose additional risks. Given this year's slowdown, it remains to be seen if the softening momentum will carry over into 2020. For now, a stabilization of the growth level is anticipated near 3.2%, before it rebounds to higher levels in subsequent years.

An important element dragging growth to lower levels in 2019 has been the slowdown in trade. The global economic growth trend in 2017 (3.7%) and 2018 (3.6%) was very much supported by global trade which expanded by 4.7% and 3.4%, respectively. The latest data shows that global trade continued to decline during the first half of 2019, a trend that started at the end of 2018.

Moreover, many uncertainties about key global trade issues remain unresolved. US-China trade tensions have risen since the start of 2018 with the imposition of tarriffs on a large variety of products. There is also still the possibility of US tariffs on cars and car parts imported to the US, potentially negatively impacting some countries, especially Germany, Korea and Japan, which are already seeing weaker growth without this additional potential challenge.

In addition, the ratification of the United States-Mexico-Canada Agreement, the revised North American Free Trade Agreement (NAFTA), remains uncertain. Further sanctions on IR Iran and existing US sanctions on Venezuela and Russia are additional elements impacting the global economy and global trade. These are areas that will need close monitoring to properly evaluate their medium-term economic growth implications. Global exports account for around a third of global GDP and constitute a vital part of the global economy. Consequently, a disruption in global trade could cause the current medium-term global economic growth forecast to be negatively impacted.

Some support over the medium-term is expected to come from monetary policies. The slowing momentum in the global economy has been reflected in a change in G4 central bank policies, with monetary policy remaining more accommodating than previously expected. This, in combination with monetary stimulus in China, has supported emerging and developing economies since the beginning of 2019 and particularly benefitted those with weak fiscal situations. Amid softening inflation and some slowdown in the US economy, the US Federal Reserve (Fed) has started to lower interest rates again and to pursue a relatively more accommodative monetary policy. The European Central Bank (ECB) has introduced new monetary support facilities and also lowered interest rates. The Bank of Japan (BoJ) has also continued its monetary stimulus and, depending on Brexit, the Bank of England (BoE) will probably also need to continue supporting the UK's economy via accommodative monetary policy.

The positive effects of these central bank policies have already taken hold in the various economies. The housing sector in the US has seen some rebound in home sales, lending activity in the Euro-zone has picked up again, and Japan and the UK – for different reasons – are at least holding up relatively well, albeit at low growth levels. This relatively accommodative monetary policy is forecast to continue, as long as inflation remains in check, a factor that is forecast to support medium-term growth development.

Another important element has been the OPEC-led recovery in the oil market since 2016. OPEC's efforts together with non-OPEC producers participating in the 'Declaration of Cooperation' to stabilize the oil market since 2016 has led to a more balanced oil market and a rising contribution from the oil sector to global economic growth. Oil producing economies, including large oil producers in the OECD, such as the US and Canada, account for more than a third of the global economy, hence a stable income and investments into the energy sector remain vital for the global economy in the medium-term. This is forecast to be of benefit for producers and consuming nations alike, as a more balanced market provides consuming nations with a stable environment to make economic decisions.

1.2.2 Medium-term economic growth

The considerable growth levels seen in 2017 and 2018 have waned over 2019 and global growth is now forecast to strengthen only slightly, from 3.2% in 2019 to 3.4% in 2024. The main reasons are that OECD growth is expected to accelerate only slightly, and while growth in China and India is forecast to continue decelerating, the countries are at the same time gaining in importance in the composition of global growth and via their relatively higher growth rates, they are supporting global growth momentum. Moreover, developing economies, particularly OPEC Member Countries, are forecast to recover in the medium-term.

Monetary policy is forecast to remain relatively accommodative, although fiscal flexibility will be limited, given high central government debt levels around the world. High debt will also be an important element keeping monetary policy relatively accommodative as rapidly rising interest rate levels may have considerable consequences. Based on the most recent findings by the International Monetary Fund (IMF), global debt has reached an all-time high of $184 trillion in nominal terms, the equivalent of 225% of GDP in 2017. This is the latest available data. On average, the world's debt now exceeds $86,000 in per capita terms (Samba Mbaye and Marialuz Moreno Badia (2019)).

The most indebted economies in the world are the richer ones. Private sector debt has tripled since the 1950s, making it the driving force behind global debt. Another change since the global financial crisis in 2008 has been the rise of private debt in emerging markets, led by China. At the other end of the spectrum, private debt has remained very minor in low-income developing countries. This is due to a lack of income and because private households have not been able to raise debt. After a steady decline up to the mid-1970s, public debt has been rising, with advanced economies at the forefront and followed more recently by emerging and low-income developing countries, economies that are usually in a more fragile situation. It should also be noted that the trend of low or even declining productivity rates in 2018 is forecast to continue in the medium-term. These observations tie into the Secretariat's outlook wherein the growth potential for the global economy is around 3.4%. Table 1.4 summarizes these projections at the global and regional level for the entire medium-term period.

Table 1.4
Medium-term annual real GDP growth rate

% p.a.

	2018	2019	2020	2021	2022	2023	2024	Average 2018–2024
OECD Americas	2.7	2.4	1.9	1.8	1.8	1.9	2.0	2.1
OECD Europe	2.1	1.2	1.4	1.5	1.6	1.6	1.7	1.6
OECD Asia Oceania	1.6	1.2	1.2	1.4	1.4	1.5	1.5	1.4
OECD	**2.3**	**1.7**	**1.6**	**1.6**	**1.7**	**1.7**	**1.8**	**1.8**
Latin America	1.3	1.3	2.0	2.4	2.4	2.5	2.5	2.0
Middle East & Africa	3.1	2.9	2.9	3.1	3.2	3.2	3.3	3.1
India	7.4	6.8	7.0	7.0	6.8	6.7	6.6	6.9
China	6.6	6.2	6.0	5.8	5.7	5.6	5.5	5.9
Other Asia	4.6	4.3	4.1	4.2	4.1	4.2	4.2	4.2
OPEC	0.0	0.4	1.0	2.0	2.4	2.6	2.6	1.6
Russia	2.3	1.4	1.4	1.5	1.6	1.7	1.7	1.7
Other Eurasia	3.7	3.3	3.0	2.9	2.9	2.8	2.7	3.1
Non-OECD	**4.6**	**4.3**	**4.4**	**4.5**	**4.5**	**4.6**	**4.5**	**4.5**
World	**3.6**	**3.2**	**3.2**	**3.3**	**3.3**	**3.4**	**3.4**	**3.3**

Source: OPEC.

The uncertainties to this medium-term forecast are manifold. The risks are skewed to the downside and the upside seems to be limited. In addition to the expectation of less monetary support even as central banks maintain relatively accommodative policies, in combination with elevated global debt levels, the limited fiscal space and the obvious limitations to productivity growth are the major uncertainties. In addition, concerns about global trade, rising geopolitical issues and uncertainty in commodity prices are risks that may impact medium-term global growth.

In **OECD Americas**, the **US** will obviously shape global economic development in the medium-term. While growth was high in 2018 and a strong trend is forecast to continue in 2019, growth rates are forecast to drop in 2020–2022, given the lessening effect of fiscal stimulus and the somewhat continued monetary policy normalization.

Growth is forecast to gradually accelerate again towards the end of the medium-term period. The fiscal space will be limited in the coming years and the sovereign debt situation is expected to worsen, leading to repercussions in the medium-term growth momentum. While the Fed is forecast to enact less monetary tightening, it is at the same time expected to continue some monetary policy normalization, weighing on US growth in the medium-term to some extent.

Canada and **Mexico** will to some extent follow the developments in the US, which is the most important trading partner for those economies. Moreover, commodity market and trade agreement developments will be an important element for all OECD Americas economies, particularly oil market developments. For now, it is assumed that trade will remain an important driver for growth in North America with no material change in its relative contribution to economic growth.

In **OECD Europe**, growth is forecast to slow considerably in 2019 to only 1.2%, before gradually recovering in the medium-term. After being impacted by slowing global trade, Brexit and domestic issues in Italy, momentum is forecast to recover. However, Germany is facing some severe strains on the back of a decline in global trade and it remains to be seen how these issues evolve.

Monetary policies of the ECB, and probably the BoE are forecast to be relatively accommodative, even though monetary tightening is expected to continue, albeit at a slightly less rapid path than envisaged in last year's medium-term forecast. As the labour market is forecast to continue improving, the upside is becoming more limited. In most economies, with few exceptions, sovereign debt levels remain high and therefore major growth enhancing fiscal measures are not to be expected. Some ongoing weakness in parts of the banking system, especially in Italy, may provide a risk to medium-term growth too.

In **OECD Asia Oceania** the future expansion of **Japan** is of particular interest. Japan's development, in combination with the future progress of **China**, which is forecast to decelerate in the coming years, will provide a strong indicator for the region's future growth. Given the ongoing challenges in the Japanese economy and the expected decelerating growth trend in China, OECD Asia's growth pattern is forecast to remain relatively stable. The region's other important economies, **South Korea**, **Australia** and **New Zealand**, will also be impacted by growth momentum in Asia, especially from China and Japan.

In **Latin America**, a recovery is anticipated towards the end of the medium-term period. Given that Argentina is currently facing a severe recession and **Brazil** is challenged by its own domestic issues, a recovery in the region's largest economies is anticipated to lead the growth rebound. In Brazil, a successful outcome of the ongoing structural reforms over the coming years is also expected. In **Argentina**, it remains to be seen how the ongoing major structural reforms, supported by the IMF, will play out. Moreover, the situation may change after the Argentine elections. Given that these two countries constitute the region's two largest economies, their development is of critical importance and may not be counterbalanced by higher growth levels in some of the region's smaller economies.

In the **Middle East & Africa**, medium-term growth is forecast to accelerate slightly. Improving regional domestic demand and the rise of the middle class will be one of the supportive factors in the near-term. The future path of commodity prices, in combination with foreign investment, constitutes another important element. In this respect, the development of China in its continued role as the major foreign investor and China's need for natural resources will be of great importance. The current slowdown in China could lead to decelerating capital inflows into the region. Moreover, some countries' high sovereign debt obligations and debt servicing may be another constraint.

The current forecast anticipates that geopolitical issues will not worsen and remain manageable. Key commodity prices are expected to slightly appreciate in line with the trend of the global economy. Moreover, wealth distribution and diversification are also expected to slowly improve the economic structure of the region too.

China will be of even greater importance in the medium-term. While it is forecast to decelerate, its high overall growth means that it will have more weight in the composition of global growth. As it is a very important trading partner for most major economies, the outcome of the ongoing US-China trade talks will be of great importance. Hence, the development of China's economy is considered to be of even greater significance than its pure economic weight in global GDP would suggest. After still relatively robust growth in 2018 of 6.6%, the economy is expected to mature with growth slowly decelerating.

Importantly, this development is supported and managed by the Chinese leadership, which is envisaging growth of around 6.0–6.5% for 2019. Its focus on external trade and investments towards a more domestically oriented focus, led by private household consumption, will likely counterbalance some of the potential shortfall from external trade. While current government-led measures support economic growth, the government has highlighted on several occasions that there will be a need to level out current economic imbalances, mainly in the banking sector, the real estate market and to reduce provincial government debt, while at the same time also continuing to improve the social safety net and accelerate wealth distribution.

India's growth recovered in 2018 after structural reforms had led to lower growth in 2017. These 2017 efforts seem, however, to have laid important groundwork for future growth. GDP growth is forecast to remain around 7% in the coming years, but then slows towards the end of the medium-term horizon. Hence, India is forecast to exceed China's overall growth performance in the medium-term. Growth in India will be led by domestic consumption and the rise of its middle class. The homogenization of the sales tax, one of the important structural reforms, is expected to be supportive of growth.

Moreover, a further facilitation of foreign investment will also be an important element to keep growth at a high level. Challenges to the expected growth momentum will be the depth of further structural reforms, particularly after the outcome of India's general election at the end of May. Additionally, albeit to a lesser extent, trade-related developments concerning rising protectionism is an area that may negatively impact the Indian economy. A potential weakening of the rupee as an outcome of India's monetary stimulus *versus* monetary tightening by the G4 central banks, may make imports more expensive and challenge economic growth. In this respect, the future development of commodity prices will be essential for Indian growth.

Other Asia continues to grow at high levels, constituting one of the most dynamic growth regions in the world. However, depending on the development of the other Asian trading partners, mainly China, the group will also face a slight deceleration over the medium-term forecast period. This comes after very strong growth in 2017 of 5.0% and in 2018 of 4.6%.

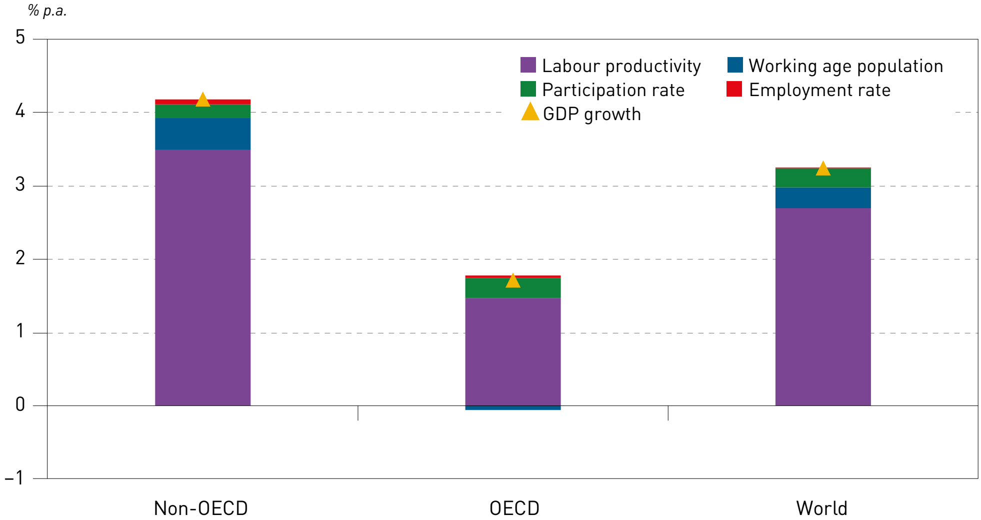
OPEC, as a group, is facing low growth in 2019, negatively impacted by US sanctions on key Members and other country-specific situations. However, OPEC is forecast to continue benefitting from the OPEC-led stabilization of the oil market, through the DoC, in combination with healthy oil demand and global growth. OPEC economies are forecast to recover and see a healthy growth pattern over the medium-term.

In **Eurasia**, **Russia** constitutes the most important economy, along with other oil producing nations. This group of countries has benefitted from the rebalancing of the oil market and the cooperation many of them have with OPEC Member Countries, which is expected to lead to relatively stable medium-term growth. However, the past years' dynamics of rising political uncertainty has continued, impacting investment and the Russian rouble. Moreover, Russia's economy remains hampered by US sanctions, although domestic demand is stable. Growth is anticipated to remain near current levels throughout the medium-term.

1.2.3 Long-term economic growth

The assumptions underlying the long-term economic growth developments are primarily productivity growth, demographic trends and developments in the labour market. Most of the growth expected throughout the forecast period will be determined by labour productivity, both at the regional and global level (Figure 1.4). The declining working age population in OECD Europe and OECD Asia, as well as in Russia and China, will limit their growth potential even as labour productivity increases.

Figure 1.4
Long-term GDP growth rates by component, 2018–2040



Source: OPEC.

In other areas, namely in the Middle East & Africa and OPEC, lower labour productivity will continue to be compensated by the spill-over into the labour market from rapidly expanding populations.

Global GDP growth between 2018 and 2040 is expected to increase at an average rate of 3.3% p.a., which is slightly lower than the WOO 2018 assumption. This is in large part due to having a lower baseline in the near- and medium-term, as well as the longer-term trend of currently emerging economies, such as China and India, beginning to reach maturity.

The majority of the growth expected through to 2040 will be driven by non-OECD countries, much as has been the case in previous editions of this publication. These countries are expected to grow by 4.2% p.a. on average (Table 1.5), largely on the back of improving labour productivity even as the pace of GDP growth begins to slow. **India** is expected to remain the fastest growing developing country with average growth of 6.3% p.a., with growth front-loaded over the projection horizon in line with expected demographic trends.

Table 1.5
Long-term annual real GDP growth rate

% p.a.

	2018–2024	2024–2035	2035–2040	2018–2040
OECD Americas	2.0	2.0	2.0	2.0
OECD Europe	1.5	1.6	1.6	1.6
OECD Asia Oceania	1.4	1.3	1.1	1.3
OECD	**1.7**	**1.8**	**1.7**	**1.7**
Latin America	2.2	2.3	2.2	2.3
Middle East & Africa	3.1	3.6	3.9	3.5
India	6.8	6.4	5.8	6.3
China	5.8	4.5	3.3	4.6
Other Asia	4.2	3.9	3.5	3.9
OPEC	1.9	3.0	3.1	2.7
Russia	1.5	2.0	1.8	1.8
Other Eurasia	2.9	2.8	2.3	2.7
Non-OECD	**4.5**	**4.2**	**3.7**	**4.2**
World	**3.3**	**3.3**	**3.0**	**3.3**

Source: OPEC.

As in previous editions of this publication, **China** is expected to have the second most rapidly growing economy, with average growth of 4.6% p.a. over the whole period. That said, with continued signals that China's economy is rapidly moving towards maturity, it is expected that the growth rate will decelerate more quickly than previously envisaged, falling to an average 3.3% p.a. in the last five years of the forecast period.

By 2040, it will thus have been overtaken by the Middle East & Africa, as well as Other Asia, where an expanding working age population will contribute to faster economic growth. Economic growth in **Other Asia** is seen decelerating from 4.2% p.a. to 3.5% p.a. by 2040, which is nonetheless still above the global average.

In the **Middle East & Africa**, growth is estimated at an average 3.5% p.a. This is a slight downwards revision from last year and in keeping with generally lower expectations for economic growth at the global level. This region is nonetheless the only one where growth is expected to accelerate throughout the forecast horizon, from 3.1% p.a. in the medium-term to nearly 4% p.a. towards 2040. There have been no major shifts in the assumptions regarding the region's productivity growth, which means that there is still significant potential that could materialize.

Labour productivity gains in **Russia** are expected to counterbalance unfavourable demographic changes and a reduction in the working age population over the first tranches of the long-term horizon. Economic growth in Russia is thus expected to rise to 2% p.a. before falling back to 1.8% towards the end of the projection horizon. It should be noted, that this is still an improvement over the medium-term outlook. Elsewhere in Eurasia, marginal growth in the working age population will help maintain GDP growth above 2% p.a. over the entirety of the forecast period.

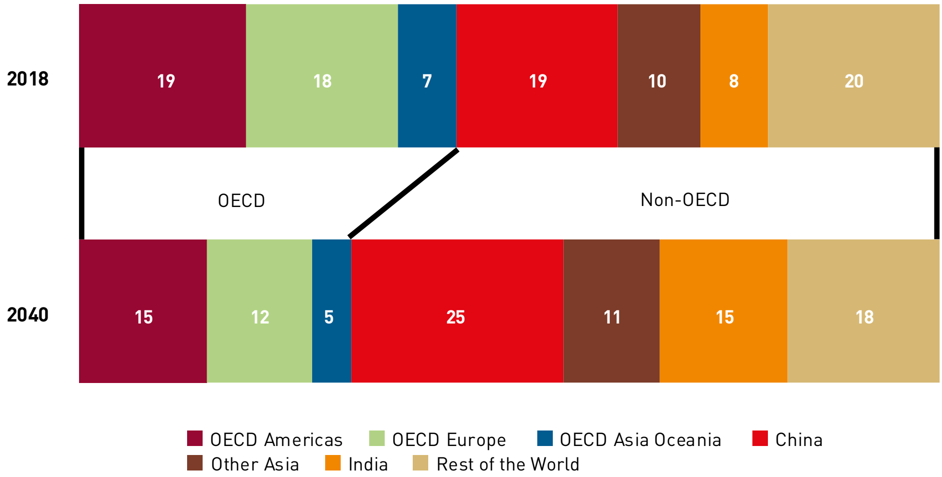
The recent challenges faced by large economies in **Latin America** increasingly appear to be structural issues that will persistently hamper the region's economic stability and outlook as the cyclical economic pattern in the region's major economies in the region will likely continue. Colombia's accession to the OECD in late-2018 and increasing investment prospects in some smaller countries such as Guyana leave some reason for optimism. Overall, growth is estimated at 2.3% p.a. for the period from 2018–2040, down only marginally from he WOO 2018 assumption of 2.4% p.a.

Within the **OECD region**, where economic growth is forecast to average 1.7% p.a. from 2018 to 2040, OECD Americas continues to lead growth prospects with a stable economic outlook at 2.0% p.a. In the longer-term, immigration will help expand the work force while labour productivity is expected to remain near current levels after having been downgraded in last year's Outlook. In the other OECD regions, most particularly OECD Asia Oceania, smaller working age populations will likely drive a deceleration of economic growth, down to 1.1% p.a. for the final five years of the projection period.

The GDP growth figures assumed here imply that the global economy in 2040 will be double the size it was in 2018. Based on 2011 purchasing power parity (2011 PPP), global GDP is projected to rise from $117 trillion in 2018 to more than $237 trillion in 2040. Figure 1.5 indicates that China and India alone will account for 40% of global GDP in 2040, whereas the OECD will only account for 32%, a striking reversal of the current weight distribution. In 2018, it was estimated that the OECD accounted for 44% of the global economy, with OECD Americas, OECD Europe and China all accounting for similar shares.

Figure 1.5
Distribution of the global economy, 2018 and 2040

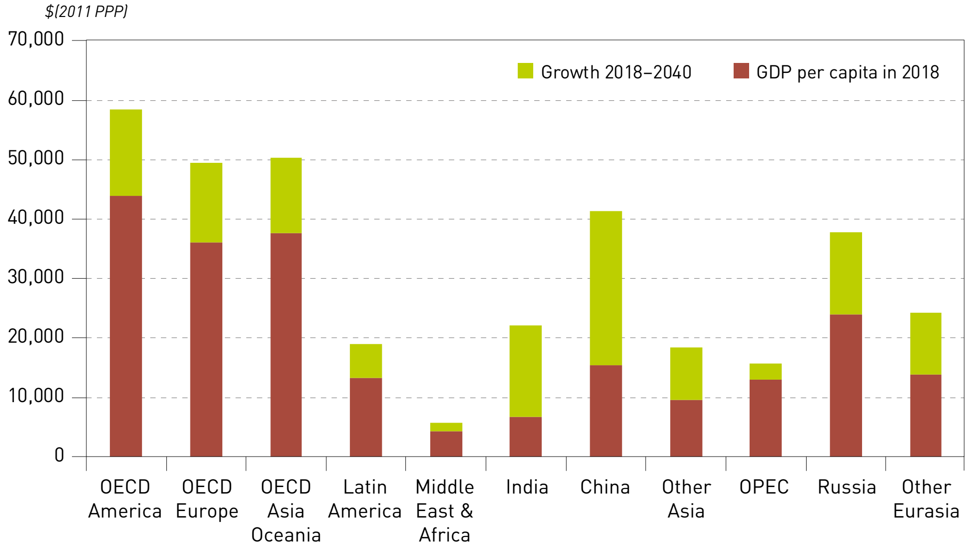
%



Source: OPEC.

Despite large shifts at the regional level, the global economic picture does not see significant changes, average income (measured as GDP per capita). OECD Americas is forecast to remain the region with the highest GDP per capita, followed by OECD Asia Oceania and OECD Europe (Figure 1.6). The regional grouping of Middle East & Africa will still have the lowest GDP per capita, and is expected to be the only region where the average income is less than $10,000 (2011 PPP) in 2040.

Figure 1.6
Real GDP per capita in 2018 and 2040



Source: IMF and OPEC.

India and China are anticipated to see the largest changes, with average income in China seen rising to a level nearly equal to those of OECD countries and overtaking Russia. The global average income is projected to rise from $15,300 (2011 PPP) to more than $25,000 (2011 PPP) in 2040 – somewhat lower than was forecast in the WOO 2018, as expected given the general downward revisions to the global economic forecast.

1.3 Energy policies

This section includes, *inter alia*, a synopsis of energy policies focusing on the Paris Agreement, as well as supply and demand. These policies were considered and incorporated in the regional and sectoral analysis conducted throughout this publication. Energy policies are a significant driver of energy market transformations.

Hence, this Outlook takes into account currently-enacted energy policies whilst also recognizing the transitory nature of policies (that they change and evolve over time). The medium-term projections are updated on a yearly basis, ensuring that newly-established and enacted policies are included in this update, as well as the results of formerly enacted policies.

Since the release of the WOO 2018, many nations around the globe have ratified the Paris Agreement, including several OPEC Member Countries. So far, ten OPEC Member Countries have ratified the Paris Agreement, reflecting a joint global movement towards balancing economic, social and environmental development.

Paris Agreement
The US offers a clear example of the evolutionary nature of policies, as the current presidential administration used the Congressional Review Act to back out of the Paris Agreement. On 15 December 2018, in Katowice, Poland, despite the US administration's stance, the UN climate conference COP24 adjourned with the conclusion to adopt a clearly stipulated rulebook to empower the Paris Agreement's implementation.

Key elements of the COP24 rulebook are, *inter alia*: the establishment of a universal system by which Parties have the ability to track and convey progress in climate change; the creation of a guidance structure and a registry to communicate their actions with respect to adopting measures to limit the impact of climate change.

Based on the targets set by the COP24, countries are to enact measures that would limit global warming to 2°C or less above pre-industrial levels by the year 2100. This target is unfortunately not achievable based on the originally planned cuts to greenhouse gas (GHG) emissions. Hence, the agreement in Katowice included a plan wherein countries should voluntarily meet on a regular basis to upgrade their intended targets.

The US government's intention to withdraw from the Paris Agreement is considered a major obstacle; however, it is not the only nation which has voiced objections to recent developments in environmental policy measures. The language used in the final IPCC special report Global Warming of 1.5°C in particular met with resistance. With the US's intention to withdraw, the EU is expected to play an increasing role in ensuring the successful achievement of set targets. The EU continues to be committed to the combined universal target to mobilize $100 billion/year by the year 2020, and through to 2025, to finance climate change targets.

1.3.1 Policies related to energy demand
The US energy mix has paved the way for rapid de-carbonization, although recently this phenomenon has mainly been due to basic economics, which favour using cheap clean energy sources as opposed to coal in power generation, rather than policy measures. Over the past decade, the share of electricity generated from coal in the US power mix has fallen from 44% to 27%. This is largely due to actions taken at the state level to invest in technology and deploy clean energy, and also allows states to take advantage of abundant gas supply generated by the 'shale boom'. Many states are setting aggressive clean energy goals and have further plans to replace natural gas in power generation with renewables to lower the dependency on fossil fuels. Be that as it may, US GHG emissions rose by 2.5% in 2018. The reasons for this are multi-factorial and include, *inter alia*, economic growth and harsh weather conditions nationwide.

At the federal level, however, a contradiction has emerged due to the current administration's clear policy targets of asserting energy dominance and reducing environmental regulations to encourage the use of coal in power generation and increase oil production. Moreover, the Environmental Protection Agency (EPA) is repealing the Clean Air Act waiver that empowers the state of California to determine its own air quality standards. This will also impact 13 other states which have adopted California's standards, and the District of Columbia. Moreover,this may apply to California's right to set its own fuel efficiency standards, which are consistently more stringent than the nationwide CAFE standards. The current administration has, furthermore, frozen CAFE standards for Model Years (MY) 2021–2026 at the MY2021 level proposed by the previous administration.

CAFE standards were created to regulate the fuel economy of cars at the manufacturer level. It dictates the specifications cars should have to be certified as road-worthy. A car manufacturer must attempt to balance the sales of sports utility vehicles (SUVs) *vis-à-vis* more fuel-efficient cars to achieve fleet-wide fuel efficiency at or below the cap mandated by the CAFE standards. The recently-mandated freeze of CAFE standards at 2020 levels (for MY 2021) is expected to result in additional oil consumption of 100,000 barrels a day (b/d) to 300,000 b/d by 2025 compared to the previously-mandated CAFE standards.

Following the 'dieselgate' controversy, diesel vehicles continue to face challenges in the EU as a result of tightening regulations, as demonstrated by legislation requiring stricter vehicle monitoring and new testing methods. The Global Fuel Economy Initiative, otherwise known as GFEI, and the International Council on Clean transportation (ICCT), have been in constant regular with the EU Commission discussing proposals for its fuel economy standards out to 2030.

Following a 2013 pilot programme, the Chinese authorities established the China V gasoline and diesel fuel quality standards (equivalent to Euro 5) to be implemented nationwide. The Chinese authorities' ambitious goal is to implement the even stricter China VI fuel standards by July 2020.

The EU, China and the US have the three largest auto-making industries and vehicle markets. Hence, the EU and China's aspirations to reduce carbon emissions and fossil fuel use, if achieved, are expected to have a significant demand side impact over the longer-term .

Policy makers in India are also setting stricter fuel emissions standards. The gradual implementation of the 2017 Bharat IV fuel quality standards (equivalent to Euro 4) has been followed by the nationwide implementation of Bharat VI fuel quality standards (equivalent to Euro 6). Although it was considered an ambitious target, all corporate automakers in India are currently reported to be in compliance with FY 2017–2018 fuel consumption standards.

1.3.2 Policies related to oil supply

The current US administration, which subscribes to the 'energy dominance' paradigm, has gradually undone the regulatory agenda established by previous administrations. This applies to the 'Clean Power Plan' (CPP) act and methane emissions, amongst others. With different parties in control of the House of Congress and the Executive Branch, it is quite unlikely that Congress and the White House will come to an agreement regarding comprehensive widespread energy legislation.

The focus of the current administration is on ensuring that the US continues to be the world's biggest oil and gas producer and to ensure that it takes a 'power-house' position in global energy markets. This is evident in the US policy makers' approach to maximizing federal onshore (and offshore) oil and gas production by opening more federal lands to drilling and making more acreage available for oil and gas exploration. The US administration is also attempting to remove barriers to investment and minimize bottlenecks in federal permitting, however, this remains a challenging issue. Although progress was made with regard to fast-tracking infrastructure and energy projects such as the Keystone XL pipeline under the current US administration, this project, in particular, remains hampered by lawsuits, adding significant costs and delays to the construction of the pipeline.

In Mexico, auctions of blocks for exploration and production (E&P) under the Energy Reform have been put on hold for up to three years following the 2018 elections, although finalized new upstream projects are expected to proceed. At the same time, a plan has been put forward to slash red tape for regulatory permits for new upstream projects to be developed by Pemex, its national oil company, cutting the permitting process from 270 days to 50 days. Pemex hopes that this will, in turn, allow for new discoveries to be brought online within 1.3 years, compared to the current typical timespan of five years.

Brazil is also continuing with its relaxation of local content rules in upstream E&P, having opened up its pre-salt blocks to foreign operators in recent years. Shallow water and onshore blocks are now being proposed as the next areas where foreign companies may be able to acquire existing assets and develop new projects, either via standard block auctions or in Transfer of Rights auctions.

1.4 Technology and innovations

Careful analysis of existing technology, as well as a comprehensive assessment of the potential impact of technology advances, are essential elements underlying the medium- and long-term projections discussed in this Outlook. Technology has not only driven the global energy business in the past but industry has also pushed for the development of new and promising concepts. This Outlook assumes an evolutionary development of existing technologies, while paying attention to the development of new technologies for the global energy business. This will be explored in detail in Chapter 7.

1.4.1 Conventional and renewable power generation

Despite substantial efforts, mainly in the past ten years, to establish renewables as a mainstream source of energy for power generation, conventional power generation continues to dominate the sector. Power generation is the perfect example of how energy can be transformed from lower to higher value forms – here, from coal and gas, but also occasionally oil, into electricity which is then used to drive other processes in a number of end-use sectors. This makes power generation one of the largest consumers of primary energy.

On the other hand, after decades of optimization, conventional power generation is reaching efficiency limits imposed mainly by natural laws, but also by cost considerations. Coal-fired power plants are among the most mature technologies in the power generation sector, and although the introduction of supercritical plants has allowed efficiency to rise above 45% or more, the investment needed to run at higher temperatures may be prohibitive. The financial investment required to squeeze out the final efficiency gains in conventional power generation has been a boon for renewable alternatives and gives them an increasing advantage.

Gas turbines are a type of ICE, since the fuel is combusted inside the engine. Most advanced, heavy-duty gas turbines are now operating with temperatures up to 1,600°C, which would be impossible for externally-fired coal power plants. Their overall fuel-to-power net efficiency can already reach above 62%, approaching the thermodynamic limit of 70% imposed by physical laws. Nevertheless, combined cycle power plants (CCPPs) will remain by far the least CO_2-emitting fossil-fuelled power plants, an advantage which should not be underestimated as countries and regions look to tackle climate change at reasonable costs.

The use of gas as a fuel for power generation has expanded with its increasing supply over recent years. Its lower costs, lower CO_2 emissions and abundant supply in the long-term, has driven an increasing use of gas as primary energy for power generation. The decline of CO_2 emissions in the US from the power generation sector is mainly due to the substitution of coal by natural gas, in many cases because it is cheaper rather than for environmental reasons. This lesson should be carefully considered by policymakers when discussions on how to reduce GHG emissions; the economic advantage of natural gas prompted a larger and faster response than policy measures.

Much of the impetus behind the increasing share of renewables – mainly wind and solar – in the power generation mix has come from the desire to secure energy supply by using local energy, as well the desire to broaden the primary energy base as a whole. In the EU, for example, the terms carbon-neutral power generation and renewables are used synonymously although power generation (and other energy use) may be carbon-neutral, but not necessarily renewable. One example is carbon capture and storage or utilization (CCS/CCU) where produced CO_2 is stored in underground repositories over a long time, if not forever, and so there are minimal-to-no CO_2 emissions.

Significant investment – often through substantial direct and indirect subsidies – has been made to develop new photovoltaic (PV) technologies and to improve existing ones – for example, increasing the efficiency of PV cells or enlarging the range of useful wind speeds for wind turbines. As a consequence, the power generation costs of these renewables have dropped faster than expected and are now, under certain circumstances, competitive with conventional ones. Nevertheless, to judge their real competitiveness, renewables lack of buffering must be taken into account too. The reduced load factor of back-up power plants may considerably increase the average power costs for reliable and year-round power supply.

Industry has recognized that large-scale power storage is an essential component for the success of renewables in energy. Pumped hydro is also a storage technology that has been used for quite some time. It is now being discussed as a potential storage option to balance out fluctuating wind and solar power. However, with a round-trip efficiency of around 80% – depending on topography and distance between power generation, storage and consumer – there is only minor potential for further efficiency improvements.

Battery storage is making progress in view of cycle stability and specific costs, basically in parallel with battery technology for vehicles. Its close-to-consumer deployment reduces the average load on the grid – an advantage which may become more important in the future when more electric vehicles (EVs) must be charged or other large power consumers will request considerably varying power levels. Nevertheless, with current and near-future battery technology – mainly lithium-ion – for large-scale power, storage appears unlikely to compete against fossil-fuelled back-up plants. Some power-to-gas – or in general power-to-fuel – initiatives attempt to store renewable power as fuel for later, long-term use in combustion engines or fuel cells. However, they are not competitive yet and may only become so if abundant cheap renewable power is available in the more distant future.

Apart from the storage issue, renewable power in sufficient amounts for large-scale use is often generated only in remote locations, such as in the desert or offshore, far from consuming centres. As a consequence, large amounts of power must be transmitted – preferably by direct current high-voltage systems – from producing areas to consuming regions. This Outlook takes into account such secondary effects impacting the expansion of renewable power.

Although renewable power generation is increasing on a global level – oil and gas producing countries are investing in this area to diversify their energy base – fossil fuels will remain essential to satisfy the world's energy demand in a severe and reliable way for an extended period of time. CCS, as well as CCU, is a convenient way to comply with the Paris Agreement. Although somewhat neglected in the past years, it has begun attracting more attention because it immediately reduces CO_2 emissions.

1.4.2 Residential and industrial sectors

Most energy consumption in the residential and commercial sector is related to space heating during cold seasons and air conditioning (A/C) in hot and/or humid conditions. Space heating has received a lot of attention in the past, as most developed countries are located in moderate to cool regions with extended cold weather periods, but nowadays A/C is playing an increasingly important role. While freezing temperatures are a more direct threat to life, the productivity of working people is also negatively affected by elevated heat and humidity. As a consequence, homes, offices and commercial spaces are increasingly equipped with A/C devices which regulate temperature and humidity to remain within a bandwidth of conditions that are considered comfortable.

In cold areas, insulation campaigns have helped increase energy savings, but such passive measures are still largely unused in hot environments to reduce the specific consumption of A/C systems. Insulating spaces against the cold environment is already a well-established strategy with a broad range of components available off-the-shelf, and similar strategies may be used for hot environments to reduce the need for A/C. The technology related to insulation materials and insulating windows is largely mature, and it simply requires the investment of capital to make their use widespread. For space heating, a substantial degree of energy could be saved in this way. Apart from that, residential consumers employ a broad variety of energy sources – from fire wood to state-of-the-art heat pumps and thermo-solar systems – and typically require low-grade energy (low-temperature thermal energy instead of electric power).

In a similar way, the major share of industrial energy consumption is related to heat, just at different temperature levels. High-temperature heat pumps may play a more important role in the future; they allow the temperature of waste heat from one process to be raised to the temperature required for another process in an industrial plant with relatively minimal power. Employing a heat pump is the most efficient way to use renewable power, which is typically provided as electricity far away from the plant. Simple resistor elements would achieve only a fraction of the effect.

In recent years, Combined Heat and Power (CHP) generation has become more attractive and more advanced technical solutions have become available. Large industrial users typically employ gas turbines whose exhaust heat is captured for thermal applications, while smaller users – for example, condominiums and hospitals – rely on reciprocating piston engines.

1.4.3 Road transportation – the main consumer of oil

ICEs have been the primary movers in the transportation sector for well over a century, and they use not only gasoline and diesel, but also Liquefied Petroleum Gas (LPG), Compressed (CNG) or Liquefied Natural Gas (LNG) and even hydrogen, alcohols – whether ethanol of chemical or biological origin, as well as methanol – or biodiesel from oil seeds. This Outlook assumes that these engines will remain dominant for the foreseeable future, but does take into account the current discussions, developments and possible future advancements of electric mobility.

The increasing competitiveness of EVs will pressure manufacturers of traditional ICEs to further improve their fuel efficiency and reduce emissions. Hybridization at all levels, from mild to full-hybrid, is already an important strategy to reduce specific CO_2 emissions (in g/km) and is also promising in view of overall costs. The latter is an important aspect when it comes to developing countries, as these will be responsible for most of the additions to the global fleet through to 2040. This Outlook, therefore, assumes that in these countries by far the largest share of vehicles will be powered by ICEs, albeit with increasing hybridization (HEV, PHEV).

Powertrain electrification is becoming more widespread, with more hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) models being designed by basically all car manufacturers for roll out in the near future. The price of BEVs will decline substantially in the medium-term, and their range will also be considerably extended compared to today's typical values. The overall efficiency of an electric powertrain, including the battery, is already quite high – battery charging/discharging is above 96% and the efficiency of electric motors typically between 90% and 96% – so there is only limited potential for further improvement. Future batteries will be smaller and lighter, reducing the overall vehicle weight significantly and, consequently, the energy needed to propel the vehicle. The combination of these factors will contribute to increasing customer readiness to at least consider buying an EV. Consequently, this Outlook considers growing penetration of PHEVs and BEVs (see Chapter 3).

When evaluating the energy and fuel demand of passenger vehicles, it can be observed that as soon as developing countries become emerging countries, customers tend to buy more luxury vehicles (large, heavier and more powerful ones). Even in OECD countries, SUVs have taken over a large share of the market that had been served by sedans. Increasing use of A/C and other power consuming components has contributed to an overall rise in energy demand at the vehicular level, substantially offsetting the improved conversion efficiency of modern combustion engines.

One of the most important alternative fuels for road transportation is CNG for passenger vehicles, and potentially LNG for commercial ones. Apart from broadening the fuel base, natural gas has lower GHG emissions and generally lower particulate emissions than conventional fuels. Some car manufacturers have, therefore, announced that they will reinforce their offer of CNG-fuelled vehicle models. Using CNG is an obvious strategy in gas-rich countries. This Outlook has, consequently, carefully considered the penetration of such CNG vehicles.

Shared mobility, expedited by internet-based systems, is growing swiftly with a focus on urbanized areas. Small electric scooter fleets are being deployed for (very) local travel without luggage. Although such sharing may reduce the number of vehicles, as well as the amount of passenger kilometres travelled, some investigations show that these new programmes might not only complement public transport, but replace it to a certain extent. There is, thus, a fair degree of uncertainty in how energy demand and consequently, fuel and electricity demand, for short-distance travel will develop through to 2040.

Commercial vehicles remain largely limited to diesel engines, as fleet managers make purchases based on a thorough overall cost analysis. Here, diesel remains the most economically attractive powertrain technology, especially for heavy trucks. The importance of cost in commercial road transportation is evident when looking at how LNG gained greater traction as an alternative to diesel beyond its established markets between 2011–2014, when oil prices were high. Favouring diesel fuel over gasoline in view of taxes, as some governments do, reinforces the economic advantage of diesel. Nevertheless, urban short-distance-only vehicles such as delivery trucks, garbage trucks and increasingly buses, are starting to use battery-electric powertrains.

With the zero-emission concept gaining traction among consumers and policymakers, a larger EV fleet share is expected in certain heavy-duty vehicle segments in the future. However, although some shift from diesel fuel towards LNG may occur, the Outlook assumes only a small transition in that direction, while fuel cells running on hydrogen are only considered as feasible in the distant future.

1.4.4 Air transportation – quickly growing sector

Today, air transportation relies entirely on fossil fuels and only a few tests have been carried out with fuels derived from biomass. Air transportation is nevertheless at the forefront of efficiency improvements, with the efficiency of each new generation of planes showing gains of 20–30% – a value substantially beyond what consumers are accustomed to in road transportation, for example.

Air transportation is the fastest growing transport segment and airplanes have witnessed significant technological advances over recent decades. Today, modern flight gas turbines have reached an astounding 50:1 compression ratio, which corresponds to a theoretical efficiency of 79%. Due to internal losses in compressor and expansion turbine stages, however, actual efficiency is well below 50%. Nevertheless, reducing the fuel consumption of the flight gas turbine has become increasingly difficult, although there is still potential to reduce internal losses and thus boost efficiency. Apart from gas turbine efficiency itself, the associated conversion of turbine power into thrust to propel the aircraft can play an important role. In this respect, geared fans are state-of-the-art for today's most efficient aviation gas turbines.

The aviation industry is committed to reducing the specific fuel consumption by 2% p.a. However, the steep increase in demand for air transportation as a whole makes it questionable as to whether the intended industry-wide CO_2 reduction can be achieved without further strategies beyond improving aircraft efficiency.

Electrification is also beginning in this sector, with the first tests of small planes equipped with electric motors running on battery power. Hybridization is also a focus, for example, with helicopters, where engine failure is among the most critical situations for fatal crashes. Several start-ups, often backed by leading airplane manufacturers, are currently developing air taxis, such as small vertical take-off and landing (VTOL) planes powered by electric motors for short distance flights.

Autonomous planes are also a point of discussion, as they will be easier to operate than road transport vehicles because there is generally less traffic, and no pedestrians. Nevertheless, it has yet to be seen how much such concepts can be developed and whether they will be widely adopted. Therefore, they play only a minor role in this Outlook.

Apart from reducing the airplane's weight, wings and hulls have also been made more efficient and this will continue with the use of more sophisticated computer-based avionics that can rapidly actuate wing flaps to maintain a safe flight path. Most advanced military planes, for example, could not be flown by a pilot alone without the assistance of such avionics; the response of a human being is too slow. As a result of improved engine and wing designs, the specific fuel consumption of today's commercial airliners is at a historical low. This Outlook takes into account this development, as well as the potential of future evolutionary engineering advances in the airline industry.

It should be kept in mind that improved flight management systems on the ground, together with advanced flight control allowing more direct and, hence, shorter connections, will also contribute to lowering the specific fuel consumption of airplanes. Precise and reliable satellite-based global navigation systems (GPS, Galileo, GLONASS, etc.) are of particular importance. These are also anticipated to advance at an evolutionary pace.

1.4.5 Marine transport – the backbone of global business

The International Maritime Organization's (IMO) upcoming ban of heavy sulphur fuel oil (HSFO) through a regulation limiting emissions from marine fuels to a maximum sulphur content of 0.5% will have profound short- and long-term impacts on marine bunkering. Exhaust gas cleaning systems can be used to achieve sulphur dioxide (SO_2) emissions complying with the regulation even when running on HSFO, or ships can burn lower-sulphur fuels.

Open loop scrubbers are the most economically attractive solution for most of the large vessels, but their use may not be allowed in shallow coastal waters or may be banned entirely in ports or in some regions. The alternative of closed-loop scrubbers may be too expensive in view of the chemicals required (mainly caustic soda) and the need to store produced wash water onboard for discharge in dedicated ports. This Outlook, therefore, expects a sharp increase in demand for low-sulphur fuels until the majority of the large vessels can be equipped with scrubbers. In the long-term, LNG may play a far more important role than it does today. Most large marine engines can already be ordered as dual-fuel engines, which can run on either liquid fuel or LNG.

The modern, large ICEs used in marine transportation are currently the most efficient combustion engines and may achieve efficiency rates above 50%. Adding a Waste Heat Recovery (WHR) unit may add another 5–8% in efficiency gains in absolute terms. However, even with available WHR engines, future improvements are limited. Other factors which may be more promising in the longer-term are hull innovations (including improved propellers) and air lubrication which is already employed in some cases. This Outlook considers such potential improvements in an evolutionary manner.

Another aspect which repeats in all transport segments is the rapid shift towards digitalization to increase value along the transportation chain. More intelligent and interconnected freight management systems may quickly grant improvements beyond the scope of pure technology hardware advances. Examples would be the possibility of optimizing the routes themselves by taking advantage of ocean currents, or increasing the average load factor (actually occupied transport space or weight *versus* deadweight tonnage (DWT) of vessels to avoid empty passages.

1.4.6 Technology related to oil production

The supply side of the energy business has been re-shaped considerably over the past decade or so by the advent of tight oil and shale gas. Both are the result of technology developments that efficiently combine the known technologies of directional drilling and hydraulic fracturing with highly advanced sensing and visualisation methods. The latter are almost entirely based on computing power provided by modern IT systems. Production costs have been brought down swiftly and tight oil is now an established segment of oil supply. The challenge nonetheless remains to convert tight oil and shale gas production into a more environmentally-friendly energy source. The proppants used, as well as the flaring of associated gas – mainly methane – are a significant setback in this regard. For oil sands, *in situ* methods are advancing and reducing production costs, as well as their environmental impact.

In the future, CCS/CCU may not only assist enhanced oil recovery (EOR) but also help to significantly reduce the overall CO_2 emissions of the oil business. Ambitious targets to restrict global warming will be nearly impossible to achieve without greater use of this concept.

1.4.7 IT, big data and artificial intelligence

Currently, the world is witnessing a new phase in IT. Computing power is still expanding at a fast pace while new information processing concepts are quickly being designed and implemented. Artificial Intelligence (AI) and machine learning have the potential to reshape the energy business. In the future, AI will move towards machine learning, which is a far broader concept, and could result in robots, for example, being able to react in a flexible manner to changing conditions in a mission- or task-oriented manner.

The combination of unprecedented computing power and increased data collection at faster speeds has made it possible to test well-known physical laws just by calculations using design software. This speeds up technology advances enormously when compared to the earlier experimental technique using physical tests in a laboratory. The ability to collect and share data has also grown at a rapid pace, giving rise to massive databases. Big Data concepts will allow increased control at a far earlier stage in the design and manufacturing process than has been possible in the past. The result will be not only a far smoother energy chain, but also a far more flexible one too.

1.4.8 New concepts

Technological advances are not only restricted to providing improved solutions for existing problems or business areas, but also include the invention of new products and services or new ways to use these goods. A good example is electricity: although initially intended mainly for lighting, it was quickly used for driving machinery.

Today, IT has begun to consume a significant – and rapidly increasing – share of the power generated around the world. For example, cryptocurrency mining can use as much energy as a small country. This new and significant consumer of electric power has a short history which dates back to the 1980s at the earliest. This outlook pays attention to such future developments. In the end, global energy consumption will rise although the world is becoming increasingly more energy-efficient.

Energy demand

Key takeaways

- Total global primary energy demand is forecast to increase by 72 million barrels of oil equivalent a day (mboe/d) from 285.8 mboe/d in 2018 to 357.5 mboe/d by 2040, representing average growth of 1% p.a.

- From 2018-2040, energy demand in non-OECD countries is expected to increase by 74.8 mboe/d, while demand in the OECD is forecast to drop by 3.1 mboe/d.

- Energy demand in India and China is anticipated to rise on average by 3.2% and 1.1% p.a., respectively, which accounts for almost 50% of energy demand growth in non-OECD countries over the forecast period.

- Oil is expected to remain the dominant fuel, with demand growth of more than 10.6 mboe/d by 2040, although this translates to a relatively low growth rate of 0.5% p.a.

- The 'other renewables' grouping (including mainly solar, wind and geothermal) remains the fastest growing source of energy (6.9% p.a.) between 2018 and 2040. The largest demand growth is seen for natural gas, with an expected increase of 24.8 mboe/d.

- Natural gas is the only fossil fuel in OECD countries that is forecast to see demand rise over the projection period, although the increment is minor compared to the expected boost in gas consumption in the non-OECD region.

- Coal is forecast to see demand growth of less than 1 mboe/d, which is below 0.1% p.a.

- Oil and gas are anticipated to retain more than a 50% share in global energy demand through to 2040.

- Demand for nuclear power is expected to increase by around 7 mboe/d (1.9% p.a.), while hydro is forecast to witness demand growth of close to 3 mboe/d (1.6% p.a.) over the forecast period.

- A slow but gradual demand increase is forecast for biomass, around 1% p.a., which equates to an additional 7 mboe/d.

- The expected overall increase in annual energy-related emissions is 4.4 billion tonnes (bt) between 2018 and 2040. This represents growth of around 13%, which is only around half of the overall energy demand increase.

- Despite the declining trend in coal demand after 2030, coal is still forecast to be the largest source of carbon dioxide (CO_2) emissions, accounting for almost 40% (14.9 bt) of total emissions in 2040.

Energy drives every aspect of the modern world and directly impacts not only the global economy, but people's quality of life. The interaction between global economic growth and increases in energy demand is, evidently, associated with the economic development of individual countries and regions, as well as changes in technology, demographics and efficiency trends. In turn, these can be driven by policies enacted to tackle climate change and address fuel diversity concerns, resulting in a complex mix of factors shaping the energy mix at the local, regional and global level. This Chapter will focus on demand for the different sources of energy, as well as overarching regional and global trends in energy use. It should be noted that the baseline data for 2018 is based on the available statistical data and supplemented by estimates for regions where final statistics are not yet available.

2.1 Major trends in energy demand

Slower population growth and improved energy efficiency have resulted in a deceleration of energy demand growth in developed regions in recent decades. Today, developing countries are responsible for a large portion of the global energy demand increase, given that they account for most of the upward trend in urbanization and population growth.

Another aspect of the modern age is the threat of climate change and the challenge to reduce CO_2 emissions. At the COP21 in Paris, France on 12 December 2015, a large number of participants signed the Paris Agreement designed to limit the global rise in temperature to well below 2°C and to pursue efforts to limit the temperature increase even further to 1.5°C, continues to receive strong support from a large number of participants and regions. However, the US administration's decision to suspend its support for the Paris Agreement remains a major uncertainty, one that casts doubt on the fate of the Agreement and the potential commitment of other countries to their pledges.

While it is true that most energy global demand has traditionally been met by fossil fuels, the use of alternative sources of energy, particularly renewables and also nuclear power, has risen considerably over the last two decades as these have continued to become more competitive. The use of renewables in power generation is increasing almost everywhere. Falling production costs, particularly for wind and solar, are making renewables more competitive than ever. Renewables tend to push out coal, further cutting into its market share in the energy mix, particularly in OECD regions. Coal demand is increasing mainly in Asia, where security of supply to meet rising energy demand is a key concern.

The prospects for hydro are limited, except in some non-OECD countries. It is a fact that most hydro potential is already being harnessed in developed countries, while access to new, suitable water sources is a serious limiting factor in many other regions.

The pathways towards an energy transition are unique to each region and country. It is believed that further shifts in the power generation mix will depend significantly on country-level policies and investments due to the varying conditions for renewable energy sources, as well as intermittent nature of renewables. Government policies play a key role in increasing the amount of electricity generated from renewable sources and in limiting the burning of coal to produce power.

Likewise, a global expansion in the use of EVs relies on strong subsidy support, as well as the construction of a sufficient number of charging stations. This continues to be a challenge, especially in developing countries. Additionally, long-term maintenance and the disposal costs and hazards of EVs are still being debated. The production and disposal of batteries that contain lithium and cobalt can heavily impact the environment, potentially leading to water pollution and other environmental consequences. Therefore, the extent of future EVs demand growth is also dependent on the innovation of appropriate solutions for the collection and recycling of EV batteries.

This all serves to highlight the influence that governments have to shape the future energy mix using policy and other tools, including direct and indirect efforts to expand the use of renewables and improve energy efficiency.

Trends in the nuclear power industry seem to be diverging in the OECD and non-OECD regions. The higher safety regulations in this sector, particularly following the Fukushima nuclear accident, mean both higher capital and maintenance costs. This also makes it more challenging to build new nuclear plants in both developing and developed countries.

Taking these major trends into account, this Outlook projects that global energy demand will rise from less than 286 mboe/d in 2018 to more than 357 mboe/d in 2040 (Table 2.1). This implies global energy demand growth of nearly 72 mboe/d, equal to an average growth rate of 1% p.a. over the long-term. A large part of this growth is anticipated to come from India, China and other non-OECD countries, where population growth, rising urbanization, economic developments and technological advances result in growing energy needs and where electricity access is expected to rise in remote areas (Figure 2.1). An average annual growth rate of 1.6% is projected for demand growth in non-OECD countries between 2018 and 2040. Demand for energy in OECD regions is expected to fall by 0.1% p.a. over the same period, due to improving energy efficiency and lower population growth.

Table 2.1
Total primary energy demand by region, 2018–2040

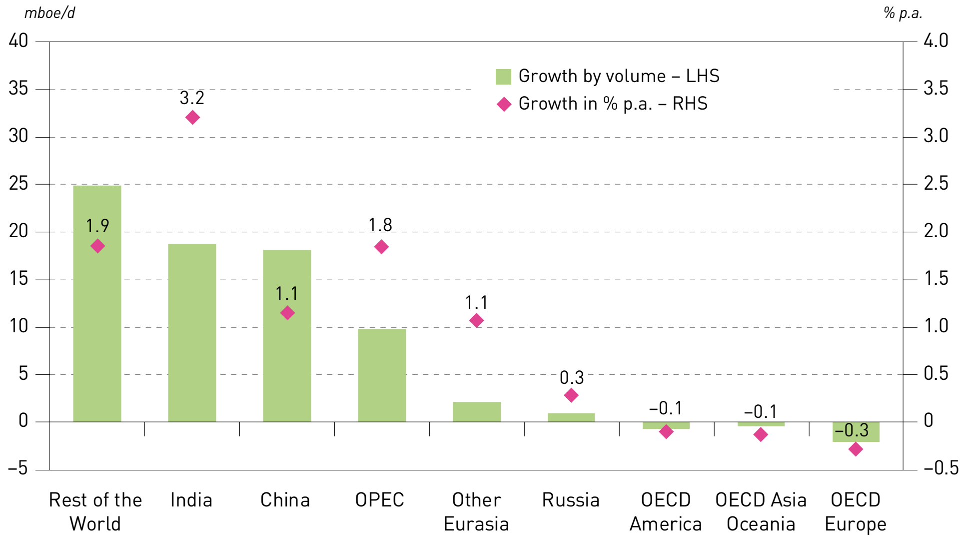
	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Share of global energy demand *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	56.0	56.7	56.6	55.3	–0.7	–0.1	19.6	19.3	17.2	15.5
OECD Europe	36.4	36.4	35.7	34.3	–2.1	–0.3	12.7	12.4	10.9	9.6
OECD Asia Oceania	18.2	18.1	18.1	17.9	–0.4	–0.1	6.4	6.2	5.5	5.0
OECD	**110.6**	**111.2**	**110.5**	**107.5**	**–3.1**	**–0.1**	**38.7**	**37.9**	**33.6**	**30.1**
China	63.6	66.1	75.5	81.8	18.1	1.1	22.3	22.5	22.9	22.9
India	18.8	20.2	28.7	37.5	18.8	3.2	6.6	6.9	8.7	10.5
OPEC	20.0	20.4	25.5	29.8	9.9	1.8	7.0	6.9	7.8	8.3
Other non-OECD	49.9	52.0	63.8	74.8	24.9	1.9	17.5	17.7	19.4	20.9
Russia	14.8	15.0	15.5	15.8	1.0	0.3	5.2	5.1	4.7	4.4
Other Eurasia	8.2	8.5	9.5	10.3	2.1	1.1	2.9	2.9	2.9	2.9
Non-OECD	**175.3**	**182.2**	**218.4**	**250.1**	**74.8**	**1.6**	**61.3**	**62.1**	**66.4**	**69.9**
World	**285.9**	**293.4**	**328.9**	**357.5**	**71.7**	**1.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

In terms of global primary energy demand through to 2040, the 'other renewables' segment is forecast to remain the fastest growing on a percentage basis (6.9% p.a.), with demand rising by nearly 18 mboe/d between 2018 and 2040 (Table 2.2). Demand for coal, on the other hand, is not expected to rise by more than 1 mboe/d, which is less than 0.1% p.a. Gas demand is projected to rise the most in volumetric terms, with nearly 25 mboe/d (1.6% p.a.) of incremental demand growth expected over the long-term. Oil demand is expected to grow by more than 10 mboe/d by 2040 (0.5% p.a.).

Nuclear and biomass are each expected to see demand growth of around 7 mboe/d over the forecast period (1.9% p.a. and 1% p.a. respectively), while demand for hydro is forecast to grow by only 3 mboe/d (1.6% p.a.).

Figure 2.1
Growth in primary energy demand by region, 2018–2040



Source: OPEC.

A gradual increase in demand for biomass is set to continue. In the long-term, however, the expected increase in demand for modern biomass, such as advanced biofuels, and falling demand for traditional biomass will likely result in a gradual decline in the share of biomass in the energy mix of non-OECD countries, given that they are major consumers of traditional biomass.

Table 2.2
World primary energy demand by fuel type, 2018–2040

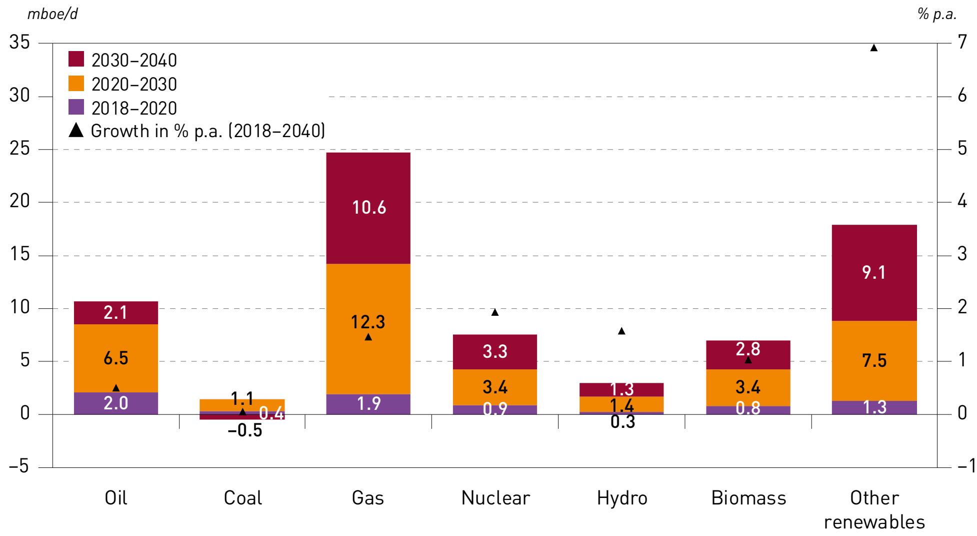
	Levels mboe/d				Growth mboe/d	Growth % p.a.	Share of global energy demand %			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
Oil	90.1	92.1	98.6	100.7	10.6	0.5	31.5	31.4	30.0	28.2
Coal	75.9	76.2	77.3	76.8	0.9	0.1	26.6	26.0	23.5	21.5
Gas	65.5	67.4	79.7	90.3	24.7	1.5	22.9	23.0	24.2	25.2
Nuclear	14.3	15.1	18.5	21.8	7.5	1.9	5.0	5.2	5.6	6.1
Hydro	7.3	7.5	8.9	10.2	3.0	1.6	2.5	2.6	2.7	2.9
Biomass	27.5	28.3	31.7	34.5	7.0	1.0	9.6	9.7	9.7	9.6
Other renewables	5.3	6.6	14.1	23.2	17.9	6.9	1.9	2.3	4.3	6.5
Total	**285.8**	**293.3**	**328.8**	**357.5**	**71.7**	**1.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

A gradual shift away from coal and oil toward renewables and gas is being driven by policies and initiatives focused on increasing the share of cleaner fuels in the energy mix, particularly in power generation. These include binding fuel efficiency regulations and higher standards across different regions and countries. As a result, oil and coal are expected to lose nearly 3 percentage points (pp) and 5 pp of their market share, respectively, by 2040. The share of gas in the global energy mix is anticipated to rise by less than 2.5 pp and 'other renewables' by 4.5 pp. Nonetheless, oil is forecast to remain the dominant fuel source, accounting for the largest share in the energy mix over the forecast period.

Despite coal seeing its share in the global energy mix fall, other fossil fuels (namely, oil and gas) are anticipated to retain more than a 50% share in the global energy mix through 2040. Demand for gas is expected to see a rapid expansion, while demand for oil will likely see its growth rate slow through to 2040 (Figure 2.2). The combined contribution of the three fossil fuels is expected to fall below 75% in 2040 from more than 80% currently.

Figure 2.2
Growth in primary energy demand by fuel type, 2018–2040



Source: OPEC.

2.2 Energy demand by region

As demand for energy increases, unique patterns of demand in each region and sub-region will continue to result in different fuel mixes across regions. A combination of several factors influences these patterns, although there are some general factors that hold true across regions that result in some similarities.

For instance, the energy mix in OECD countries reflects the importance of oil as a major source of energy, with gas second in the fuel mix (Table 2.3). In this region, oil and gas combined account for more than 60% of total primary energy demand, and this is expected to remain more or less in the same range by 2040. However, the share of the two fuels are estimated to approach parity towards the end of the long-term horizon.

Non-OECD countries currently rely more on coal than any other fuel to meet their energy demand. In the growth pattern shown in Table 2.4, it is evident that even though coal will lose some market share to gas, nuclear and renewables, it will still account for a large share of the non-OECD energy demand mix through to 2040.

Table 2.3
OECD primary energy demand by fuel type, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Fuel shares *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
Oil	41.5	41.6	38.1	32.5	–9.0	–1.1	37.5	37.4	34.5	30.2
Coal	17.5	16.9	14.2	12.0	–5.4	–1.7	15.8	15.2	12.9	11.2
Gas	29.8	30.1	31.3	32.1	2.3	0.3	27.0	27.0	28.4	29.9
Nuclear	10.3	10.4	10.8	11.1	0.7	0.3	9.3	9.3	9.7	10.3
Hydro	2.5	2.5	2.7	2.9	0.4	0.7	2.3	2.3	2.5	2.7
Biomass	6.5	6.7	7.9	8.9	2.4	1.4	5.8	6.0	7.1	8.2
Other renewables	2.6	3.1	5.5	8.0	5.4	5.3	2.3	2.8	4.9	7.4
Total	**110.6**	**111.2**	**110.5**	**107.5**	**–3.1**	**–0.1**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Table 2.4
Non-OECD primary energy demand by fuel type, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Fuel shares *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
Oil	48.6	50.5	60.5	68.2	19.6	1.6	27.7	27.7	27.7	27.3
Coal	58.4	59.4	63.1	64.8	6.3	0.5	33.3	32.6	28.9	25.9
Gas	35.7	37.3	48.4	58.2	22.5	2.2	20.4	20.5	22.1	23.3
Nuclear	4.0	4.8	7.8	10.7	6.8	4.6	2.3	2.6	3.6	4.3
Hydro	4.8	5.0	6.2	7.3	2.6	2.0	2.7	2.7	2.8	2.9
Biomass	21.0	21.6	23.9	25.6	4.6	0.9	12.0	11.9	10.9	10.2
Other renewables	2.8	3.5	8.7	15.2	12.5	8.1	1.6	1.9	4.0	6.1
Total	**175.3**	**182.2**	**218.4**	**250.1**	**74.8**	**1.6**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

In terms of the non-OECD region, it is worth looking in more depth at India and China (Tables 2.5 and 2.6), given they are the main engines driving energy demand growth and are expected to account for the majority of global electricity demand growth. Coal is the primary energy source in both countries, accounting for approximately 45% and 60% of India's and China's total energy demand, respectively, in 2018. However, it is expected that China's coal consumption will drop by 0.3 % p.a. on average through to 2040, unlike in India, where demand for coal is forecast to grow at an average rate of 3% p.a., adding more than 8.5 mboe/d of demand through to 2040.

Gas consumption rose by nearly 17% in China in 2018, straining both pipelines and LNG facilities. Gas demand in this country is expected to grow in the medium- and long-term at a pace of almost 4 % p.a., with gas replacing coal power generation as a means to reduce air pollution. In absolute

Table 2.5
China primary energy demand by fuel type, 2018–2040

	Levels mboe/d				Growth mboe/d	Growth % p.a.	Fuel shares %			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
Oil	12.1	12.7	14.7	15.9	3.8	1.3	19.0	19.3	19.5	19.5
Coal	39.0	39.1	38.4	36.7	–2.3	–0.3	61.3	59.1	50.9	44.9
Gas	4.9	5.5	8.8	11.3	6.3	3.8	7.7	8.4	11.7	13.8
Nuclear	1.6	2.2	4.3	6.0	4.4	6.3	2.4	3.3	5.6	7.3
Hydro	2.1	2.1	2.5	2.8	0.7	1.4	3.3	3.2	3.3	3.4
Biomass	2.5	2.6	2.8	3.2	0.7	1.2	3.9	3.9	3.7	4.0
Other renewables	1.5	1.9	4.0	5.8	4.3	6.4	2.4	2.9	5.2	7.2
Total	**63.6**	**66.1**	**75.5**	**81.8**	**18.1**	**1.1**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Table 2.6
India primary energy demand by fuel type, 2018–2040

	Levels mboe/d				Growth mboe/d	Growth % p.a.	Fuel shares %			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
Oil	4.6	4.9	7.2	9.8	5.2	3.5	24.5	24.5	25.1	26.0
Coal	8.4	9.1	13.1	17.1	8.6	3.3	44.9	45.2	45.7	45.4
Gas	1.0	1.1	2.0	3.0	1.9	4.9	5.5	5.6	6.9	7.9
Nuclear	0.2	0.3	0.6	1.0	0.8	6.8	1.3	1.5	2.2	2.8
Hydro	0.3	0.3	0.4	0.5	0.3	3.4	1.4	1.4	1.5	1.5
Biomass	4.0	4.1	4.4	4.3	0.3	0.3	21.5	20.4	15.2	11.5
Other renewables	0.2	0.2	1.0	1.8	1.7	11.5	0.9	1.2	3.4	4.9
Total	**18.8**	**20.2**	**28.7**	**37.5**	**18.8**	**3.2**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

terms, gas demand is estimated to witness the highest incremental demand (6.4 mboe/d) through to 2040, followed by nuclear and 'other renewables' at 4.4 mboe/d and 4.3 mboe/d, respectively, although both are starting from a very low baseline.

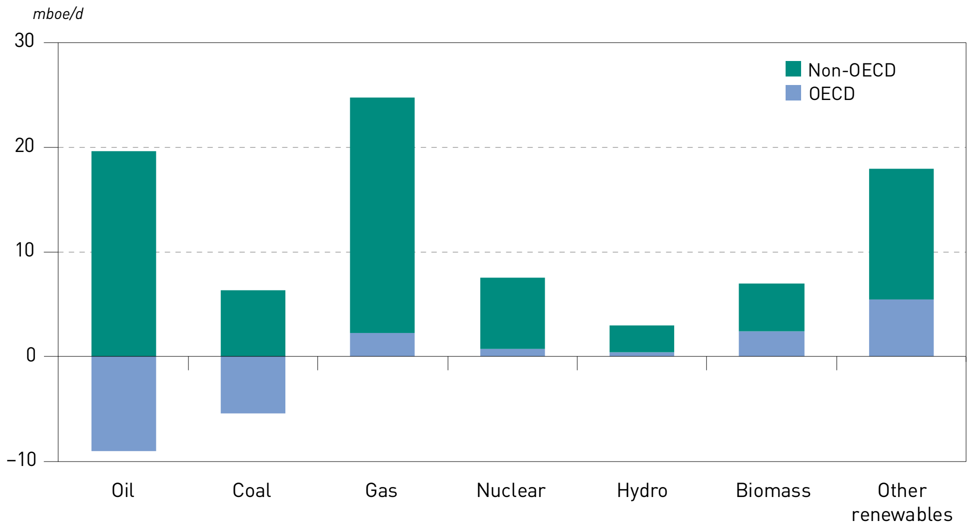
Over the same period, demand for oil, hydro and biomass in China is expected to see annual growth averaging less than 1.5%. This translates to additional demand of nearly 4 mboe/d of oil versus a combined addition of 1.4 mboe/d for hydro and biomass.

In India, gas demand rose by more than 8% in 2018. Growth is projected to continue throughout the forecast period at a rate of nearly 5% p.a., a pace that is slower than that for 'other renewables' (11.3% p.a.) and nuclear (7.4% p.a.). By 2040, it is expected that coal demand will be almost

10 mboe/d higher than in 2018, followed by demand growth for oil (6 mboe/d) and gas (2 mboe/d). Additionally nuclear, hydro , biomass and 'other renewables' are estimated to provide a combined 4 mboe/d of additional demand over the same period, rising from a very low baseline in 2018. This is due to supportive policies and a continuous lowering of costs, especially for solar and wind. In comparison to 'other renewables', there is no significant increase in demand for hydro expected in any region, and this is particularly true in the OECD, where hydro resources are already widely utilized.

Looking at the projections with more granularity, overall energy demand in the OECD is expected to decline by 0.1% p.a. on average between 2018 and 2040. 'Other renewables', as the fastest growing energy source in the OECD region, is also expected to lead demand growth in absolute terms with an overall increment of close to 5.5 mboe/d (Figure 2.3). In this region, oil and coal together are estimated to see demand decline by more than 14 mboe/d, while the combined increase in demand for gas, nuclear, hydro and biomass will be near 9 mboe/d.

Figure 2.3
Growth in energy demand by fuel type and region, 2018–2040



Source: OPEC.

In the non-OECD region, demand for nuclear power is expected to expand at a relatively strong pace of around 4.5% p.a., even if in absolute terms this amounts to only 6.8 mboe/d between 2018 and 2040. 'Other renewables' will be the fastest-growing source of energy throughout the region within the forecast period.

In fact, demand for all of the energy sources is expected to grow through to 2040, although the growth rate for coal and biomass demand is estimated to be below 1%. These lower growth rates are seen mainly as a result of emission reduction policies and a shift away from the traditional usage of biomass in rural areas given further efforts to alleviate energy poverty.

2.3 Energy demand by fuel

2.3.1 Oil

It is important to note that the figures shown in this Chapter are not directly comparable with those shown in other chapters. There are two main reasons for this. Firstly, Chapter 2 uses energy equivalent units (mboe/d) to allow for a comparison between the different fuel types. In other chapters, however, oil is expressed in volumetric units (million barrels per day (mb/d)). Secondly, the definition of oil in Chapter 2 is different from that used in Chapters 3 through 6. While Chapter 2 deals with primary energy sources, other chapters consider the outlooks for all liquid fuels. In that sense, in this chapter, biofuels is considered as biomass, coal-to-liquids (CTLs) as coal and gas-to-liquids (GTLs) as gas, but they are all part of the liquids outlook in Chapter 3 (and 4–6).

As discussed earlier, oil will remain an important part of the global energy mix for the entire forecast period, despite its share in the global energy mix declining by more than 3 pp between 2018 and 2040, from almost 32% in 2018 to some 28% in 2040. Measured on an energy content basis, oil demand is expected to grow by 10.6 mboe/d in the period between 2018 and 2040 to reach 100.7 mboe/d in 2040. This makes oil the third largest contributor to global energy demand growth, surpassed only by gas and 'other renewables'. Moreover, oil is forecast to remain the fuel with the largest share in the energy mix over the period to 2040.

At the regional level, as presented in Table 2.7, a contrasting picture is expected to develop between the two major regions over the forecast period, with demand for oil declining in OECD countries, but rising in non-OECD countries. Oil demand in the non-OECD region is expected to increase markedly in the years to 2040, driven by an expanding middle class, high population growth rates and stronger economic potential. The demand increase in this group of countries is projected to be close to 20 mboe/d between 2018 and 2040.

Turning to the OECD, oil demand in this group of countries is expected to plateau over the coming years before beginning a longer-term decline. The steepest fall in demand is projected to be in OECD Americas (–4 mboe/d), although in relative terms, demand is expected to drop in OECD Asia

Table 2.7
Oil demand by region, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Fuel shares *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	21.2	21.6	20.1	17.2	–4.0	–0.9	23.6	23.4	20.3	17.1
OECD Europe	12.8	12.8	11.6	9.9	–3.0	–1.2	14.3	13.9	11.8	9.8
OECD Asia Oceania	7.4	7.3	6.4	5.4	–2.0	–1.5	8.2	7.9	6.5	5.3
OECD	**41.5**	**41.6**	**38.1**	**32.5**	**–9.0**	**–1.1**	**46.0**	**45.1**	**38.6**	**32.3**
China	12.1	12.7	14.7	15.9	3.8	1.3	13.4	13.8	14.9	15.8
India	4.6	4.9	7.2	9.8	5.2	3.5	5.1	5.4	7.3	9.7
OPEC	8.5	8.7	10.5	11.4	2.9	1.4	9.4	9.4	10.7	11.4
Other non-OECD	18.2	18.7	22.1	25.1	7.0	1.5	20.2	20.3	22.4	25.0
Russia	3.4	3.4	3.7	3.6	0.2	0.3	3.7	3.7	3.7	3.6
Other Eurasia	1.9	2.0	2.3	2.4	0.5	1.0	2.1	2.2	2.3	2.3
Non-OECD	**48.6**	**50.5**	**60.5**	**68.2**	**19.6**	**1.6**	**54.0**	**54.9**	**61.4**	**67.7**
World	**90.1**	**92.1**	**98.6**	**100.7**	**10.6**	**0.5**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Oceania much faster than in OECD Americas. Given that oil is the primary focus of this publication, a detailed analysis of the drivers behind these changes and a further breakdown of trends at the sectoral level is included in Chapter 3.

2.3.2 Coal

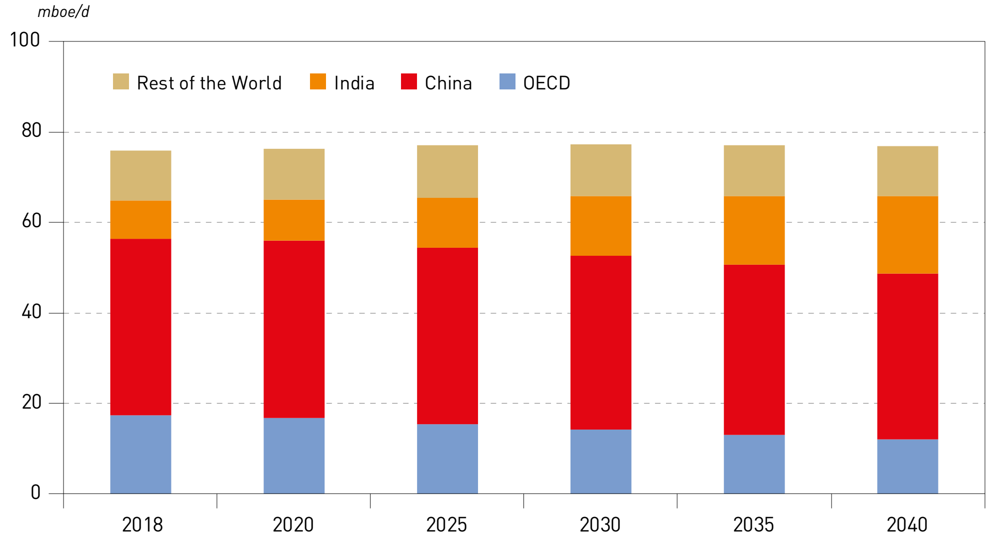
Slower global economic growth and environmental concerns have discouraged demand growth and resulted in struggles for the coal sector. That said, the world is still highly dependent on coal and there was a slight increase in global coal demand in 2018. This growth is mainly reflective of the growing economies and populations of China, India and South Asia, while trade into Europe continued to decline.

Demand for coal is expected to expand in the medium-term, largely due to higher demand in India, South East Asia, Turkey and Brazil. The fact that there is limited new investment in mining capacity for steam coal production to meet rising demand from power plants could result in considerable steam coal price volatility going forward.

It should be noted that the coking coal market, which is closely linked to the steel industry, is expanding and has to date not been visibly impacted by climate change policies. Prices have been volatile in this market of late, mainly due to growing demand and supply disruptions out of Australia's Dalrymple Bay in Queensland. Indian coking coal imports increased over 2018, and this is expected to continue in 2019. South Korea, Japan, Brazil and Turkey are also expected to experience growing medium-term demand for coking coal, although at a slower pace.

Global coal demand is evidently linked to its demand trajectory in China, which accounts for 50% of the total (Figure 2.4). As a result, China can strongly influence global coal markets and any change in Beijing's environmental policies will have an impact on future coal medium- and long-term demand. Additionally, Chinese import restrictions meant to protect its domestic mining sector have negatively impacted Australia's mining industry.

Figure 2.4
Coal demand by major region, 2018–2040



Source: OPEC.

Since 2016, in line with **China**'s commitment to reduce pollution and improve safety, the Chinese National Development & Reform Commission (NDRC) has been implementing a set of policies that have thus far resulted in the retirement of more than 400 million tonnes of inefficient coal mining capacity – half of the 2020 retirement target. The NDRC also recently announced a plan to close all mines producing less than 300,000 tonnes a year in four regions. The NDRC is also seeking to close mines with low reserve quality and competitiveness in regions such as Heilongjiang, Hubei and Hunan. Mines have also been restricted to operating 276 days per year. Moreover, in 2018, Beijing set a cap on imports of thermal coal, coking coal and anthracite to help domestic producers, a policy that continued in 2019.

As a result of these policy measures, demand for coal in China is expected to decline gradually, from just less than 40 mboe/d in 2018 to below 39 mboe/d in 2030 and then to 36.7 mboe/d by 2040 (Table 2.8). This means an average demand reduction of 0.3% p.a. over the forecast period, resulting in China's expected 2040 coal demand being 4 mboe/d below its 2013 peak. Coal's share in the Chinese energy mix is expected to drop by nearly 15% through to 2040. This lost market share is anticipated to be captured largely by gas, but also by renewables and nuclear.

Table 2.8
Coal demand by region, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Share of global energy demand *%*			
	2018	**2020**	**2030**	**2040**	**2018–2040**	**2018–2040**	**2018**	**2020**	**2030**	**2040**
OECD Americas	7.4	7.1	5.9	5.0	–2.4	–1.7	9.7	9.3	7.7	6.5
OECD Europe	5.2	4.9	3.9	3.0	–2.2	–2.4	6.8	6.5	5.1	3.9
OECD Asia Oceania	4.9	4.8	4.4	4.0	–0.9	–0.9	6.4	6.3	5.7	5.2
OECD	**17.5**	**16.9**	**14.2**	**12.0**	**–5.4**	**–1.7**	**23.0**	**22.1**	**18.4**	**15.7**
China	39.0	39.1	38.4	36.7	–2.3	–0.3	51.4	51.2	49.7	47.8
India	8.4	9.1	13.1	17.1	8.6	3.3	11.1	12.0	16.9	22.2
OPEC	0.1	0.1	0.1	0.1	0.0	–0.4	0.1	0.1	0.1	0.1
Other non-OECD	6.8	7.0	7.4	7.1	0.3	0.2	9.0	9.2	9.6	9.3
Russia	2.3	2.3	2.2	2.0	–0.3	–0.6	3.0	3.0	2.8	2.6
Other Eurasia	1.8	1.9	1.9	1.8	0.0	0.0	2.4	2.4	2.4	2.4
Non-OECD	**58.4**	**59.4**	**63.1**	**64.8**	**6.4**	**0.5**	**77.0**	**77.9**	**81.6**	**84.3**
World	**75.9**	**76.2**	**77.3**	**76.8**	**0.9**	**0.1**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

In **India**, urbanization, industrialization and population growth has resulted in consistently increasing demand for steam coal, as hydro and renewables are unable to meet growing electricity demand. However, India's domestic coal production is insufficient to meet demand, which makes the country dependent on imports even though new coal production capacity is being brought online. Recently, smaller, privately-owned companies have begun mining coal in India, however, this will not be enough to offset expanding demand.

Although India has plans to reduce its reliance on coal-fired power generation in the long-term, it is estimated that coal demand in this country will rise by 3.3% p.a. and reach almost 17 mboe/d by

2040. This means the share of coal in the Indian energy mix is forecast to remain almost unchanged at roughly 45% over the medium- and long-term, despite the compelling expansion of renewables.

Coal demand elsewhere in **non-OECD Asian countries**, such as in Thailand, Vietnam, the Philippines, Indonesia and Malaysia, is also anticipated to rise over the medium- to long-term. It is interesting to recall that before 2000, OECD Europe and OECD Americas accounted for the majority of global coal demand. The picture has changed markedly, with coal consumption in OECD regions having fallen sharply and emerging and developing Asian countries now consuming the most coal.

In the **EU**, climate change mitigation measures and higher carbon prices as part of its Emission Trading Scheme (ETS) have resulted in a reduction of steam coal imports. European countries are moving quickly to reduce their thermal coal consumption, resulting in imports falling in 2017 and 2018, a trend expected to continue in 2019 and throughout the medium- and long-term.

For example, in recent years the power generated from coal in Germany fell consistently, while electricity generation from renewables rose significantly. Nonetheless, Germany is still expected to fall short of its target to reduce GHG emissions by 40% by 2020 (compared to 1990 levels) if no further action is taken. Therefore, early in 2019, the German government approved an aid package for coal regions worth as much as €40 billion to phase out coal-fired power generation by 2038 and to transform the energy sector with high-tech and clean energy sources. However, this plan has been criticized by some for its potential to raise electricity prices and result in job losses over the medium-term.

Looking to the future, coal demand in **OECD Europe** is expected to decline by 2.5% p.a., from nearly 5 mboe/d in 2018 to 3 mboe/d in 2040. In line with this demand reduction, the share of coal in the region's energy mix is estimated to shrink to less than 9% by 2040, with renewables picking up a large portion of coal's lost market share.

A similar trend is expected in **OECD Americas**, where coal use is dominated by the US. Demand for coal is forecast to fall by an average of 1.7% p.a. over the outlook period. This translates into almost 2.5 mboe/d less demand by 2040, compared to 2018 levels.

Demand for coal in **OECD Asia Oceania** is expected to contract by less than 1% p.a. on average over both the medium- and long-term. Japan and South Korea account for most of the decline as both are increasing their use of renewables. In Japan, the gradual restart of nuclear plants is also expected to contribute to lower coal use.

In summary, global coal demand has begun to peak as more attractive, cleaner alternatives become more financially viable, particularly in terms of wind and solar for power generation. The wider availability of natural gas is also playing a large role in certain regions. The retirement of a number of coal power plants and low investment into new plants, as well as rising operating costs at less efficient coal plants, have also negatively impacted global coal demand.

It is expected that global coal demand will slowly increase for a couple more years from the current level of roughly 76 mboe/d, before beginning a decline by 2030. As a result, average global demand for coal is expected to grow only marginally between 2018 and 2040, and the share of coal in the global energy mix is expected to drop by around 5% by 2040. Nevertheless, it should be highlighted that even if coal continues to lose market share in the global energy mix, it is still anticipated to remain a dominant fuel in the power generation sector due to its affordability and accessibility.

2.3.3 Natural gas

Global gas demand increased by more than 4% year-on-year (y-o-y) in 2018, the highest increment since 2010. This demand growth came from several regions and countries, led by the US and

China. In fact, the two countries alone accounted for more than 60% of the growth. Strong growth was also recorded in some countries in the Middle East and the Asia-Pacific. The demand increase was supported by several drivers, such as the policy-driven phase out of coal plants, weather-related demand effects and economic growth. However, traditional gas markets, such as Europe, witnessed a demand decline, partly due to rising gas prices, which increased by almost 40% in 2018 relative to the year prior.

In the **US**, gas demand grew by more than 10% in 2018, driven by an increase in gas used for power generation, mostly replacing coal in the power mix. The residential, as well as the industrial sector, also contributed to this trend. Rising US gas supply and low Henry Hub prices were significant factors, especially in price-sensitive demand sectors such as power generation. Rising US supply resulted in some regional hubs even recording negative prices at times in 2019.

Chinese gas demand increased by almost 18% in 2018, driven by continuous governmental support for switching from inefficient and old coal power plants as a means to reduce air pollution. **China** has also announced its so-called 'blue sky' plan on pollution controls for the period 2018–2020. The 'blue sky' plan targets a phasing out of inefficient coal units, thus supporting the expansion of gas demand in the country. The policy-driven measures more than offset increases in regional gas prices – the Asian spot LNG price rose more than 40% y-o-y in 2018.

Furthermore, several countries in the **Middle East** saw significant gas demand growth, with continuously rising domestic power demand amidst efforts to replace oil and oil products in the power generation sector. Modest increases were also seen in some Asian countries, such as India, Bangladesh and Pakistan.

Gas consumption in **OECD Europe**, on the other hand, fell by around 2% in 2018 due to rising gas prices and the increasing penetration of renewables in the power generation sector, which has squeezed out some gas-fired plants. Milder-than-average weather also led to lower residential demand over the winter. In **Japan**, another large gas consumer, demand dropped slightly as several nuclear reactors were brought back online and rising spot price levels lowered the price advantage of gas over other energy sources.

On the supply side, 2018 and early 2019 saw a strong increase in LNG supplies, predominantly from the US. As of mid-2019, around 50 metric tonnes per annum (mtpa) of LNG liquefaction capacity had come online since early 2018, mainly in the US, but also in Russia and Australia. According to estimates based on project lists, another 65 mtpa of LNG capacity – mostly in the US, but also Canada, Indonesia, Mozambique and Russia – is under construction and is scheduled to come online before 2025.

Looking forward, global gas demand is forecast to continue its upward growth trajectory, rising from 65 mboe/d in 2018 to just above 90 mboe/d in 2040 (Table 2.9). This 25 mboe/ increase is the largest volumetric growth expected for all of the energy sources over the outlook period. The surge in demand is being driven by greater supply availability, coupled with more pipeline and LNG export capacity that makes gas more widely available. This is expected to result in lower prices and make the substitution of gas for coal in the power generation sector more economically attractive.

Natural gas is expected to overtake coal in the primary energy mix by 2030, as power and heat generation switch from coal to gas. Consequently, natural gas is forecast to become the second largest energy source by 2030. In 2040, the share of natural gas in the primary energy demand mix is expected to be just above 25%, up almost 2.5 pp from 2018.

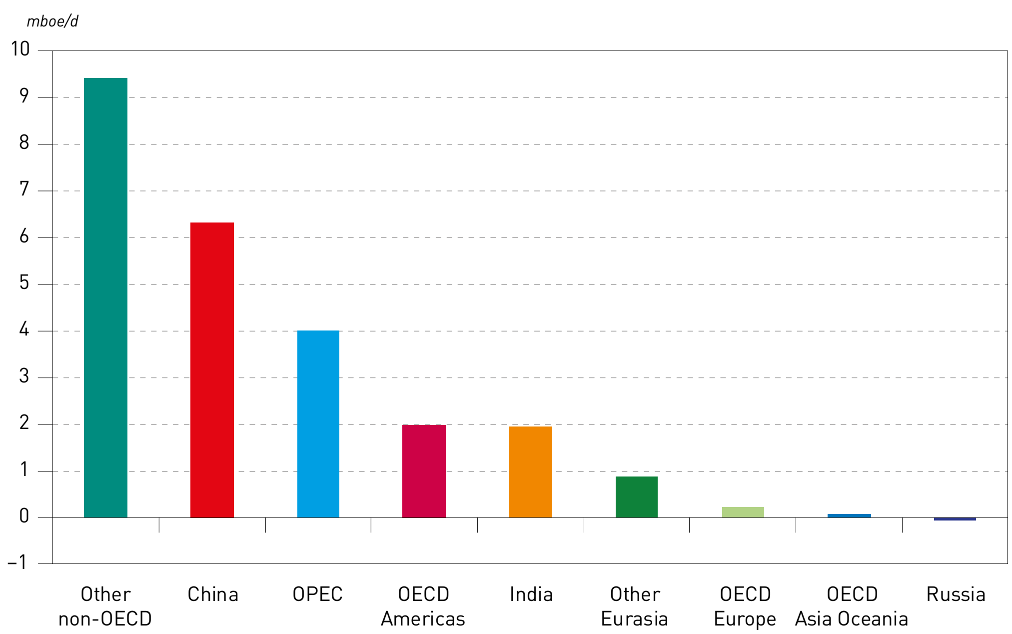
Natural gas demand is expected to grow in all regions, although with significant variations. The majority of gas demand growth is expected in developing regions, led by China, India and OPEC (Figure 2.5).

Table 2.9
Natural gas demand by region, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Share of global gas demand *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	17.5	17.8	18.8	19.5	2.0	0.5	26.7	26.4	23.6	21.6
OECD Europe	8.6	8.6	8.8	8.8	0.2	0.1	13.1	12.8	11.1	9.8
OECD Asia Oceania	3.8	3.7	3.7	3.8	0.1	0.1	5.7	5.4	4.6	4.3
OECD	**29.8**	**30.1**	**31.3**	**32.1**	**2.3**	**0.3**	**45.5**	**44.6**	**39.3**	**35.6**
China	4.9	5.5	8.8	11.3	6.3	3.8	7.5	8.2	11.1	12.5
India	1.0	1.1	2.0	3.0	1.9	4.9	1.6	1.7	2.5	3.3
OPEC	8.7	8.8	11.0	12.6	3.9	1.7	13.2	13.0	13.8	14.0
Rest of the world	10.2	10.9	15.2	19.6	9.4	3.0	15.6	16.2	19.0	21.8
Russia	7.6	7.6	7.5	7.5	–0.1	0.0	11.6	11.2	9.4	8.3
Other Eurasia	3.3	3.4	3.8	4.1	0.9	1.1	5.0	5.0	4.8	4.6
Non-OECD	**35.7**	**37.3**	**48.4**	**58.2**	**22.4**	**2.2**	**54.5**	**55.4**	**60.7**	**64.4**
World	**65.5**	**67.4**	**79.7**	**90.3**	**24.7**	**1.5**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Figure 2.5
Growth in natural gas demand by region, 2018–2040



Source: OPEC.

In **China**, gas demand is estimated to more than double from just below 5 mboe/d in 2018 to over 11 mboe/d in 2040. Gas is expected to increase its share in the power generation mix, replacing coal as part of the 'blue sky' policy mandating the phasing out of old and inefficient coal plants.

In addition, gas is likely to play a larger role in the industrial and residential sectors, in line with the build-out of gas distribution networks in urban areas. According to official plans, a significant part of this demand growth should be covered by domestic supply increases, including shale gas volumes. Consequently, the share of natural gas in China's energy mix is expected to rise from around 7.7% in 2018 to almost 14% in 2040, albeit this is still far below coal, estimated to have a share of almost 45% in 2040.

India is also forecast to increase its gas consumption, although at more moderate levels. It is estimated to rise to around 3 mboe/d in 2040, up from around 1 mboe/d in 2018. Supported by government policies, various companies are expanding their gas distribution networks, which should lead to rising consumption in the residential and transportation sectors (predominantly CNG). Higher gas consumption in the residential sector should help to curb the consumption of biomass for heating and cooking.

OPEC countries are also expected to see rising gas use based on rising demand for power generation and continuing efforts to diversify away from oil in the power generation mix. The large-scale addition of water desalination plants in the Middle East is another factor driving OPEC gas demand. Consequently, gas consumption is expected to rise to above 12.5 mboe/d, up from less than 9 mboe/d in 2018.

In **other non-OECD countries** (including countries in Asia, Africa and Latin America), gas demand is set to rise from 10 mboe/d in 2018 to around 19.5 mboe/d in 2040. This is in line with the rising availability of gas in some countries and a general expansion in energy demand. Several countries are likely to see increasing demand in line with domestic supply expansion trends, such as Egypt, Indonesia, Argentina and Brazil.

In **Eurasia**, gas demand is expected to increase moderately, by less than 1 mboe/d to reach 4.1 mboe/d in 2040, in line with economic developments. The availability of cheap gas will help the fuel remain dominant in the region's energy mix.

At the same time, gas demand growth in OECD regions is projected to be only 2 mboe/d in the period 2018–2040. This basically reflects an increase in gas demand in **OECD Americas**, or narrowing it down further, the **US**. As noted, the rising availability of gas supplies has already led to falling gas prices in the US and a consequent strong increase in gas demand. This trend is expected to continue, with an increase in OECD Americas gas demand from 17.5 mboe/d in 2018 to 19.5 mboe/d in 2040.

In **OECD Europe**, gas demand for power generation will likely remain dependent on the availability of gas supply at competitive prices and EU-ETS prices, in combination with coal-related policies and the penetration of renewables.

Greater efficiency and the penetration of renewable energy sources in the residential sector may lead to a reduction in gas demand. Consequently, while some countries may see a marginal contraction in gas demand in the long-term, the overall trend looks relatively stable, with gas demand inching up to 8.8 mboe/d in 2040.

In **OECD Asia Oceania**, the expected gradual comeback of nuclear plants in Japan is likely to limit upward potential for gas demand. This effect may already be visible, with Japan anticipated to significantly lower its LNG imports in 2019 following the restart of five nuclear reactors in 2018. More reactors are expected to restart in the coming years. This will be offset by limited growth in other sectors, with overall gas demand remaining stable at around 3.7 mboe/d over the long-term.

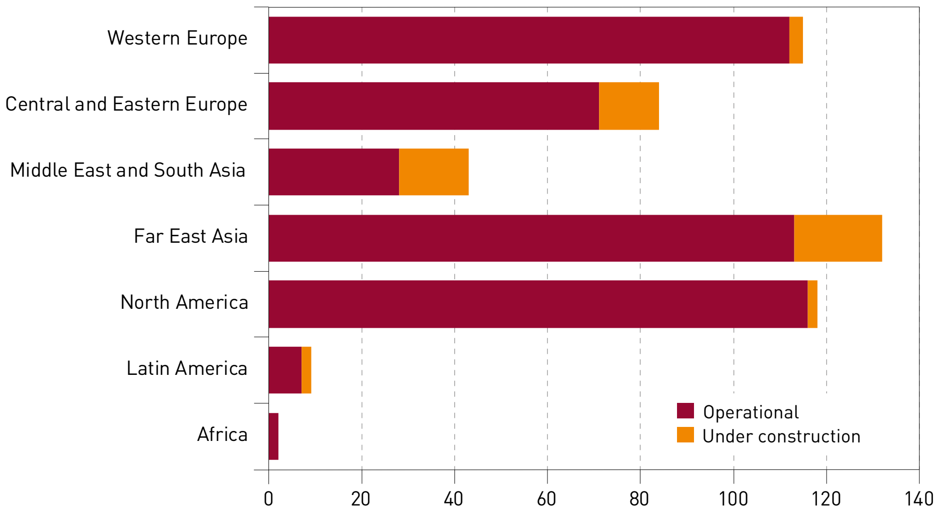
2.3.4 Nuclear

Today, nuclear science is used around the world in the health, water and agricultural sectors, as well as for power generation. In terms of public perception, the nuclear industry is associated with positives such as being a secure source of supply with limited CO_2 emissions and low operating costs, while the negatives include high capital costs, radioactive waste by-products and the risk of disasters, including vulnerability to natural disasters, such as the Fukushima nuclear accident.

Demand for nuclear power is unquestionably on the rise, with China, India and the US leading demand growth. In 2018, 2.5% more power was generated from nuclear sources than in 2017. This was mainly driven by China, while additional generation from nuclear plants was also reported in Japan, France, Switzerland, Sweden, India and a few other countries. Currently, the US, France and China are the largest nuclear power generators, however, the countries with the highest share of nuclear power in their total power generation mix are France (71 %), Ukraine (55%) and Slovakia (54%).

As of July 2019, the International Atomic Energy Agency (IAEA) considers 449 reactors to be operational around the world, with the majority installed in North America, Western Europe and Far East Asia (Figure 2.6). The IAEA has further reported that 52 reactors are currently being built, of which nine reactors with a combined capacity of 8.3 gigawatts (GW) are in China, seven are in India (4.8 GW) and six in Russia (4.6 GW). Simultaneously, the development of small modular reactors (SMRs), which generally produce 300 megawatts (MW) equivalent or less, is ongoing in a few countries. SMRs use components that can be factory-built, reducing costs and construction time, and are assumed to be more resilient to security threats with enhanced safety features.

Figure 2.6
Number of nuclear reactors by region, 2018



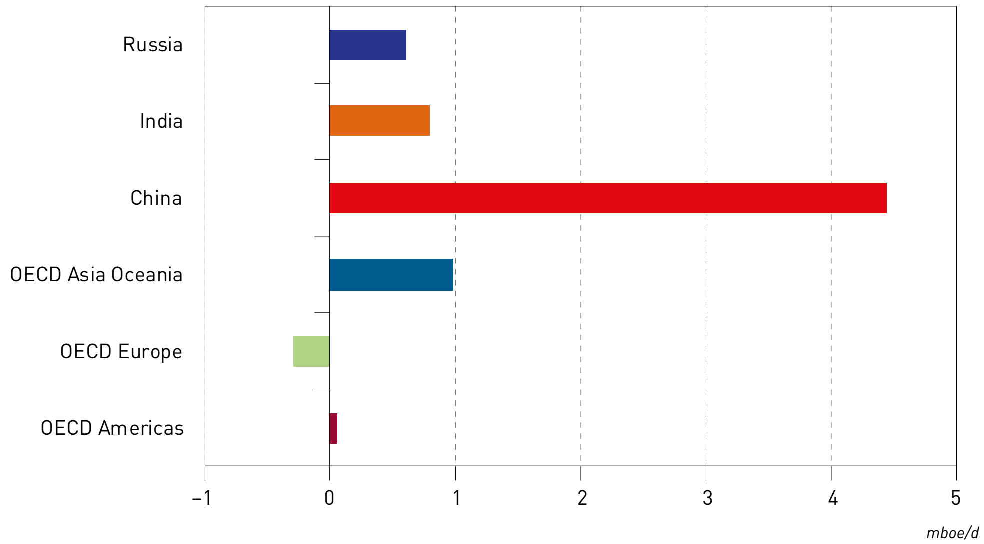
Source: International Atomic Energy Agency (IAEA).

Nonetheless, as a very new technology that has yet to be deployed, the cost benefit calculations for SMRs are purely theoretical. Actual power generation costs may be significantly higher than estimated and would not benefit from economies of scale in the same way as larger reactors. One study in the UK claimed that power generated from SMRs may cost nearly 33% more than conventional nuclear power generation in 2031.

While new reactors are being built, old ones are also being retired or decommissioned. Germany has already shut down 12 of its 19 nuclear power plants with renewables expected to substitute for its closed coal and nuclear plants in the medium-term. In the US, nuclear plants are generally failing to meet economic expectations and struggling to compete with natural gas and renewables, especially wind and solar. At the same time, stricter safety regulations and the advanced age of most reactors make maintenance and inspections more expensive. These issues are forcing more reactors into permanent retirement. Some reactors have already closed while the shutdown of others in the near future have been announced.

Future developments in nuclear power generation are expected to vary across regions. Demand for nuclear power in OECD Europe is expected to drop by 0.3 % p.a. in the long-term, while demand growth in OECD Americas is forecast to wane to almost a standstill (Figure 2.7). OECD Asia Oceania, on the other hand, is estimated to see demand grow by 3% p.a. between 2018 and 2040. At the same time, non-OECD countries are expected to see demand for nuclear power grow by an average 4.5% p.a. to help meet rising demand for electricity.

Figure 2.7
Demand growth for nuclear energy, 2018–2040



Source: OPEC.

Altogether, an additional 1 mboe/d of demand for nuclear power is expected in the OECD region and a further 6.7 mboe/d will come from non-OECD countries in the long-term (Table 2.10). This translates into global demand for nuclear energy increasing from 14.3 mboe/d in 2018 to 21.8 mboe/d in 2040, rising by an average of 1.9% p.a. from 2018–2040.

Table 2.10
Demand for nuclear energy by region, 2018–2040

	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Share of global energy demand *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	5.0	5.0	5.0	5.0	0.1	0.0	34.9	33.0	26.8	23.1
OECD Europe	4.3	4.2	4.0	4.0	–0.3	–0.3	30.0	27.7	21.8	18.3
OECD Asia Oceania	1.1	1.2	1.8	2.0	1.0	3.0	7.4	7.9	9.5	9.4
OECD	**10.3**	**10.4**	**10.8**	**11.1**	**0.7**	**0.3**	**72.3**	**68.6**	**58.1**	**50.8**
China	1.6	2.2	4.3	6.0	4.4	6.3	10.9	14.3	23.0	27.5
India	0.2	0.3	0.6	1.0	0.8	6.8	1.7	2.1	3.5	4.8
OPEC	0.1	0.1	0.2	0.5	0.4	10.3	0.4	0.7	1.3	2.3
Other non-OECD	0.4	0.4	0.5	0.6	0.2	1.8	2.9	2.8	2.7	2.7
Russia	1.1	1.1	1.4	1.7	0.6	2.0	7.6	7.6	7.5	7.8
Other Eurasia	0.6	0.6	0.7	0.9	0.3	1.7	4.2	4.1	4.0	4.0
Non-OECD	**4.0**	**4.8**	**7.8**	**10.7**	**6.8**	**4.6**	**27.7**	**31.4**	**41.9**	**49.2**
World	**14.3**	**15.1**	**18.5**	**21.8**	**7.5**	**1.9**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

2.3.5 Hydro

Hydro has long been viewed as one of the cleanest energy sources for electricity generation, with limited emissions and no mining, waste or leakage risks. Nevertheless, hydro projects can be disruptive for nearby populations and wildlife. The large amount of land used for reservoirs and the environmental changes brought about by the dam often require residents, both upstream and downstream to move, and may even create risks to national heritage in some countries.

Stable hydro production is usually managed via conventional and pumped storage plants that can help balance and smooth out supply and demand variations. However, one drawback is that hydro is itself subject to changes in the weather. A shortage of rainfall can lead to unstable production volumes and variations in generation capacity over time. This is particularly true for countries with extreme and changeable weather.

Globally speaking, the technology for hydro is fairly mature and hydro plants are considered the most efficient way to generate electricity, with conversion rates as high as 90%. However, as already mentioned, there is still potential in some regions to improve grid connectivity and optimize reservoirs to enhance the security of supply to households and industrial users.

In 2018, demand for hydro increased by less than 2% compared to 2017. It is estimated that more than 7 mboe/d of global energy demand is currently met by hydro , and this is expected to increase by 1.6% p.a. on average through to 2040 (Table 2.11). On a regional basis, trends differ. In OECD regions, for instance, new hydro project plans are rare as most potential has already been exploited. However, this low carbon and relatively easy to harness energy source is favoured within China, India and some developing countries as a means to meet growing energy demand (Figure 2.8).

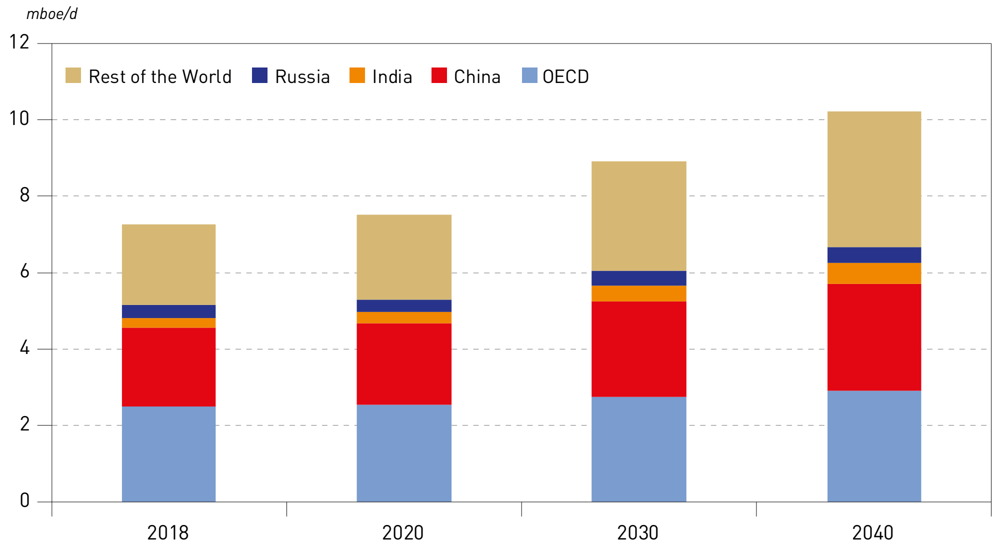
Table 2.11
Demand for hydro by region, 2018–2040

	Levels mboe/d				Growth mboe/d	Growth % p.a.	Share of global hydro demand %			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	1.3	1.3	1.4	1.5	0.3	0.9	17.3	17.0	15.8	14.8
OECD Europe	1.0	1.0	1.1	1.1	0.1	0.5	14.1	13.8	12.5	11.2
OECD Asia Oceania	0.2	0.2	0.2	0.2	0.0	0.6	3.0	2.9	2.6	2.4
OECD	**2.5**	**2.5**	**2.7**	**2.9**	**0.4**	**0.7**	**34.3**	**33.7**	**30.9**	**28.4**
China	2.1	2.1	2.5	2.8	0.7	1.4	28.6	28.4	28.0	27.3
India	0.3	0.3	0.4	0.5	0.3	3.4	3.6	3.8	4.8	5.3
OPEC	0.2	0.2	0.3	0.3	0.1	2.0	2.9	2.9	3.0	3.2
Other non-OECD	1.7	1.8	2.4	3.0	1.3	2.6	23.2	23.8	26.5	29.2
Russia	0.3	0.3	0.4	0.4	0.1	1.0	4.5	4.5	4.2	4.0
Other Eurasia	0.2	0.2	0.2	0.3	0.1	1.0	2.9	2.8	2.6	2.5
Non-OECD	**4.8**	**5.0**	**6.2**	**7.3**	**2.6**	**2.0**	**65.7**	**66.3**	**69.1**	**71.6**
World	**7.3**	**7.5**	**8.9**	**10.2**	**3.0**	**1.6**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

More granular analysis shows demand in **OECD Europe** is expected to remain virtually unchanged and the amount of electricity generated by hydro in this region is forecast to grow by only 0.5% p.a. between 2018 and 2040, to reach 1.1 mboe/d. Only a few countries such as Austria and Norway are likely to add hydro units and they will be relatively small.

Figure 2.8
Hydro demand by major region, 2018–2040



Source: OPEC.

Likewise in **OECD Americas**, additional demand for hydro is expected to be limited, expanding by less than 0.3 mboe/d by 2040. In **OECD Asia Oceania**, only 0.2 mboe/d of energy is supplied by hydro and no major additions are expected, thus demand is unlikely to grow by more than 0.6% p.a. over the long-term horizon.

As already mentioned, however, hydro is expected to expand sharply in parts of **non-OECD Asia**, especially India and China. Thailand, Vietnam, the Philippines and Indonesia are also anticipated to expand their long-term hydro capacity.

Demand for hydro in **India** is projected to experience nearly 3.5% growth on average p.a. from 2018–2040. The Indian authorities are considering lowering tariffs for new hydro projects to make them more competitive and attract more investors. It has been estimated that nearly $3 billion is required to expand the country's capacity as planned.

The largest increase in hydro capacity in a single country is expected to be in **China**, where demand is expected to grow by 0.7 mboe/d between 2018 and 2040. This reflects the existence of some untapped resources and the government's efforts to reduce air pollution and CO_2 as part of its emissions reduction commitments. Meanwhile, potential exists in several Latin American countries, such as Brazil, Venezuela and Peru, as well as in sub-Saharan Africa. Subsequently, hydro in non-OECD countries is projected to increase from 4.8 mboe/d in 2018 to 7.3 mboe/d in 2040.

In the long-term, the share of hydro in the global energy mix is estimated to expand, albeit slightly, matching the increase in primary electricity demand in specific regions, mainly Asia and some developing countries.

2.3.6 Biomass

Global demand for biomass (including firewood, liquid biofuels, charcoal, industrial and municipal waste etc.) increased to 27.5 mboe/d in 2018 from nearly 27 mboe/ in 2017. Non-OECD countries consumed 21 mboe/d of biomass in 2018, which represents nearly 75% of global biomass demand. Global demand is projected to rise by a further 1% p.a. on average between 2018 and 2040 (Table 2.12). This will result in nearly 7 mboe/d of additional demand on top of existing consumption for both traditional and advanced biomass. This is sufficient for biomass to maintain its current share in the global energy mix, although different regions will show disparate trends in line with factors influencing biomass use.

Urbanization levels, the use of renewable energy sources, and efficiency and emission controls are all on the rise in developing countries, resulting in two contradictory trends. Demand for traditional biomass is falling, but demand for modern biofuels is increasing, especially in India, Brazil and China. As a result, and in absolute terms, non-OECD countries are expected to see 4.6 mboe/d of demand growth from 2018–2040 (Figure 2.9). Despite this, biomass is projected to lose almost 2% of its share in the total primary energy demand mix of the non-OECD regional grouping, unlike for the OECD.

In OECD countries, where increasing biofuels demand accounts for most of the regional growth, just less than 3 mboe/d additional demand is expected for biomass by the end of forecast horizon. However, this results in a more than 2% surge in the share of biomass in the primary energy mix of the region.

2.3.7 Other renewables

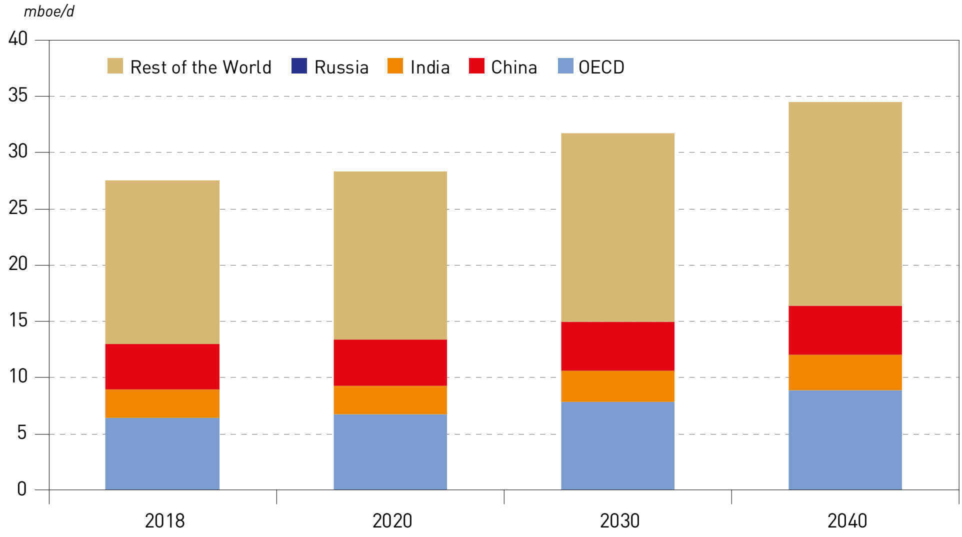
Advances in renewable energy and investments into this sector have been significant in recent years. In the power generation sector, in particular, it is widely considered that renewables will

Table 2.12
Biomass demand by region, 2018–2040

	Levels mboe/d				Growth mboe/d	Growth % p.a.	Share of global energy demand %			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	2.7	2.8	3.2	3.6	0.9	1.4	9.8	9.8	10.0	10.5
OECD Europe	3.2	3.4	4.0	4.5	1.3	1.5	11.7	11.9	12.6	13.0
OECD Asia Oceania	0.5	0.6	0.7	0.8	0.2	1.5	2.0	2.0	2.1	2.2
OECD	**6.5**	**6.7**	**7.9**	**8.9**	**2.4**	**1.4**	**23.5**	**23.7**	**24.8**	**25.7**
China	2.5	2.6	2.8	3.2	0.7	1.2	9.1	9.0	8.8	9.4
India	4.0	4.1	4.4	4.3	0.3	0.3	14.7	14.6	13.7	12.5
OPEC	2.4	2.5	2.7	2.9	0.5	0.9	8.9	8.8	8.7	8.5
Other non-OECD	11.5	11.9	13.4	14.4	2.8	1.0	42.0	42.0	42.1	41.7
Russia	0.2	0.2	0.2	0.3	0.1	2.5	0.6	0.6	0.7	0.8
Other Eurasia	0.4	0.4	0.4	0.5	0.1	1.2	1.3	1.3	1.3	1.3
Non-OECD	**21.0**	**21.6**	**23.9**	**25.6**	**4.6**	**0.9**	**76.5**	**76.3**	**75.2**	**74.3**
World	**27.5**	**28.3**	**31.7**	**34.5**	**7.0**	**1.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

Figure 2.9
Biomass demand by major region, 2018–2040



Source: OPEC.

play an important role in the transition to a more affordable and sustainable system in all regions. Today, some renewable technologies used for power generation, particularly solar and wind, can be considered cost-competitive in parts of the world. According to the Renewable Energy Policy Network for 21st Century (REN 21), in 2018, more than 90 countries had at least 1 GW of renewable generating capacity, with at least 30 countries exceeding 10 GW. In fact, for the past few years more renewable capacity has been installed than for fossil fuels and nuclear power combined.

In 2018, however, despite significant additional capacity and investments for renewables, demand remained broadly at 2017 levels. Global investment in wind energy in 2018 increased slightly following huge investments in China, the US, India and Europe, in terms of both onshore and offshore projects. On the other hand, investments in solar witnessed a significant deterioration following a slowdown in China, but also due to lower capital costs for solar PV projects in many regions.

Global investments in geothermal fell in 2018, while ocean power witnessed increased investment compared to 2017.

The phenomenon of increasing demand for renewables can be observed across all regions, albeit with varying patterns and levels (Table 2.13). In 2018, China, the US and Japan led the way, followed by India and Australia.

From the perspective of **China**, changes in policy regarding support for subsidized solar PV projects was the main reason behind the global slowdown in investment and capacity additions for renewables in 2018. According to the BP Statistical Review of World Energy, China's solar power capacity additions in 2018 were nearly 45 GW, which is less than the record 53 GW in 2017. In terms of wind power, China added nearly 20 GW of new capacity in 2018, compared to 16 GW in 2017.

Table 2.13
Demand for 'other renewables' by region, 2018–2040

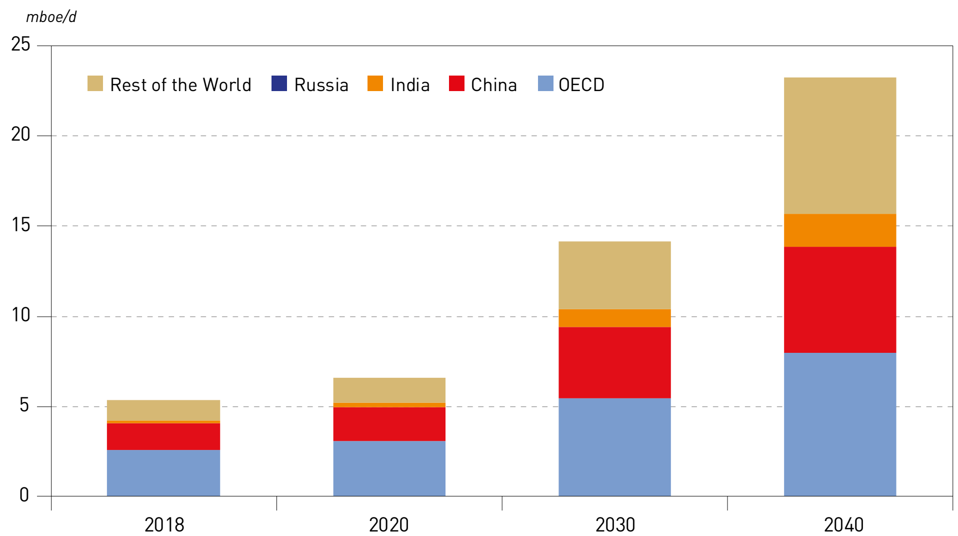
	Levels *mboe/d*				Growth *mboe/d*	Growth *% p.a.*	Share of global energy demand *%*			
	2018	2020	2030	2040	2018–2040	2018–2040	2018	2020	2030	2040
OECD Americas	1.0	1.2	2.3	3.4	2.4	5.8	18.6	18.2	15.9	14.7
OECD Europe	1.2	1.4	2.2	3.0	1.8	4.1	22.9	21.6	15.7	12.8
OECD Asia Oceania	0.4	0.4	1.0	1.6	1.3	7.1	6.7	6.6	7.0	6.9
OECD	**2.6**	**3.1**	**5.5**	**8.0**	**5.4**	**5.3**	**48.2**	**46.4**	**38.6**	**34.4**
China	1.5	1.9	4.0	5.8	4.3	6.4	28.2	29.1	28.0	25.2
India	0.2	0.2	1.0	1.8	1.7	11.5	3.1	3.6	6.9	7.8
OPEC	0.0	0.0	0.6	1.9	1.9	31.4	0.1	0.1	4.6	8.3
Other non-OECD	1.0	1.3	2.8	4.9	3.9	7.4	19.4	19.6	20.1	21.2
Russia	0.0	0.0	0.1	0.3	0.3	11.8	0.5	0.6	0.9	1.3
Other Eurasia	0.0	0.0	0.1	0.4	0.4	12.5	0.6	0.6	1.0	1.8
Non-OECD	**2.8**	**3.5**	**8.7**	**15.2**	**12.5**	**8.1**	**51.8**	**53.6**	**61.4**	**65.6**
World	**5.3**	**6.6**	**14.1**	**23.2**	**17.9**	**6.9**	**100.0**	**100.0**	**100.0**	**100.0**

Source: OPEC.

While China once again led the field in additional renewable power generation capacity in 2018, the medium-term outlook for the country remains uncertain, particularly given changes to support schemes for new solar projects. However, the country dominates the production of solar panels, wind turbines and batteries and is a global leader in grid technology. Thus, it is clear that China, alongside India and OECD countries (Figure 2.10), will continue to be a leading long-term player in this sector in response to its growing demand for energy, a result of urbanization and population growth, and due to environmental concerns.

'Other renewables' are expected to be the fastest growing source of energy in China, increasing by nearly 6.5 % p.a. on average over the forecast period. In absolute terms, demand for 'other renewables' in China is projected to increase from around 1.5 mboe/d in 2018 to nearly 6 mboe/d by 2040. This escalates the share of 'other renewables' in China's energy mix to 7.2% by the end of period.

Figure 2.10
'Other renewables' demand by major region, 2018–2040



Source: OPEC.

While the Indian authorities continue to support renewable developments, **India** is expected to miss its target to have 100 GW of operational solar power by March 2022. This is mainly due to regulatory issues that are not supportive of the government's capacity expansion target. Additionally, the country is behind its initial timeline to develop new onshore wind projects and in launching offshore wind farms. India's solar capacity increased from less than 10 GW in 2017 to almost 18 GW in 2018, while wind added only around 3GW over the same period. Despite the highlighted challenges, 'other renewables' are expected to be India's fastest growing source of energy in the medium- to long-term, with a growth rate of 11.5% p.a. between 2018 and 2040.

The **EU** also witnessed a deceleration in renewable additions from 2017 to 2018 with capacity growth slowing to nearly 10% for solar and 7% for wind. If this slowdown continues, it could lead to a number of EU member states not meeting their 2030 targets of having a renewable contribution of at least 32% in terms of energy consumption. Currently, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, Italy, Hungary, Lithuania, Romania, Sweden, Austria, Greece and Latvia have either already hit the renewables target, or are expected to face no major problems in doing so.

In 2019, Germany could see renewables replace coal as the largest source of power generation. It should also be noted that France and the UK are aiming to completely eliminate the use of coal by 2022 and 2025, respectively, which will be mainly substituted by solar and wind.

In the **US**, the 2016 US Congress federal spending bill contained a five-year solar tax credit extension, which made solar energy more affordable. Simultaneously, the federal solar tax credit, also known as the investment tax credit (ITC), allowed residential and commercial users to reduce by up to 30% the cost for solar systems from their federal tax. It is clear these developments have encouraged solar capacity development in the US, with sharp growth of 19.6% recorded in 2018. This growth momentum is forecast to continue in 2019, given that it is the final year with the maximum 30% possible tax reduction rate. Afterwards the ITC, although remaining effective through 2021, will see the tax reduction rate reduced gradually.

Wind power capacity in the US expanded at a slower pace than solar power in 2018, according to the BP Statistical Review of World Energy, growing by almost 8% y-o-y to reach 95 GW, from 87 GW in 2017.

The annual growth for 'other renewables' in OECD Europe and OECD Americas is forecast to be 4% and 6%, respectively, while in OECD Asia it is expected to be higher, above 7% p.a.

It is important to note that major energy companies, ones that could make significant investments and intend to integrate renewables into their existing portfolio, are struggling with the smaller margins in renewables. Moreover, competition in the power generation sector is higher relative to complex oil and gas projects. At present, oil majors remain predominantly focused on oil and gas despite some efforts to shift portfolios toward low carbon sources of energy.

Looking ahead, the private sector will be a key player in driving the deployment of renewable energy, but it is evident that private companies are looking for the long-term support of governments and global decision makers before undertaking major investment initiatives in the renewables sector.

Wind and solar PV are now less expensive than ever before and no longer require financial assistance to be profitable in some regions. It underscores that renewables are fast becoming a competitive option to achieve climate-related goals. Moreover, some countries, especially emerging economies, are looking to deploy renewables as decentralized energy projects to enable energy access to households in remote areas.

Over the long-term, it is expected that the role of 'other renewables' in the global energy mix will expand at an accelerated pace of nearly 7% p.a., which boosts demand by 18 mboe/d. It means the share of other renewables in the energy mix is set to increase from less than 2% in 2018 to 6.5% by 2040. This high growth rate will mainly be due to developments in the power generation sector.

Globally, the actual growth of 'other renewables' remains somewhat uncertain and will evidently depend on energy policies, technology improvements and future cost developments. Moreover, other related challenges such as cyber security risks, storage issues and supply instability need to be monitored carefully.

2.4 Energy-related CO_2 emissions

The summary of energy-related annual CO_2 emissions by energy source over the forecast period is provided in Table 2.14. It shows that these will continue increasing to reach a level of more than 38 bt by 2040, more than 4 bt higher than observed in 2018. It is to be noted, however, that the pace of growth will decelerate significantly over time. The main reason is that global coal demand will peak around 2030 and start declining during the last decade of the forecast period. Moreover, oil demand growth will also slow over the same period. These two factors will, to some extent, offset growing emissions related to the rising use of natural gas.

At the same time, despite a declining trend in coal demand after 2030, coal is still expected to be the largest source of CO_2 emissions, accounting for almost 40% (14.9 bt) of total emissions in 2040.

Some of the increase in emissions will also be related to the use of oil. Oil-related emissions are projected to reach 13.7 bt by 2040, around 1.7 bt more than in 2018. However, the largest

Table 2.14
Energy-related annual CO_2 emissions by energy source, 2018–2040 *billion tonnes*

	2018	2020	2025	2030	2035	2040
Coal	14.8	14.9	15.0	15.1	15.0	14.9
Oil	12.0	12.3	12.9	13.3	13.6	13.7
Gas	6.9	7.1	7.7	8.4	9.0	9.6
Energy-related emissions	33.8	34.3	35.6	36.7	37.6	38.2

Source: OPEC.

increase in emissions (on an annual basis) is expected for natural gas (+2.7 bt) as demand for this energy source is set to increase significantly over the forecast period. Combined, the overall increase in annual energy-related emissions of 4.4 bt between 2018 and 2040 represents around a 13% increase, which is only roughly half of the overall increase in energy demand. This is a clear sign of the trend towards the use of lower-emission energy sources in the future.

Figure 2.11 presents annual CO_2 emissions from a regional perspective. The bulk of incremental emissions is clearly related to growing energy demand in non-OECD countries. Correspondingly, emissions in this region are expected to grow from 21.7 bt in 2018 to 28 bt in 2040. The increase in annual emissions in this region will be partially offset by a reduction of emissions in the OECD, on the back of a strong decline in coal and oil usage, a significant expansion in renewable energy and the region's falling total energy demand.

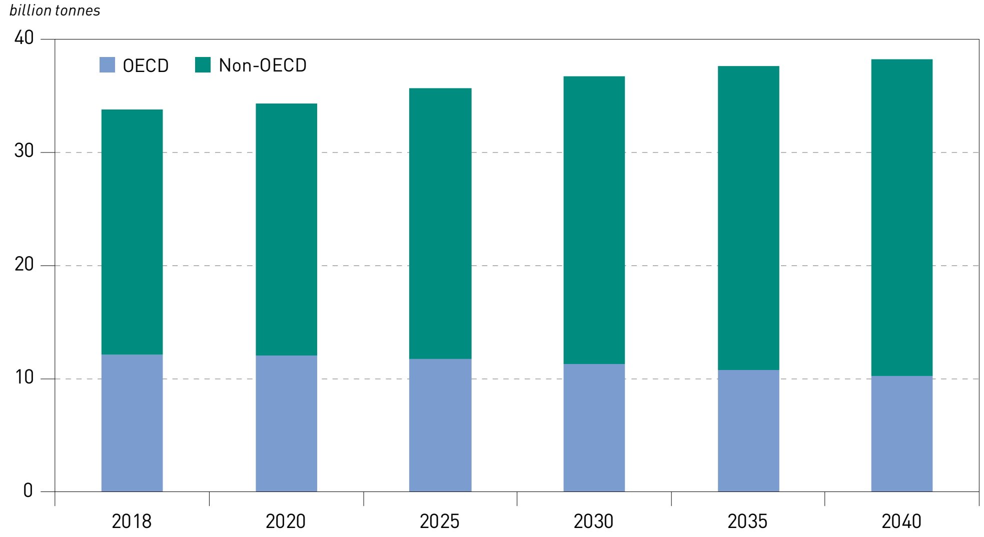
Figure 2.12 highlights another dimension of the regional distribution of energy-related emissions. If emissions are considered on a per capita basis, then the previous picture of growing emissions in non-OECD countries changes to one that barely shows any growth.

In 2018, per capita emissions in OECD countries were almost three times higher than in the non-OECD region. This gap is expected to persist over the entire forecast period, despite becoming slightly narrower over time. More importantly, energy-related emissions on a per capita basis in non-OECD countries are projected to remain at very low levels, signalling that energy poverty will continue be an issue in many of these countries.

Another dimension of the discussion on emissions relates to historical cumulative emissions. These are presented in Figure 2.13 from the perspective of Annex I and non-Annex I countries since 1990. This figure shows the long-standing and significant gap in cumulative emissions.

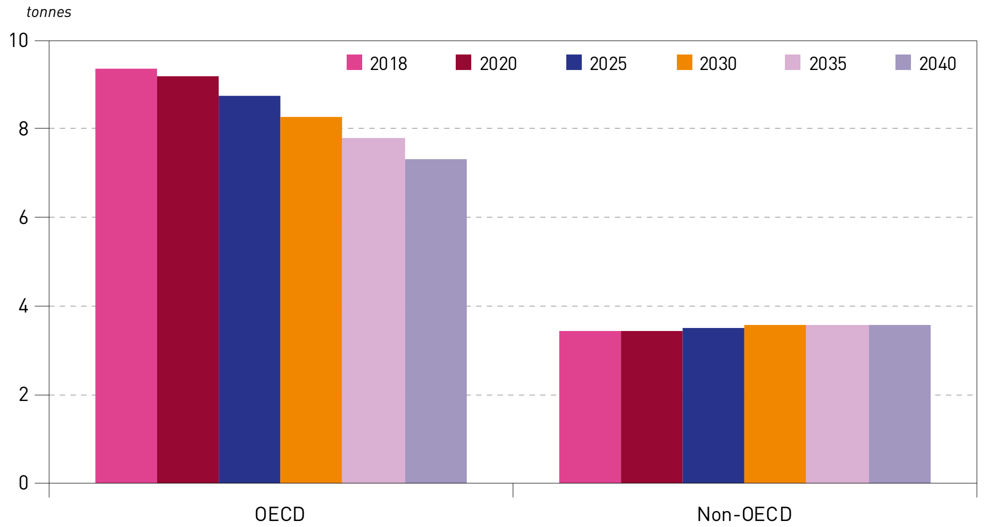
Towards the end of the last century, cumulative emissions from Annex I countries were almost four times higher than those from non-Annex I. Moreover, despite growing energy

Figure 2.11
Energy-related annual CO_2 emissions by major region, 2018–2040



Source: OPEC.

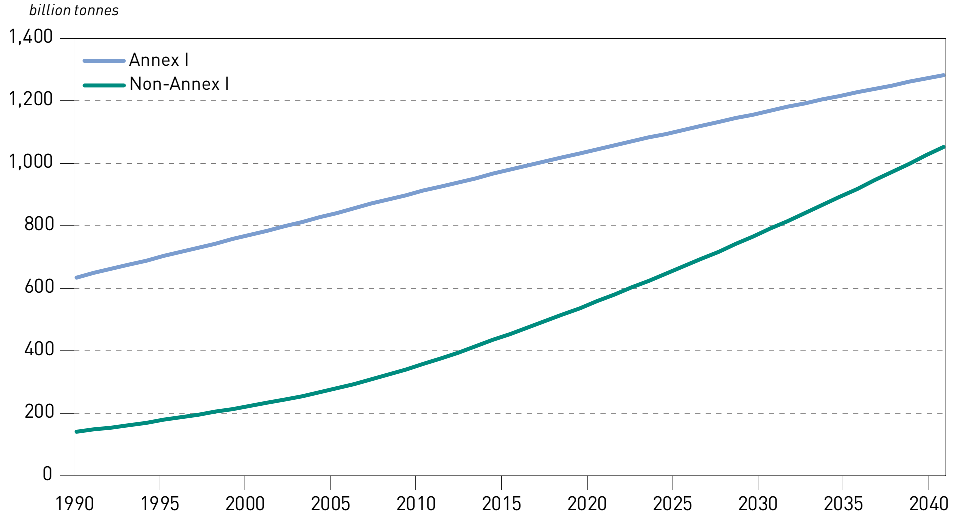
Figure 2.12
Per capita CO_2 emissions by major region, 2018 and 2040



Source: OPEC.

demand in developing countries, this gap is expected to persist throughout the forecast period. Even by 2040, historical cumulative emissions from non-Annex I countries are estimated to be more than 200 billion tonnes of CO_2 lower than those generated by Annex I countries since 1900.

Figure 2.13
Cumulative CO_2 emissions since 1900, 1990–2040



Source: OPEC.

2.5 Energy intensity and consumption per capita

Energy intensity is typically defined as the ratio of energy used per unit of GDP. The inverse of energy intensity is often used as a proxy to measure energy efficiency. This implies that as energy efficiency increases, energy intensity declines; leading to a higher economic value out of every unit of energy used.

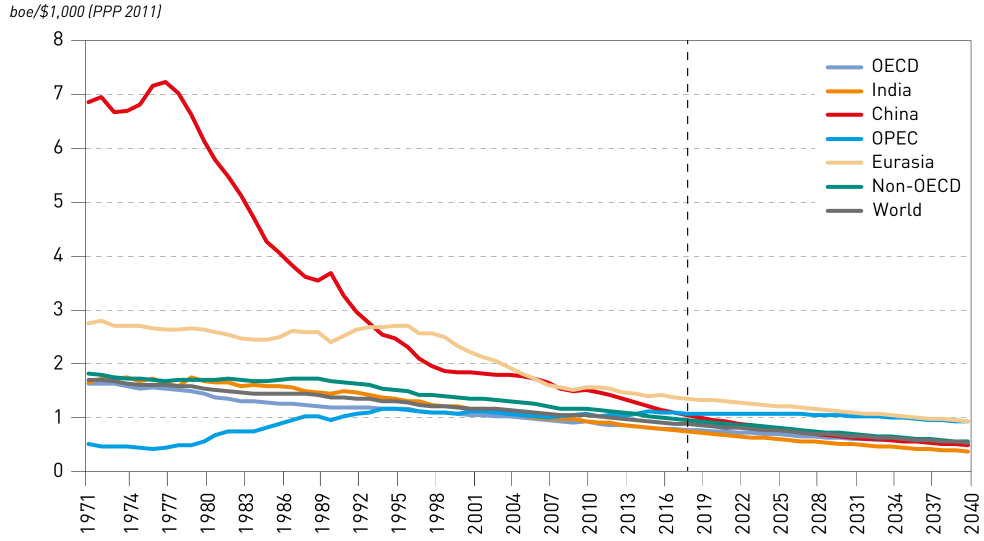
However, energy intensity comparisons across countries and regions need to be handled with caution as there are often many other factors entering into the equation. These include the economic structure of an economy, the level of economic development of a nation, demographics of the population, climate of the region and urbanization levels, to name a few.

Efforts to reduce energy intensity are usually more visible at the sectoral level. For example, in the transportation sector, energy efficiency is best measured in terms of tonne/km or l/km depending on the transport activity, which is then used to assess energy efficiency improvements. For the services and residential sectors, energy efficiency is usually directly measured against specifically targeted energy improvements.

Historical energy efficiency performance across major regions is summarized in Figures 2.14 and 2.15. It is evident that technology developments and policies have played a decisive role in lowering energy intensity over time. Energy intensity patterns indicate that in most regions, and at the global level, the amount of energy required to produce one unit of GDP is falling. Currently, the global economy is around 2.5 times larger than in 1990, yet energy efficiency improvements achieved since then mean that energy demand in 2018 was only 1.6 times that of 1990. Moreover, in most regions, improvements are expected to continue at the same pace, if not accelerate, compared to those achieved over the past 50 years or so.

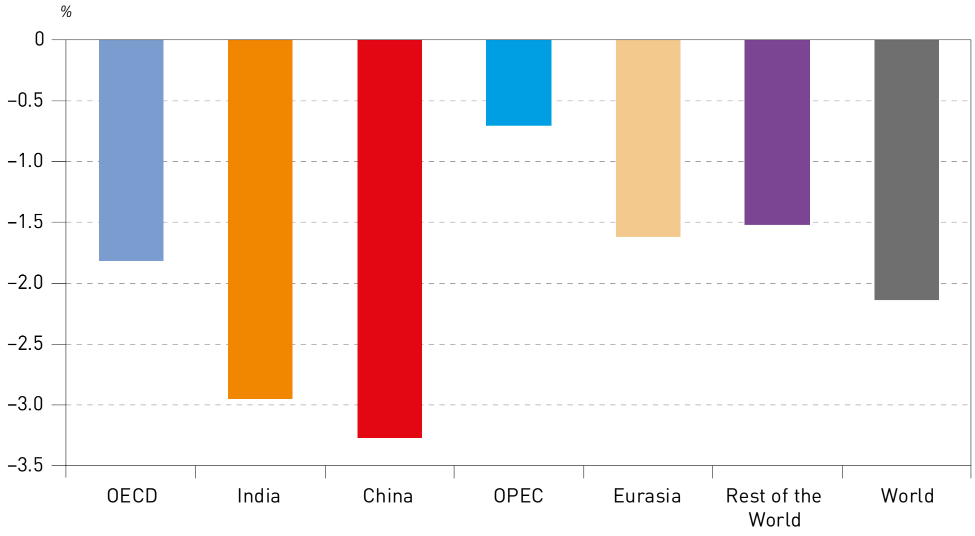
A remarkable improvement in energy intensity has been observed in **China** (Figure 2.14). OECD countries, particularly OECD Americas and OECD Europe, have already moved through

Figure 2.14
Evolution and projections of energy intensity, 1970–2040



Source: OPEC.

Figure 2.15
Average annual rate of improvement in global and regional energy intensity, 2018–2040



Source: OPEC.

sustained improvements in energy intensity. A longer-term pattern, where technological progress and the increasing number of energy efficiency policies foster a decoupling between economic growth and energy use, can be expected in these regions. Decoupling is less striking for OECD Asia Oceania.

However, it is worth noting that globally these levels are still a long way from attaining the SDG 7.3 target of doubling past energy intensity improvement rates.

Improving energy efficiency is evident in other non-OECD countries and regions too. **Russia** has a specific downward energy intensity pattern post-1990, which is largely due to the breakup of the Soviet Union. Other Eurasia follows a similar pattern. Figure 2.14 highlights the evolution of energy intensity in specific developing countries and regions. It also illustrates an expectation that energy intensities across developing regions will move towards convergence, as previously wide gaps in energy intensities are gradually eliminated.

What is clear is that energy efficiency improvements will continue in both OECD and non-OECD regions. Moreover, in most regions, these improvements will accelerate compared to those achieved in the past 25 years. The fastest reduction in energy intensity is expected to be achieved in China and India, achieving on average 3.27 % p.a. and 2.95 % p.a., respectively, between 2018 and 2040. The OECD is expected to see a reduction of 1.81 % p.a. Other regions will see a reduction generally in the range of 1% to 2% p.a., whereas the global average is projected at 2.14% p.a.

Another important issue and trend to underscore is that global energy poverty is declining. In 1970, there was a wide gap between energy consumption per capita in the OECD and non-OECD regions. Average energy consumption was almost 27 boe per capita in the OECD, while in developing countries it was only 3 boe per capita. In some specific countries such as China and India, the average consumption was even below 1.5 boe per capita.

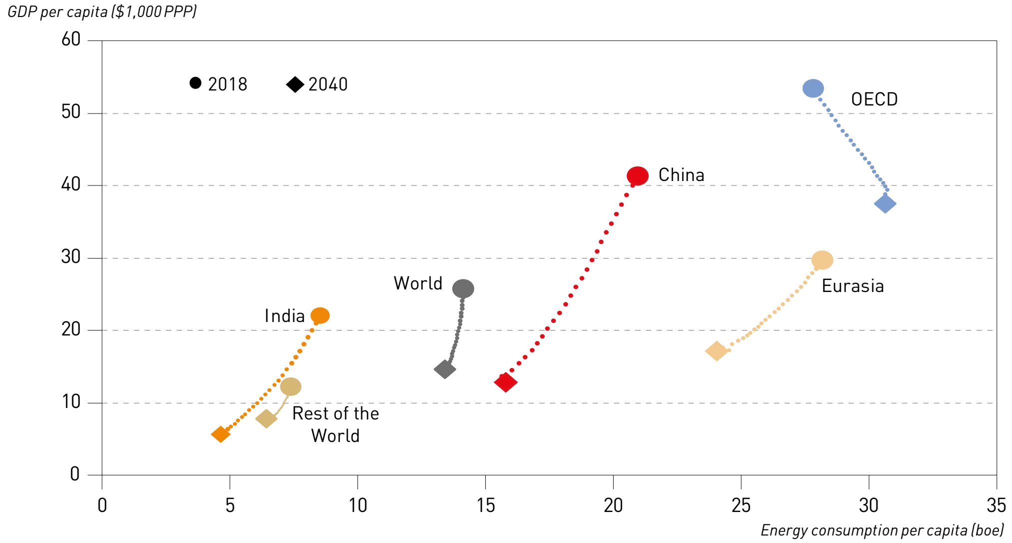
The gap has not narrowed significantly by 1990 and average consumption in the OECD region was still more than six times higher than in developing countries. However, since then, rapid economic expansion in the developing world, particularly in developing Asia, has lifted millions of people out of poverty and enlarged the middle class, prompting an increase in access to energy. In 2015, average energy consumption in non-OECD countries had almost tripled with respect to 1970 and the gap with the OECD had narrowed. Nevertheless, the gap still remains wide and energy poverty remains an extremely important issue.

From the perspective of energy demand, Figure 2.16 shows that differences in average per capita energy consumption (in a very broad sense, a proxy to energy poverty/wealth) can be linked to differences in the level of development and, therefore, in average income levels. This Outlook anticipates that energy consumption in the non-OECD region will remain coupled with rapid economic growth. This will bring increasing electrification, rising income levels, increasing urbanization and an expanding middle class.

This is clearly apparent for the two largest economies: China and India. In the former, average per capita energy consumption is expected to increase significantly, from almost 16 boe in 2018 to more than 21 boe in 2040. In the latter, average consumption is anticipated to move from a level of just over 5 boe to almost 9 boe at the end of the forecast period.

Contrary to these cases, and despite anticipated modest economic growth, the OECD regions, where economies are more service-oriented, is set to see energy consumption per capita continue to decline, a trend that began in 2004. This a distinct sign of the decoupling between GDP growth and energy demand, due mainly to technology and policy driven energy efficiency gains.

Figure 2.16
Average annual rate of improvement in global and regional energy intensity, 2018–2040



Source: OPEC.

Oil demand

Key takeaways

- Medium-term global oil demand is expected to continue growing at a relatively healthy rate to reach a level of 104.8 mb/d by 2024.
- Oil demand in OECD countries is projected to shift after 2020 from growth to a declining trend for the rest of the forecast period.
- The global refining system will have sufficient flexibility to address the sudden fuel mix change in the marine sector due to IMO 2020 regulations. Nevertheless, the impact on HSFO prices, the gasoil/HSFO spread and HSFO-rich crude oil prices will be significant, although less severe than previously expected.
- Long-term oil demand is estimated to increase by almost 12 mb/d from 2018 to reach 110.6 mb/d in 2040. Oil demand in the non-OECD region is expected to increase by 21.4 mb/d between 2018 and 2040.
- Oil demand growth in non-OECD countries will be partly offset by falling demand in the OECD. By 2040, OECD demand is forecast to be nearly 10 mb/d lower than in 2018.
- At the global level, annual incremental oil demand is estimated to slow from 1.4 mb/d in 2018 to around 0.5 mb/d at the end of the next decade and to further decelerate through to the end of the forecast period.
- India is projected to see the fastest demand growth and the largest additional demand (+5.4 mb/d) in the period to 2040.
- Oil demand in China is forecast to reach 17.1 mb/d by 2040, which represents an increase of 4.4 mb/d compared to 2018 levels.
- Between 2018 and 2040, the largest incremental oil demand is expected to come from the petrochemicals sector (+4.1 mb/d), followed by road transportation (+2.9 mb/d) and aviation (+2.4 mb/d). Electricity generation is the only sector where oil demand is projected to decline.
- Road transportation will remain the primary sector for oil demand, estimated to account for 43% of total demand by 2040. However, oil demand in this sector is set to plateau during the last decade of the forecast period.
- The total vehicle fleet is estimated to grow by more than 1 billion between 2018 and 2040. The large majority of the increase (953 million vehicles) comes from non-OECD countries. The total vehicle fleet is expected to reach 2.4 billion by 2040. EVs are estimated to reach around 320 million units in 2040, making up 13% of the global fleet.
- The largest part of future incremental demand is anticipated to come in the form of light products. These are projected to increase by 6.7 mb/d between 2018 and 2040, followed by middle distillates (+4.1 mb/d) and heavy products (+1 mb/d).
- The largest demand increase among all major refined products is projected for ethane/LPG, at 3.3 mb/d between 2018 and 2040. Strong growth for these two products is linked to the petrochemical and residential sectors.

This Chapter provides insights into the evolving outlook for oil demand. It is evident that there is an interplay between several trends and developments, often with counter-balancing effects, in shaping future oil demand. Population growth and economic activity typically support oil demand. On the other hand, energy policies, especially in developed countries, mostly tend to reduce oil demand, be it for environmental, health, energy dependency and/or other concerns.

In some cases, however, energy policies can also result in support for oil demand. This is often the case in least developed countries where the substitution of traditional fuels, such as wood, by much cleaner refined products improves the quality of life for millions. In a similar manner, technology can also work both ways. Providing new technology solutions, such as plastic materials, fertilizers, chemicals and aircraft, creates opportunities for an increase in oil demand, while technology can also drive a more efficient use of oil products, thus lowering demand.

Obviously, this is not an exhaustive list of factors, but it illustrates of the many drivers and related uncertainties that surround oil market developments and make future projections challenging. Nevertheless, this chapter tries to capture the highlighted factors and provide an outlook for oil demand in the medium- and long-term.

Despite a variety of uncertainties, it is clear that oil demand at the global level will remain on a growing trajectory for some time. Demand growth, especially in non-OECD countries, will be supported by strong new passenger car and commercial vehicle sales, which are set to continue over the forecast period, despite signs of some weakening over time. Developments in the aviation segment will also likely contribute to expanding demand. Large investments and an increasing propensity to travel, especially in a number of Asian countries, are bolstering the prospects for oil demand growth in this sector. Another source of significant incremental demand over the medium-term will be the petrochemical industry.

On the flip side, this Chapter also emphasizes decelerating demand growth over the long-term. Indeed, following a period of relatively strong oil demand growth between 2015 and 2018, supported by robust economic growth coupled with lower oil prices, the signposts for the next five years indicate demand growth will head towards moderate levels of around 1 mb/d p.a. It will then decline further to almost no growth by the end of the forecast period.

The analysis also pays due attention to the potential implications of the implementation of the IMO regulations to limit bunker fuel sulphur content to 0.5%, effective January 2020. Finally, an extended analysis of sectoral demand is supplemented by a demand outlook for the main refined products.

3.1 Medium-term oil demand outlook

Medium-term global oil demand is expected to continue growing at relatively healthy rates to reach a level of 104.8 mb/d by 2024, as presented in Table 3.1 and summarized in Figure 3.1. Compared to the base year of 2018, this represents an increase of 6.1 mb/d. The average annual increase is 1 mb/d over the forecast period, declining from a projected 1.1 mb/d in 2019 to 0.9 mb/d in 2024.

As in previous years, incremental demand is forecast to come from non-OECD countries (+6.6 mb/d between 2018 and 2024). Oil demand growth from this group of countries is projected to remain within a relatively narrow range of 1–1.2 mb/d over the medium-term period. The demand pattern here results from a mixture of factors. Increases due to continued GDP and population growth are expected to be partially offset by other factors such as efficiency improvements and the implementation of various policy measures.

Turning to the OECD, the pattern and importance of the various factors change. Oil demand in this region is projected to gradually shift from slight growth in the initial years of the forecast period

Table 3.1
Medium-term oil demand outlook, 2018–2024

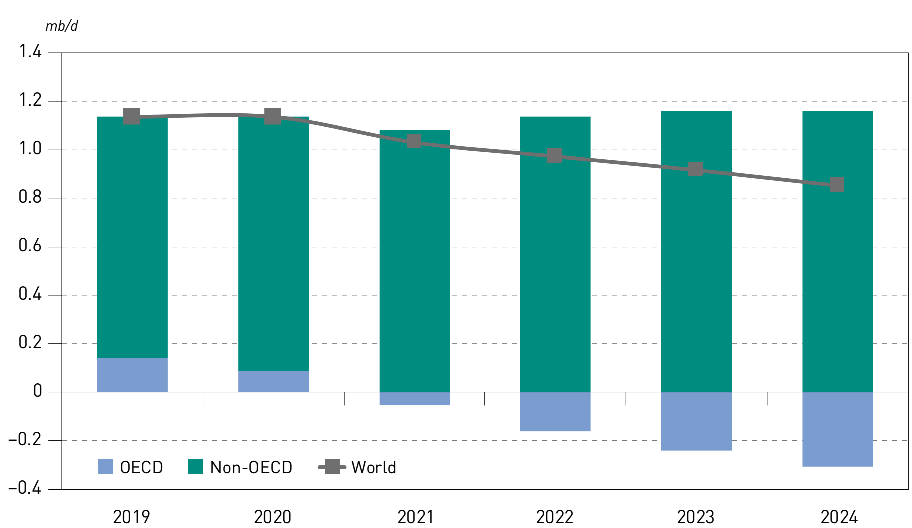
mb/d

	2018	2019	2020	2021	2022	2023	2024	Growth 2018–2024
OECD Americas	25.5	25.8	25.9	26.0	26.0	25.9	25.7	0.2
OECD Europe	14.3	14.3	14.3	14.2	14.2	14.1	14.0	–0.3
OECD Asia Oceania	8.0	7.9	7.9	7.8	7.7	7.7	7.6	–0.4
OECD	**47.8**	**48.0**	**48.1**	**48.0**	**47.9**	**47.6**	**47.3**	**–0.5**
Latin America	5.9	5.9	6.0	6.1	6.2	6.2	6.3	0.5
Middle East & Africa	4.2	4.3	4.4	4.5	4.6	4.7	4.8	0.6
India	4.7	4.9	5.1	5.3	5.5	5.7	6.0	1.2
China	12.7	13.1	13.4	13.7	13.9	14.2	14.5	1.7
Other Asia	9.0	9.1	9.3	9.5	9.7	9.9	10.1	1.1
OPEC	8.8	8.9	9.0	9.2	9.4	9.6	9.8	0.9
Russia	3.6	3.6	3.7	3.7	3.8	3.8	3.8	0.3
Other Eurasia	2.0	2.0	2.1	2.1	2.2	2.2	2.2	0.3
Non-OECD	**50.9**	**51.9**	**52.9**	**54.0**	**55.2**	**56.3**	**57.5**	**6.6**
World	**98.7**	**99.9**	**101.0**	**102.0**	**103.0**	**103.9**	**104.8**	**6.1**

Source: OPEC.

to declining demand after 2020. This change is primarily driven by continued efficiency improvements across all sectors and by fuel substitution, especially in the residential and industrial sectors, as well as in power generation. The combined effect of these factors is expected to more than offset any potential oil demand increase related to economic growth in this regional grouping.

Figure 3.1
Annual oil demand increments by region, 2019–2024



Source: OPEC.

Another important feature of recent projections, evident in Figure 3.1, is decelerating demand growth in the medium-term. Indeed, following a period of relatively strong oil demand growth between 2015 and 2018, supported by robust economic growth and lower oil prices, the signposts for the next five years indicate growth heading towards moderate levels of annual incremental demand of around 1 mb/d.

There are several reasons behind this trend, the details of which are laid out in other sections of the publication, including:

- *Lower GDP growth:* as discussed in detail in Chapter 1, global GDP growth is expected to decelerate this year to 3.2% p.a., compared to 3.6% and 3.7% p.a. in 2017 and 2018, respectively. The lower growth rate is expected to continue through 2020 and the global economy is seen only moderately recovering in the years thereafter to reach 3.4% p.a. in 2024. Moreover, further structural changes in the contributing elements to GDP are taking place in several countries, such as China, with a higher share coming from the service sector. Understandably, less economic activity in energy/oil intensive sectors will result in lower oil demand growth.

- *Further efficiency improvements*: efficiency improvements are being implemented in all consuming sectors, but are most visible in road transportation. Most OECD countries, as well as China and, to some extent India, are pursuing strict measures and setting targets for more efficient personal and commercial vehicles. Some examples of these were mentioned in Chapter 1, but a non-exhaustive list also includes corporate emissions targets in the EU and China and measures supporting a faster penetration of electric and alternative-fuelled vehicles. The EU has also introduced the World Harmonised Light Vehicle Test Procedure (WLTP). In 2018, global BEV sales surpassed 1.2 million (and two million if including plug-in hybrids). This is important to note, especially if combined with the fact that total new sales of passenger cars fell in 2018, compared to the previous year. This was the first annual drop since 2009.

- *Continued oil substitution*: driven by both fuel competition and specific policy measures, oil is expected to continue to be replaced by other fuels, especially natural gas. Examples of such measures include the City Gas Distribution initiative in India that targets a replacement of LPG and kerosene by natural gas; the reduction of direct crude burning in the Middle East (though part of it is offset by the increasing use of fuel oil); the progressive substitution of heavy fuel oil in the power sector in OECD countries; the growing number of LNG-powered vessels in the shipping industry; and expectations of continued higher carbon prices in the EU.

None of the highlighted factors has the potential to significantly slow or even reverse the medium-term demand growth trend at the regional or global level on its own over the medium-term. However, some combination of these factors may have a measurable effect on oil demand in a given region, leading to an overall decelerating trend at the global level.

On the other hand, there are several factors that can be expected to support oil demand over the medium-term. Firstly, strong sales of new passenger cars and commercial vehicles are set to continue, despite some signs of potential weakening. It is estimated that around 96 million new vehicles were sold worldwide in 2018 and the rate of sales growth in a number of large non-OECD countries was in a range of around 10–20% (Thailand +20%, Brazil +14%, Russia +13% and India +9%). Assuming that future vehicle sales continue in this range, they will provide a solid base for oil demand growth in non-OECD countries.

Within the transportation sector, developments in the aviation segment also provide support to growing demand. Large investments to expand the necessary infrastructure for air traffic are being made in every part of the world. An increasing propensity to travel, especially in a number of Asian countries that have a rapidly expanding middle class, is also bolstering oil demand growth prospects in the aviation sector. This Outlook indicates that aviation will be the fastest growing segment in terms of oil demand within the transportation sector.

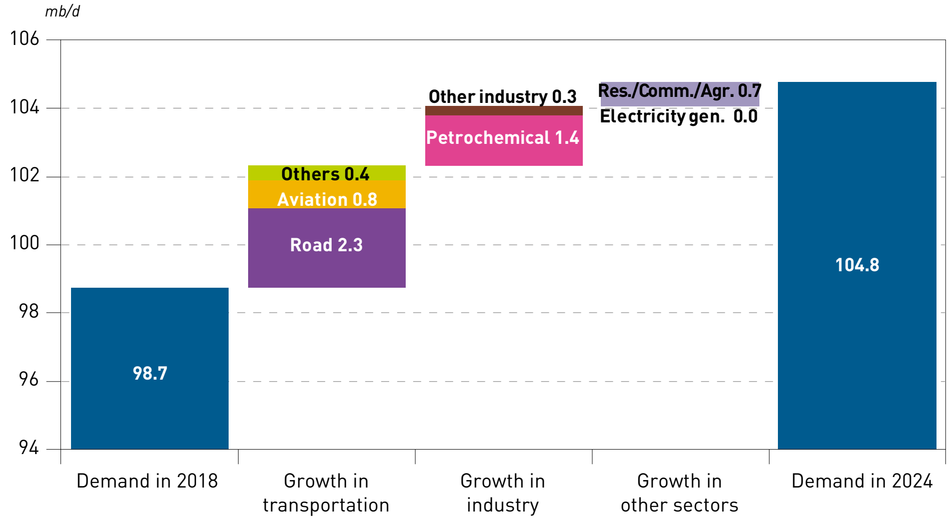
Another source of significant incremental demand over the medium-term is expected to be the petrochemical industry. Driven by strong demand for a wide range of petrochemical products, a large expansion of petrochemical capacity is projected during the medium-term, primarily in the US and China. The cumulative incremental capacity of petrochemical projects currently planned for start-up within the medium-term could potentially result in more than 2 mb/d of incremental oil demand if all projects come on stream as scheduled. However, it is unlikely that this will be the case.

Moreover, increased competition in the sector will likely lead to lower utilization rates at less profitable plants, so net incremental demand is estimated to be 1.5 mb/d higher in 2024 compared to 2018. While investments in the US are almost exclusively geared towards using ethane and LPG as feedstocks, projects in other countries are more diverse and include naphtha and other minor streams as potential feedstock.

The net effect of these global trends on sectoral oil demand is presented in Figure 3.2. Apart from the already discussed major contributions to future oil demand from the road transportation, aviation and petrochemical sectors, this figure also shows the importance of the residential/commercial/agriculture sector. Nearly all of this growth is expected to come from non-OECD countries, as demand in these sectors is already declining in the OECD. Demand in Eurasia is projected to remain relatively unchanged. The largest part of it relates to the expanding use of oil products in the residential sector, followed by the agriculture sector and, to a lesser extent, by the commercial and public services sector.

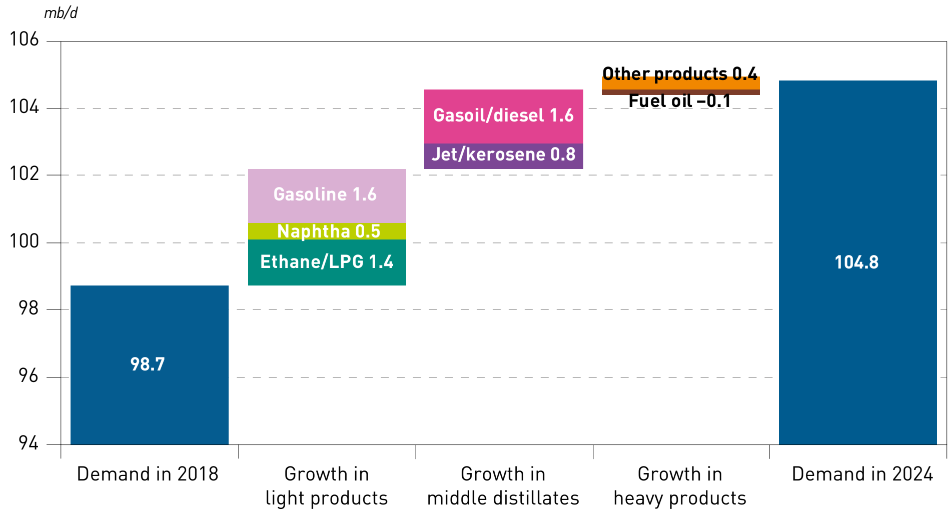
Figure 3.3 translates regional and sectoral oil demand trends into demand for specific refined products. There are three major product groups dominating this figure: gasoline, diesel/gasoil and ethane/LPG. In a departure from past trends where the role of diesel/gasoil was much more pronounced, this product is expected to continue to lessen in importance. The reasons behind this change include slowing GDP growth, ongoing shifts in the structures of major economies,

Figure 3.2
Growth in global oil demand by sector between 2018 and 2024



Source: OPEC.

Figure 3.3
Growth in global oil demand by product between 2018 and 2024



Source: OPEC.

revisions to the expected impact of the IMO regulations (higher assumptions for scrubber use) and a decline in European diesel car sales.

Incremental demand for gasoline has also seen mostly downward revisions as the time horizon for the medium-term outlook has moved forward. However, the range of revisions for gasoline is smaller and mostly reflects steady changes in the overall car fleet.

Demand for ethane/LPG, meanwhile, is gaining momentum as the petrochemical industry undergoes a period of strong expansion. Moreover, LPG demand will also likely receive support from the residential and industry sectors.

Another product projected to record a significant medium-term demand increase is jet/kerosene. An overall increase of 0.8 mb/d for this product broadly corresponds to the expected expansion of the aviation sector. Domestic use of kerosene will likely remain relatively stable over the medium-term. As discussed earlier in this publication, the 0.5 mb/d demand increase for naphtha is tightly linked to an expansion of naphtha crackers in a number of countries.

Turning to the heavy part of the refined barrel, demand for the group of 'Other products', which includes mainly asphalt, bitumen, petcoke, still gas, lubricants and waxes, is also spread over several sectors. From a growth perspective, the largest share of incremental demand is for bitumen, mainly for road construction in developing countries, and lubricants.

Fuel oil demand is set to decline over the medium-term mainly as a result of stagnant demand in electricity generation and some displacement in the marine sector by diesel. It should be noted that this is the only product for which demand is projected to decline over the medium-term.

3.1.1 Impact of the IMO regulations

Another important development that warrants special attention is the upcoming 1 January 2020 implementation of the IMO's sulphur cap for marine fuels (0.5% on a weight basis). As already pointed out in previous reports (WOO 2018), the onset of the new regulation is expected to be a disruptive event, not only for the shipping sector, but also for the global refining system and respective refined products' supply. Although the projections in this Outlook still maintain this general view, changing market conditions and projections in terms of oil demand, supply and refining, as well as developments within the shipping industry, have led to some adjustments of previous IMO-related conclusions.

There are several ways that the shipping industry can comply with the IMO regulations: switch to 0.5% compliant fuel (either low sulphur fuel oil (LSFO), middle distillates or a compliant fuel blend); continue to consume HSFO while running an exhaust gas cleaning system (scrubber); and switch to an alternative fuel (LNG or biofuels).

In practical terms, the last option is only relevant in the longer-term . Thus, in 2020, ships will have to comply either by using LSFO, middle distillates, a compliant blend or by installing scrubbing facilities on-board. Given the variety of options, there is significant uncertainty as to how shippers and the global refining system will react and adjust. These uncertainties regarding compliance options and the (initial) levels have deterred early IMO-related investment in the shipping and/or refining industries, at least until recently. This is another argument in favour of the view that the first year following the rules being enacted may see some market turmoil.

As in previous years, this Outlook assumes a certain level of non-compliance despite efforts to enforce the regulation, especially in the early years of its implementation. It is highly probable that some regions may see lower compliance due to a lack of compliant fuel. Furthermore, over 100 countries, with a combined 15 mb/d of refining capacity, are not even signatories to the IMO treaty, which creates uncertainty regarding the potential enforcement of the sulphur rule.

In terms of scrubbers, the second half of 2018 and first half of 2019 saw a rapid increase in orders relative to the time of completion of the WOO 2018, with more orders having since been placed than previously expected. Several major shipping companies such as Maersk, Scorpio Tankers and MSC announced plans to install scrubbers on-board their ships. As of mid-2019, there were more than 2,000 scrubbers installed or on order, which is a significant increase from only 500 in early 2018. According to reports, most scrubbers will likely be 'open-loop' scrubbers, despite growing opposition to this type of scrubber. Due to concerns about the potential pollution of coastal waters, several countries and/or ports have prohibited the discharge of waste from open-loop scrubbers in coastal and/or port areas. This opposition, however, is not considered a major hurdle in the medium-term, as ships may switch to LSFO in the affected areas or may have installed scrubbers with a hybrid option, capable of storing limited volumes of waste on-board.

Regarding the availability of compliant fuel, an increasing number of refiners, including ExxonMobil, BP, Total, Repsol, Shell, Cosmo Oil, Hellenic Petroleum and Sinopec have already announced more detailed specifications of fuels they will offer to comply with the IMO regulation and several shippers have already tested some compliant LSFO blends. However, the results of these trials remain largely unknown at the time of completing this Outlook.

In terms of refining capacity, 2019 and 2020 are likely to see a larger-than-expected number of new builds, especially in the non-OECD. According to preliminary data, the additional crude distillation capacity from new builds in these two years is expected to be around 3.6 mb/d. This includes some projects that were officially commissioned in late 2018, but started commercial operations in 2019. This projection also includes several IMO-driven restarts of idled plants, such as the Hovensa refinery in the US Virgin Islands and the Wilhelmshaven refinery in Germany.

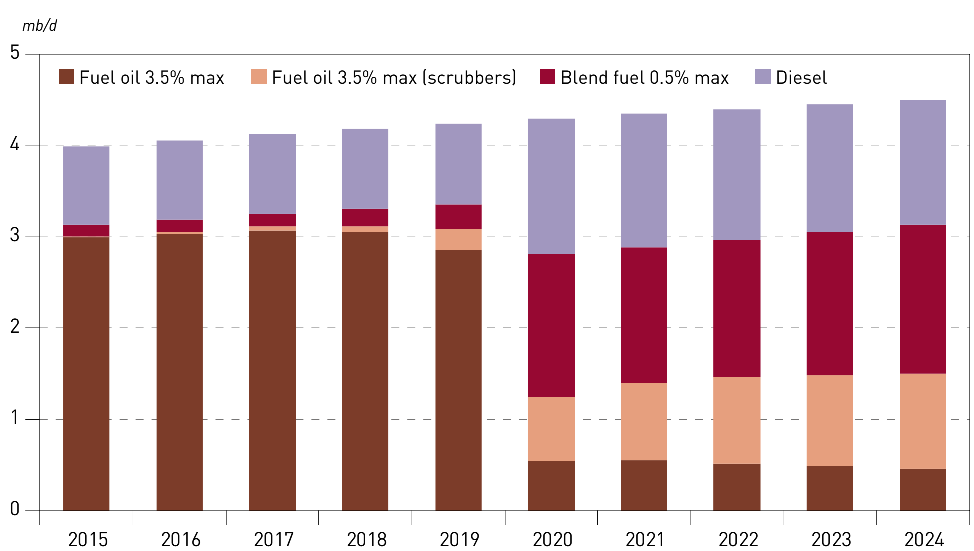
Overall, this large addition of refining capacity contrasts with oil demand growth of some 2.4 mb/d for 2019 and 2020 combined. On top of the assumed refinery additions, several refiners have announced intentions to bring forward maintenance and increase debottlenecking efforts, which should help to maximize the operational flexibility of the refining system, especially during the first half of 2020.

Apart from the factors inherent to the shipping and refining sectors, there are other market drivers set to influence future developments surrounding the implementation of the IMO regulations. Firstly, overall product demand and the respective product mix affect the flexibility of the refining system to react to the regulations. The current outlook sees global oil demand in 2020 significantly lower than last year's assumption. In addition, an upside revision to petrochemical demand in 2020 of around 0.2 mb/d has led to a reduction of the so-called 'call-on-refining', as these volumes are mainly natural gas liquids (NGLs) and largely bypass refining systems. This puts less demand side pressure on the global refining system and provides more flexibility with regards to base refinery throughput to switch to IMO-compliant fuels.

The changing quality of the global crude slate will also increase the refining system's ability to address the challenge of a shifting bunker fuel mix. The global crude slate has become even lighter than was projected a year ago due to the larger-than-expected expansion of US tight oil production, as well as shortfalls at the heavy end of the slate. Expectations for US tight crude production in 2020 have been revised upwards by around 0.8 mb/d relative to the WOO 2018 assumption. At the same time, there is less output seen coming from some medium- and heavy-sour crude producers, not only in OPEC Member Countries, but also Mexico and Canada. This change in feedstock quality is expected to lower the pressure on conversion and desulphurization units, which are crucial for the production of IMO-compliant fuels.

Figure 3.4 shows the medium-term projections for the marine bunker fuel mix. Due to the favourable developments described earlier, the initial compliance rate with the IMO regulations is expected to be higher than was assumed last year. This is also supported by the official approval of a non-compliant fuel oil carriage ban unless a scrubber is installed on-board. Consequently, this Outlook assumes a compliance rate of around 85% in 2020 (higher by some 10 percentage points compared to last year's publication), with compliance expected to rise gradually to almost 90% in 2024 and to near full compliance at some point after the medium-term. This assumption translates into non-compliant HSFO consumption of just above 0.5 mb/d in 2020, followed by a gradual decline in line with rising compliance.

Figure 3.4
Marine bunker demand by fuel type



Source: OPEC.

Regarding scrubber-related HSFO demand, this Outlook is modestly more optimistic compared to the WOO 2018, with around 2,500 vessels expected to have scrubbers in 2020. Towards the end of the medium-term, the number of installed scrubbing facilities is expected to have more than doubled, to almost 5,500. This translates into HSFO demand from scrubbers of around 0.7 mb/d in 2020, which then rises above 1 mb/d in 2024.

In line with this, this Outlook assumes that the price difference between HSFO and LSFO will be wide enough to justify this development. Accounting for non-compliance, as well as for compliant HSFO consumption, demand for marine HSFO is set to decline from above 3 mb/d in 2019 to just 1.2 mb/d in 2020 and then gradually recover to around 1.5 mb/d towards the end of the medium-term.

At the same time, this Outlook estimates combined demand of around 3 mb/d for marine distillates and LSFO in 2020, an increase of nearly 1.9 mb/d y-o-y. Diesel demand in the bunker sector is projected to increase to around 1.5 mb/d in 2020, which is an increment of around 0.6 mb/d *versus* 2019. At the same time, the annual demand increase for compliant 0.5% blend fuel is estimated at around 1.3 mb/d, with outright demand reaching almost 1.6 mb/d in 2020.

Contrary to the expectations of previous years, this year's Outlook does not see a need for additional crude runs, which would have led to excess HSFO. In other words, this Outlook sees sufficient flexibility in the refining system in 2020 to address the sudden change in the fuel mix. The major reasons for this are, as explained earlier, lower-than-expected total global liquids demand, a lightening of crude oil supply, a more optimistic refining capacity outlook and a higher number of vessels with on-board scrubbers in 2020. Furthermore, market tightness may also be partly addressed by using middle distillate and LSFO commercial stocks, with market participants expected to build stocks ahead of the implementation date. The short-term excess supply of HSFO may be absorbed by existing storage for crude and/or dirty products.

Another issue to be considered is the volumetric processing gains in switching from fuel oil to diesel. In 2020, when the need for additional diesel demand is largest, the resulting increase in processing gains is almost 0.1 mb/d. The effect of higher processing gains will likely ease over time, however, since the increasing number of scrubbers and the availability of LSFO will gradually eliminate the need to use more marine gasoil.

In terms of pricing, this Outlook maintains the view that the impact of IMO rules on HSFO prices, as well on the gasoil/HSFO spread, will be significant. However, as the current HSFO market tightness has been caused mostly by declining medium-and heavy-sour crude supply, the impact of the IMO regulations on HSFO pricing is likely to be less severe than previously expected.

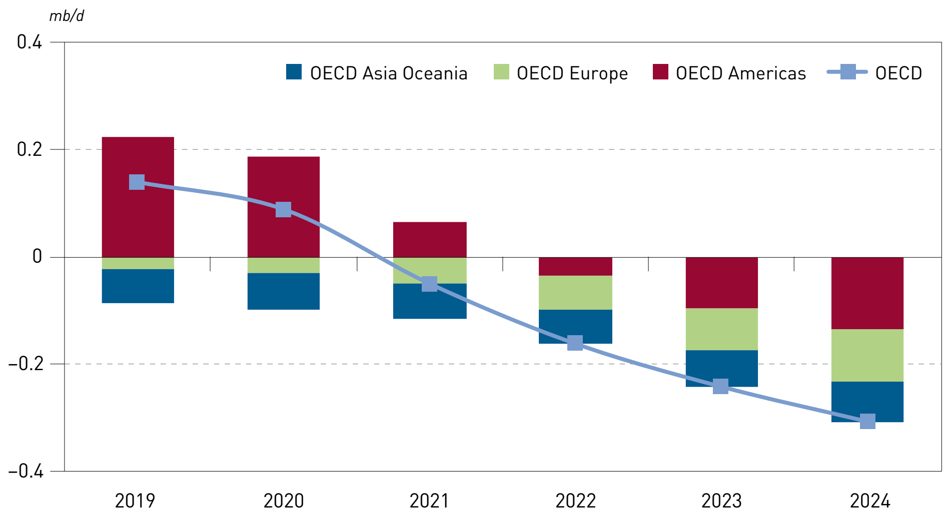
In addition, this Outlook does not assume an oversupply of HSFO in 2020, which means that there is little probability that HSFO will have to compete against coal and gas in the power generation sector to manage excess volumes. Consequently, the negative impact on the spreads of HSFO-rich, medium and heavy-sour crudes is projected to be less significant relative to the WOO 2018 estimate.

3.1.2 Oil demand outlook by region

OECD

Oil demand in **OECD** countries is forecast to shift after 2020 from growth to a declining trend for the remaining part of the medium-term period (Figure 3.5). Decelerating growth in OECD Americas is the key element behind this, since oil demand in the other two regions, OECD Asia Oceania and OECD Europe, underwent this shift in 2017 and 2018, respectively. With expectations for a sluggish economic performance and continued efficiency improvements over the next few years, falling

Figure 3.5
Annual oil demand growth in the OECD, 2019–2024



Source: OPEC.

demand in these regions will likely be even more pronounced. It should be noted, however, that oil demand has fallen in OECD countries before. After peaking in 2005, oil demand in OECD countries was on a declining trend until 2015, when a combination of collapsing oil prices and relatively high GDP growth rates (2.5% in both OECD Americas and OECD Europe in 2015) stimulated a return of demand growth. After five years of growth, however, the outlook for OECD oil demand is reverting back to a declining trend.

This trend is most pronounced in **OECD Asia Oceania**, where demand is projected to drop over the entire medium-term period and with the pace of the decline slowly accelerating. It should be noted that this is the region with the lowest average GDP growth among all regions considered in this publication. Moreover, it is the region with the highest fuel economy for the existing car fleet, especially in Japan and South Korea. In addition, there are also tight regulations for commercial vehicles in these countries, resulting in declining demand for both gasoline and diesel.

Turning to **OECD Europe**, the region's surprisingly strong demand growth of 0.2–0.3 mb/d from 2015–2017 is not expected to continue. Demand was essentially flat in 2018 and is anticipated to decline marginally in 2019, in line with a further deceleration in GDP growth to just 1.2% p.a. This view is also supported by the trend in the region's new car registrations. In 2018, these were broadly at the same level as in 2017, but the latest figures for 2019 indicate a decline of 2% for the first half of the year. Moreover, BEVs, PHEVs, hybrids and alternative fuel vehicles (AFVs) all recorded strong growth, hence eliminating part of the gasoline and diesel demand associated with vehicle sales.

Additionally, the share of diesel engines in new European passenger car registrations dropped significantly in 2018 due to increasing anxiety about diesel fuels following 'dieselgate'. Higher nitrogen oxides (NO_x) and particulate matter emissions, which are strictly regulated in Europe, are the main concerns in this regard. According to the European Automobile Manufacturers Association, diesel car sales fell by 18.4% in 2018 to just over 5.5 million new car registrations and they also showed a decline of 17.9% in the first quarter of 2019. This trend will likely continue with gasoline engines and alternative powertrains expected to fill the gap left by diminishing demand for diesel engines.

Looking ahead, GDP growth in OECD Europe is expected to recover slowly over the medium-term. Nevertheless, growth will remain at relatively low levels, in the range of 1.5% to 1.7% p.a. These prospects, combined with a relatively stable price environment, continued efficiency improvements and stricter environmental regulations, will pressure regional oil demand. The overall demand decline over the medium-term is projected to be around 0.3 mb/d, with total demand falling slightly below 14 mb/d in 2024, compared to 14.3 mb/d in 2018.

The largest part of OECD oil demand is accounted for by **OECD Americas**. Developments in this region also bear a greater level of uncertainty compared to OECD Europe and OECD Asia Oceania, making it more challenging to forecast.

This includes sudden changes in policies, the dynamic political situation, potentially rapid economic responses to a changing environment and the potential impact of higher prices on consumer behaviour, among other factors. Moreover, the expected rapid expansion of the US petrochemical sector in the next two to three years (covered in detail in section 3.3) raises questions about the sustainability of this trend over a longer period.

Despite these uncertainties, several trends in the region's oil demand projections are evident. The most striking is anticipated strong growth in ethane/LPG consumption as a petrochemical feedstock, especially in the period 2019–2021. This expansion, however, is expected to moderate during the latter part of the forecast period. Steady growth is also forecast for jet kerosene, albeit at much lower levels compared to ethane/LPG.

The other two key products – gasoline and diesel – will likely see a changing medium-term demand pattern. Gasoline demand will likely be gradually hit by the impact of US CAFE standards and lower economic growth (compared to the 2017–2019 period), and demand is seen contracting from 2021 onwards.

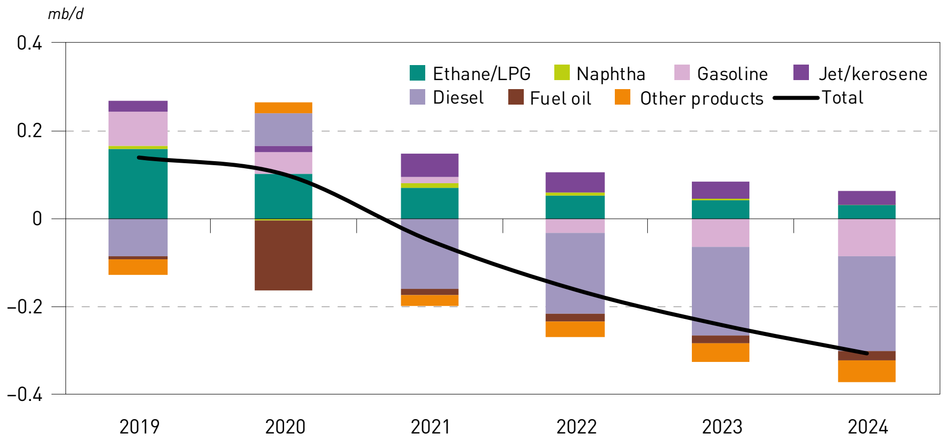
The prospects for diesel demand in OECD Americas are more volatile. Following strong growth in 2018, supported by healthy GDP growth and activity related to tight oil production, it is expected to decline during 2019 as GDP growth moderates and new pipelines become operational in tight oil producing areas, eliminating part of the diesel demand. During 2020, however, a shifting demand pattern in the marine sector due to the onset of IMO regulations will likely see a return of expanding diesel demand.

This one-off effect will be more than offset in later years by the greater use of scrubbers with the demand slate of bunker fuels gradually shifting back towards fuel oil at the expense of diesel. The net effect of these trends is that the region's oil demand is expected to rise from 25.5 mb/d in 2018 to 26 mb/d in 2021 and 2022, before declining to 25.7 mb/d in 2024, which is nonetheless still higher than in 2018.

Figure 3.6 shows the medium-term change in **OECD** demand for major refined products on an annual basis. At the lighter end, demand growth for ethane, LPG and naphtha in this region is largely dominated by an expanding petrochemical sector. This is particularly evident for ethane/LPG demand in the US, while a minor increase in naphtha demand is expected in South Korea. Gasoline demand is still expected to grow during 2019 and marginally in 2020 because of developments in the US and an increasing share of gasoline engines in new vehicle sales in Europe. After 2020, however, improving fleet efficiency (partly also due to non-oil powertrains) will likely lead to a declining trend in gasoline demand.

As already described for OECD Americas, diesel demand for the broader OECD region will be determined by the implementation of IMO regulations in 2020 and lower economic growth in the area. This will also be supported by changing consumer behaviour in Europe, with buyers shying away from diesel cars. Finally, OECD fuel oil demand is projected to decline sharply during

Figure 3.6
OECD annual oil demand growth by product, 2019–2024



Source: OPEC.

the first year of the IMO sulphur regulation's implementation and to continue declining for the rest of the medium-term period. This is due to a continued substitution of fuel oil in the power sector by other energy sources and lower economic activity that will more than offset a partial recovery in the marine sector.

Non-OECD

As discussed in detail in Chapter 1, GDP growth in **non-OECD** countries (as a group) is expected to remain robust and relatively stable over the medium-term. Some decline in 2019 and 2020, from 4.8% in 2018 to an average of 4.6%, will be partially offset in later years, despite a continued decelerating trend in China and India. In line with this outlook, oil demand in non-OECD countries will also remain robust over the medium-term, growing on average by 1.1 mb/d p.a. (Figure 3.7).

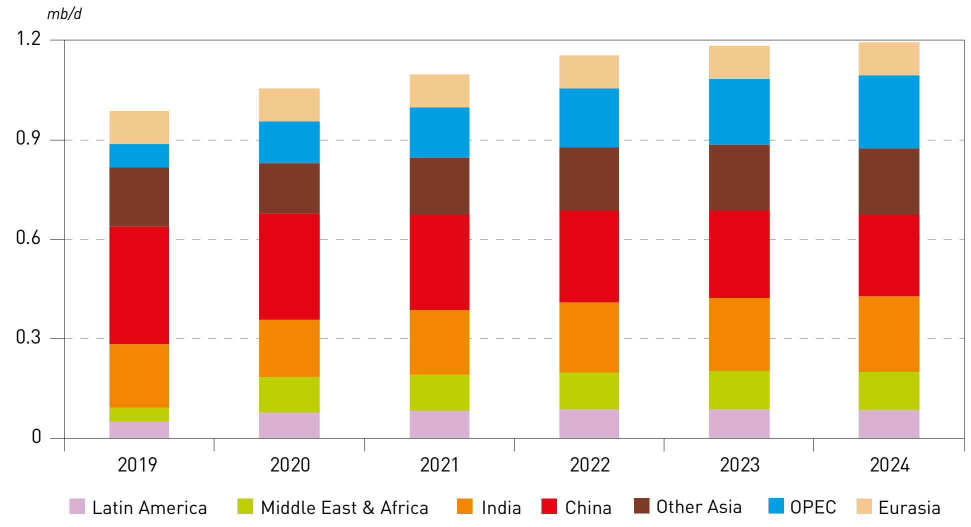
Contrary to the OECD, incremental oil demand in this region is estimated to continue to rise even as GDP growth holds relatively stable. This is partly because the base oil demand level increases each year, but more importantly because many of these countries are still in the development stage where economic progress requires more energy and traditional fuels such as biomass, which is still widely used, are being substituted by modern energy sources.

Translated to absolute levels, this steady annual growth is expected to result in an overall demand increase of 6.6 mb/d between 2018 and 2024, to reach an outright demand level of 57.5 mb/d in 2024, compared to 50.9 mb/d in 2018. Figure 3.8 shows how this growth is distributed between regions (including OECD regions, for ease of comparison), together with the corresponding average annual demand growth rate.

As has been the case in the past, most growth is concentrated in **non-OECD Asia** regions, led by China and India. Combined, these regions are estimated to require an additional 4.2 mb/d of oil. Demand in China alone is expected to increase by 1.7 mb/d, making it the largest contributor to oil demand over the medium-term.

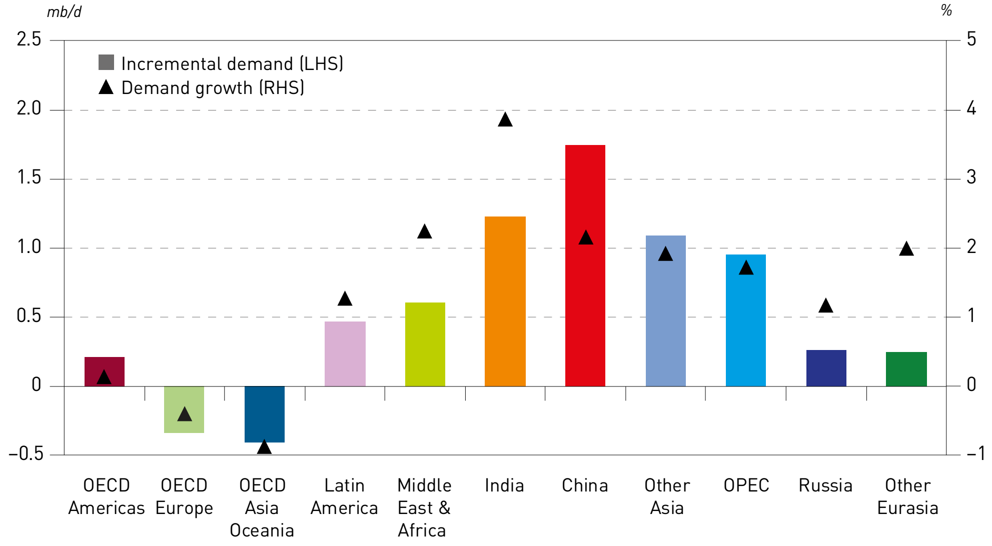
However, the pace of demand growth in India will be by far the fastest among all regions, at 4% p.a. on average, albeit this is from a much lower demand base than for China and Other Asia. It should be noted, however, that the higher demand growth rate in India implies that the country will gradually 'catch-up' with China in terms of annual incremental growth. Indeed, both countries are anticipated to contribute almost the same volume to annual demand increases by 2024 (China +0.24 mb/d *versus* India +0.23 mb/d), and India is expected to surpass China in 2025.

Figure 3.7
Annual oil demand growth in non-OECD countries, 2019–2024



Source: OPEC.

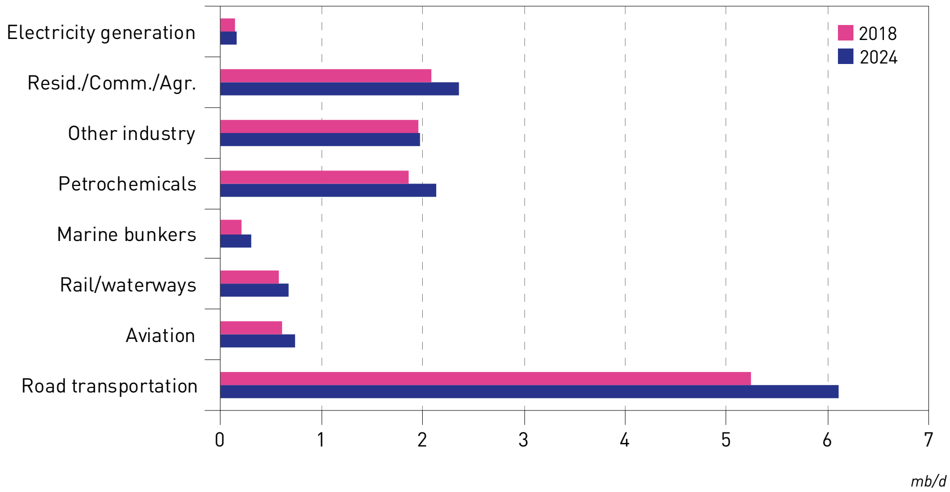
Figure 3.8
Regional oil demand growth between 2018 and 2024



Source: OPEC.

In **China**'s case, three sectors are critical to its medium-term oil demand growth: the road transportation, petrochemical and residential/commercial/agriculture sectors (Figure 3.9). This is despite demand in both the aviation and marine sectors growing at much higher rates in 2018, albeit from lower baselines. Developments in the road transportation sector are very complex, with several trends having counter-balancing effects on oil demand.

Figure 3.9
Oil demand in China by sector, 2018 and 2024



Source: OPEC.

New car sales in China reached 23.7 million passenger cars in 2018, making it by far the largest global car market despite the pace of sales declining by around 4% compared to 2017. Preliminary figures for the first half of 2019 indicate a further decline in new sales, primarily due to new emissions regulations. In terms of the structure of new sales, there is strong momentum in the EV and SUV segments. Adding to the complexity is a decelerating trend in commercial vehicle and bus sales, whereas, at the same time, there is an ongoing shift towards electric buses – especially for urban transport systems – and LNG-powered trucks. The net effect of these trends is an estimated demand increase of 0.9 mb/d between 2018 and 2024, which is almost equally shared between gasoline and diesel.

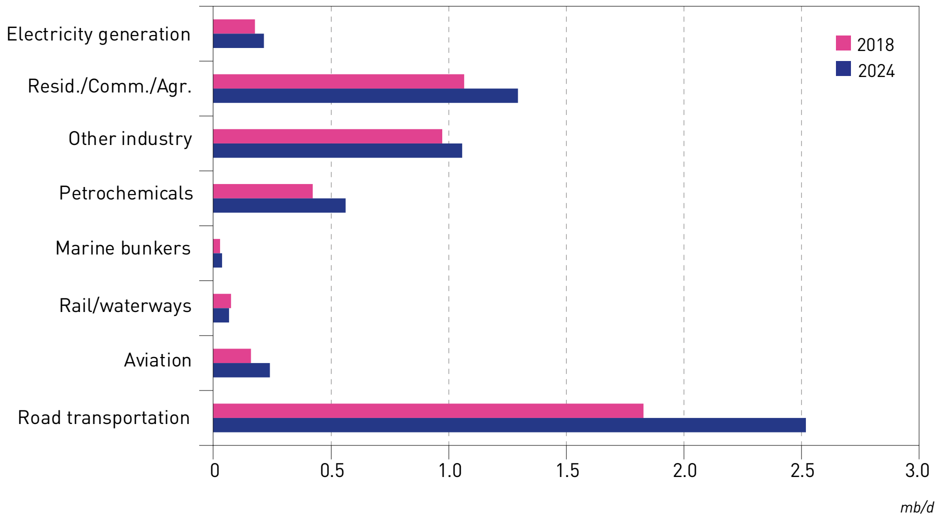
On top of this, around 0.3 mb/d of incremental demand is expected from the petrochemical industry, making it the second fastest growing country for this sector, behind the US. Almost 0.3 mb/d of additional demand is anticipated to materialize in the residential/commercial/agriculture sectors, while almost no growth is expected from 'Other industry' and the electricity generation sector.

Overall, China's oil demand growth is already on a decelerating growth path on the back of slowing economic growth and a profound economic restructuring. Volumetrically, demand is expected to increase by 0.3 mb/d p.a. on average in the medium-term, reaching an outright level of 14.5 mb/d in 2024.

The demand outlook for **India** shows a moderate acceleration in growth, with incremental demand rising from 4.7 mb/d in 2018 to 6 mb/d in 2024. Despite the backdrop of a slowing global economy, India's economy is expected to remain strong with GDP growth of about 7% on average over the medium-term. This should provide the impetus for further industrialization, infrastructure development and urbanization. In turn, this is expected to result in robust energy demand with an increased appetite for all forms of energy. From the perspective of oil, driven by strong economic growth, demand is set to grow from 4.7 mb/d in 2018 to 6 mb/d in 2024, which is an average annual growth rate of 4%.

In terms of sectoral oil demand growth, all sectors except rail are expected to contribute to rising oil demand growth (Figure 3.10). Road transportation continues to be at the forefront, far ahead of all other sectors, with expectations for an additional 0.7 mb/d of oil demand through to 2024. The residential and petrochemical sectors are projected to contribute 0.2 mb/d and 0.15 mb/d, respectively. In terms of relative growth, the aviation sector is expected to have the highest average growth rate of 6.9% p.a., contributing to a medium-term increase of close to 0.1 mb/d. Demand for oil on India's railways is anticipated to decline as the country has announced major plans to electrify its rail network.

Figure 3.10
Oil demand in India by sector, 2018 and 2024



Source: OPEC.

India's automobile industry is dominated by two-wheelers, such as scooters and motorbikes, which tend to be gasoline-powered. Two-wheelers account for more than 80% of all vehicles in India. As the Indian economy grows, the number of people who can afford vehicles is likely to increase due to higher household incomes. The first choice of vehicle for the majority of the Indian population is a two-wheeler as it is a much cheaper and fuel-efficient means of transportation than alternatives. Moreover, even in big cities, many people prefer to use two-wheelers even if they can afford a four-wheeler due to traffic congestion. Therefore, the trend of two-wheelers dominating sales in the Indian automobile industry is likely to continue.

Nevertheless, four-wheelers and especially mid-range passenger car sales are also likely to see a jump in the coming years. Gasoline is the preferred fuel for private-use cars, with more than half of private cars currently fuelled by gasoline. Thus, in the road transportation sector, gasoline demand is likely to grow at a faster pace than other fuels, as both two-wheelers and the majority of four-wheeled cars are gasoline-powered. Demand for gasoline is projected to reach 0.8 mb/d in 2024, up from less than 0.6 mb/d in 2018.

Despite there being vastly more gasoline-fuelled vehicles in India, oil demand in the road transportation sector is dominated by diesel as the use of this product by commercial vehicles outstrips the combined demand of all other vehicles. In 2018, demand for diesel in this sector stood at more than 1.2 mb/d, while gasoline demand was just half that of diesel at 0.6 mb/d. This is a relatively unique situation as, typically, gasoline and diesel demand are close to parity in most developing countries. A similar situation exists in Europe, although for different reasons, namely the preference for diesel-powered passenger cars in the past.

Diesel in the road transportation sector is also projected to witness healthy growth, rising by 0.4 mb/d over the medium-term. The majority of the diesel demand is expected to come from commercial vehicles, partially supplemented by passenger cars. Private four-wheeled cars running on diesel represent less than 40% of the total fleet. Furthermore, sales of diesel-powered cars have been declining in recent years, especially after Delhi banned diesel cars older than 10-years old as a measure to combat air pollution. Thus, diesel consumption will likely grow at a slower pace than gasoline. Minor incremental demand in the road transportation sector is also projected for LPG, but it is limited due to a lack of adequate retail stations.

Agricultural activities are also set to pick up in view of the growing economy and expanding population, which will likely support a minor increase in diesel demand. In the agricultural sector, diesel-fuelled tractors used for ploughing and harvesting and diesel-powered water pumps for irrigation are the main source of diesel demand.

It should be noted that the demand projections take into account the potential impact of the City Gas Distribution (CGD) project announced by the Indian government. The government recently granted licenses to private domestic companies, as well as foreign players, to set up infrastructure for the distribution of cleaner cooking (piped natural gas) and transportation (CNG) fuels to the domestic market. With a goal of extending the CGD network coverage to more than 400 districts, or about 70% of the country's population over the next two-to-three years, diesel and gasoline consumption in the transportation sector may see some substitution by CNG. Moreover, the role of LPG in the transportation sector is likely to decline after the CGD networks become fully operational.

In the residential sector, LPG holds the dominant oil demand role. More than 87% of India's LPG demand is for cooking. From the demand side, LPG is one of the fastest growing products in India. With India's commitment to move towards cleaner fuels, a lot of impetus has been given to substituting kerosene with LPG for domestic cooking. However, with more than 80% of households now using LPG, demand growth is not likely to maintain the pace witnessed over the past few years. Furthermore, LPG demand will be affected by the CGD project.

Nonetheless, LPG demand in the residential sector is likely to grow to 0.9 mb/d in 2024, up from less than 0.7 mb/d in 2018. Demand for kerosene as a domestic fuel is expected to continue on its downward trend, falling to around 0.1 mb/d in 2024.

The aviation sector is also expected to see a boom as the economy expands and the general standard of living improves. According to the International Air Transport Association (IATA), about 158 million people travelled to, from and/or within India in 2017. In 2018, the number of air passengers increased by more than 18%. Moreover, IATA estimates that India will be the third largest air transportation market in the world by 2026, up from its 7th place ranking in 2017. In light of these developments, demand for aviation fuel is expected to have the highest average medium-term growth pace of almost 7% p.a. among transportation fuels.

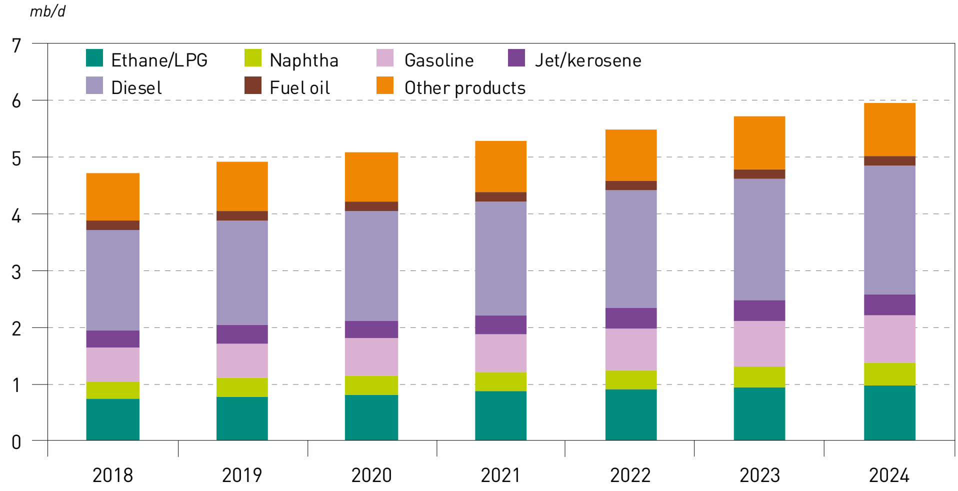
In terms of the petrochemical industry, this sector will likely reap the benefits of an expanding Indian economy given its direct relationship with economic growth. Currently, the largest petrochemical project under construction is by HPCL-Mittal Energy Ltd., which will add two petrochemical units to an existing refinery in Bhatinda, Punjab.

This will create more demand for feedstock, mainly naphtha. Naphtha is expected to remain one of the prime feedstocks as there is surplus domestic supply. Nevertheless, there is further upside potential for demand in the petrochemical sector. One project that may help to meet demand is the planned Ratnagiri refinery, a joint venture between Saudi Aramco, ADNOC and Indian state-owned oil marketing companies. With a planned capacity of 1.2 mb/d of crude distillation capacity, combined with 18.5 mt/y of petrochemical capacity, it would significantly boost naphtha/ethane demand.

Some oil demand increase is also projected in India's industrial sector, which includes the refining sector. Many industries, such as the steel industry, also use fuel oil and diesel to power their furnaces. This provides a solid base for steady demand growth in the sector, which is projected to reach almost 1.1 mb/d in 2024, compared to less than 1 mb/d in 2018. For the remaining sectors, such as rail and waterways, electricity generation and marine bunkers, oil demand is relatively low and no major changes are expected.

Figure 3.11 translates the oil demand trends to products. Demand growth is expected for almost all refined products, with the exception of kerosene, which has traditionally been used in rural areas for cooking. Diesel is projected to see the largest demand increase. This is primarily attributable to transportation, industry and the agricultural sector, in line with the robust economic outlook.

Figure 3.11
Oil demand in India by product



Source: OPEC.

Diesel demand is expected to grow from 1.8 mb/d in 2018 to 2.3 mb/d in 2024, at an average growth rate of 4.3% p.a. This product is followed by gasoline and LPG, which are also set to witness strong medium-term growth.

One characteristic of India's oil industry is its relatively low demand for fuel oil. Almost no fuel oil is consumed in the power sector, which is dominated by coal, renewables and natural gas. There are also no major international bunkering hubs in India. Therefore, fuel oil use is largely contained within the refining sector itself, industry, and the residential and petrochemical sectors. The combined demand for fuel oil from these sectors is expected to remain relatively stable, below 0.2 mb/d, over the entire medium-term period.

As a growing economy boosts industrialization, demand for other products such as bitumen, pet coke, lubes/greases and waxes for manufacturing, cement, aluminium, steel and other industries will also likely grow significantly. Demand for all these products combined is likely to increase by 0.1 mb/d to reach almost 1 mb/d in 2024, from less than 0.9 mb/d in 2018.

Falling just slightly behind India, the medium-term demand outlook for **Other Asia** shows strong growth of an additional 1.2 mb/d, with total demand reaching 10.2 mb/d expected in 2024. This outlook is supported by expectations of solid economic growth of consistently above 4% p.a. – despite some downward revisions compared to the WOO 2018 – and an expansion of the region's petrochemical sector.

For **OPEC**, the prospects for demand growth in 2019 and 2020 are limited to 0.1 mb/d as GDP growth is expected to be severely impacted by current circumstances. However, this is expected to change in the years thereafter as economic activity will recover, supported by more stable markets. In line with this expectation, annual oil demand growth will also double to 0.2 mb/d. By 2024, demand is projected to reach 9.8 mb/d, an increase of 1 mb/d, compared to the base year of 2018.

Unfavourable economic conditions are expected to continue in **Latin America** throughout the rest of 2019. This will likely put a cap on oil demand growth, which is assessed at less than 50 thousand barrels per day (tb/d). However, this is expected to change in 2020 when economic conditions are anticipated to improve, particularly in Brazil and Argentina. Oil demand will likely respond, but overall demand gains over the medium-term are forecast to be quite limited, at 0.4 mb/d.

Total demand is expected to reach 6.3 mb/d at the end of the medium-term. In a similar vein, the outlook for faster economic growth and strong demographic developments in **Middle East & Africa** (excluding OPEC Member Countries) is anticipated to lead to a medium-term oil demand increase in this region of 0.5 mb/d, with outright demand expected to reach 4.8 mb/d in 2024.

The last major group of non-OECD countries consists of Russia and non-OECD countries in Europe. Their combined oil demand is around 6 mb/d. Accordingly, the annual incremental demand expected from the region is also fairly low, at around 0.1 mb/d. Moreover, there is a clear decelerating trend for demand growth in the region, especially in the case of **Other Eurasia**. This is primarily driven by declining GDP growth rates, with GDP projected to fall from around 4% in 2017 and 2018 to below 3% by 2024. Nevertheless, this still robust economic growth results in relatively strong demand growth of around 2% p.a. on average. Translated into volume, this represents an overall increase of almost 0.3 mb/d over the medium-term, moving from slightly less than 2 mb/d in 2018 to more than 2.2 mb/d in 2024.

Similar to Other Eurasia, oil demand in **Russia** is expected to increase by 0.3 mb/d to reach 3.8 mb/d in 2024. However, the annual increments expected from Russia are more stable, reflecting its fairly stable GDP growth outlook. This is expected to remain within the range of 1.5% to 1.7% p.a. for each year through to 2024.

In terms of sectoral demand, growth in Russia's petrochemical sector over the medium-term is almost at parity with the road transportation sector, both increasing by around 80 tb/d. This indicates the growing importance of Russia's petrochemical sector. In addition to these two sectors, some growth is also expected from aviation and industry, and to a lesser extent from the rail and residential/commercial sectors.

3.2 Long-term oil demand outlook by region

Global oil demand is expected to increase by almost 12 mb/d over the long-term, rising from 98.7 mb/d in 2018 to 110.6 mb/d in 2040. The regional breakdown of future oil demand is provided in Table 3.2. In several respects, the demand trends set out in this table broadly

Table 3.2
Long-term oil demand by region, 2018–2040

mb/d

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD America	25.5	25.9	25.6	24.3	22.8	21.1	–4.5
OECD Europe	14.3	14.3	13.9	13.1	12.2	11.3	–3.0
OECD Asia Oceania	8.0	7.9	7.5	7.0	6.4	5.9	–2.1
OECD	**47.8**	**48.1**	**46.9**	**44.4**	**41.5**	**38.3**	**–9.6**
Latin America	5.9	6.0	6.4	6.8	7.0	7.3	1.4
Middle East & Africa	4.2	4.4	5.0	5.6	6.2	6.8	2.6
India	4.7	5.1	6.2	7.4	8.8	10.2	5.4
China	12.7	13.4	14.7	15.7	16.5	17.1	4.4
Other Asia	9.0	9.3	10.3	11.2	12.1	12.8	3.8
OPEC	8.8	9.0	10.0	10.9	11.5	11.8	3.0
Russia	3.6	3.7	3.9	3.9	3.9	3.8	0.3
Other Eurasia	2.0	2.1	2.3	2.4	2.4	2.5	0.5
Non-OECD	**50.9**	**52.9**	**58.6**	**63.9**	**68.5**	**72.3**	**21.4**
World	**98.7**	**101.0**	**105.6**	**108.3**	**109.9**	**110.6**	**11.9**

Source: OPEC.

follow those outlined in the medium-term, although some additional factors and drivers will increasingly play a role. These relate primarily to energy policy issues and technology developments that may impact future cost structures and bolster options that are less competitive over the medium-term period.

It is worth noting that current oil demand projections for 2040 represent a downward revision of more than 1 mb/d to the levels projected in the WOO 2018. The largest part of this revision relates to lower economic activity compared to 2018 expectations. This is supplemented by assumed stronger efficiency gains and fuel switching in several countries, especially those where a stronger policy emphasis on reducing emissions is expected. Finally, some adjustments to historical demand data and downward revisions to demand in the base year also play a role.

From the regional perspective, long-term demand projections show a contrasting picture between the two major regions: declining long-term OECD demand and growing demand in non-OECD.

OECD demand is expected to plateau around 48 mb/d for the next few years before it begins a longer-term decline to around 38 mb/d by 2040. There are several reasons for this OECD oil demand forecast.

Population growth in the OECD is very low, long-term economic growth is in the range of 1.6%–1.7% p.a. and decelerating, efficiency improvements will take place across all sectors of consumption, including a significant penetration of AFVs in the transportation sector, as well as some fuel substitution from oil (and coal) to gas and renewable energy in other sectors. Combined, a declining path for OECD oil demand looks to be inevitable.

The projected demand decline in the OECD will, however, be more than offset by growth in the **non-OECD** region. Driven by an expanding middle class, high population growth rates and stronger economic growth potential, oil demand in this group of countries is expected to increase by 21.4 mb/d between 2018 and 2040. It is expected to rise from 50.9 mb/d in 2018 to 72.3 mb/d in 2040. The largest contributor to this incremental demand is anticipated to be India, adding some 5.4 mb/d between 2018 and 2040.

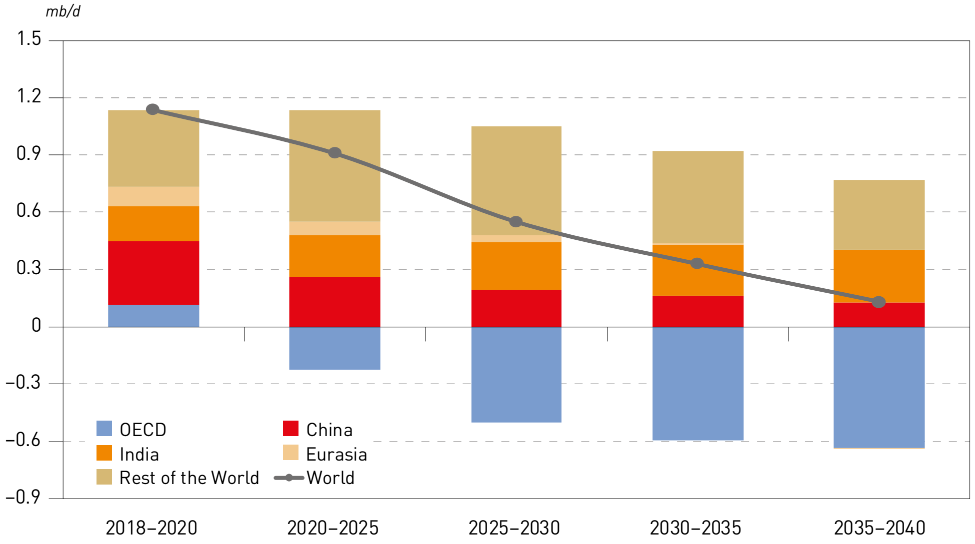
At the same time, **India** is also projected to be the country with the fastest demand growth at 3.5% p.a. on average. Despite this impressive growth, its total demand will still be far below the level of China, the main consumer in the non-OECD region. Indeed, oil demand in **China** is forecast to reach 17.1 mb/d by 2040, which represents an increase of 4.4 mb/d compared to the 2018 level.

Strong demand growth is also projected in the **Middle East & Africa** (2.2% p.a.) and **Other Asia** (1.7% p.a.). In the case of the Middle East & Africa, this translates to just 2.6 mb/d of incremental demand between 2018 and 2040, due to the region's relatively small baseline. In Other Asia, incremental demand is closer to 4 mb/d, since the region's baseline demand is more than twice of the Middle East & Africa.

Projected demand growth in **Latin America** and **OPEC** is relatively moderate, at 1% p.a. and 1.4% p.a., respectively. Finally, oil demand in **Eurasia** is forecast to increase by 0.8 mb/d to reach 6.3 mb/d in 2040. Demand in this region is projected to be on a declining path towards the end of the forecast period, driven by demand declines in Russia on the back of a declining population, improved efficiency and continued fuel substitution.

In analyzing future oil demand, it is important to note a steady deceleration in demand growth, which is clearly presented in Figure 3.12. At the global level, this growth is forecast to slow from a level of 1.4 mb/d in 2018 to around 0.5 mb/d at the end of the next decade. It then leads to almost no growth at the end of the forecast period.

Figure 3.12
Average annual oil demand growth, 2018–2040



Source: OPEC.

This is the result of a combination of several factors. As discussed in Chapter 1, population growth will moderate significantly over time. Related to this is an expectation that long-term GDP growth will slow towards a level of 3% p.a. In addition to this, many economies, especially in developing countries, are anticipated to undergo a structural change in shifting away from heavy industry, which tends to be more oil intensive, to a more service-oriented structure. Demand will also be reduced by further efficiency improvements and fuel switching.

This trend has been visible in the electricity generation sector for a number of years. It will increasingly be felt in the road transportation, marine bunkers, residential and other sectors as time progresses.

3.3 Long-term oil demand outlook by sector

The key trends in sectoral oil demand are outlined in Table 3.3 and Figure 3.13. Clearly, the largest portion of oil demand in this Outlook is, and will continue to be, for transportation. Currently, almost 58% of global oil demand comes from various forms of transportation. Moreover, the share of the transportation sector in global demand is projected to remain fairly stable over the entire forecast period, although some shifts in the share between various transport modes will be inevitable.

Within the transportation sector, the largest demand for oil comes from road transportation. In 2018, this sector represented 45% of global demand at 44.4 mb/d. Over the long-term, however, road transportation demand is expected to lose more than 2% of its share, despite an overall increase of close to 3 mb/d in volume terms. In the years to come, this sector is forecast to witness a strong decoupling between oil demand and transport services and the number of vehicles on the road. This will primarily result from efficiency improvements driven by technological developments, the tightening of energy policies and an increasing penetration of EVs, natural gas and to some extent hydrogen as an energy source.

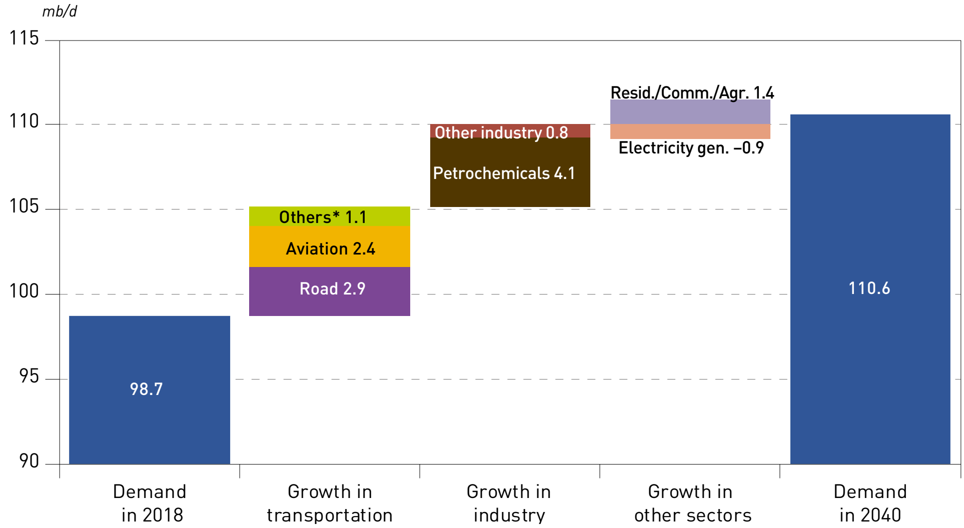
Table 3.3
Oil demand by sector, 2018–2040

mb/d

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
Road	44.4	45.4	47.0	47.3	47.4	47.3	2.9
Aviation	6.5	6.7	7.5	7.9	8.6	8.9	2.4
Rail/waterways	1.8	1.8	1.9	2.0	2.1	2.1	0.3
Marine bunkers	4.1	4.2	4.5	4.7	4.8	4.9	0.8
Transportation	**56.8**	**58.2**	**60.9**	**62.0**	**62.8**	**63.2**	**6.4**
Petrochemicals	13.4	14.0	15.1	16.2	17.0	17.6	4.1
Other industry	12.8	13.0	13.1	13.4	13.6	13.6	0.8
Industry	**26.3**	**27.0**	**28.2**	**29.5**	**30.6**	**31.2**	**4.9**
Resid./Comm./Agr.	10.8	11.0	11.6	12.1	12.2	12.2	1.4
Electricity generation	4.9	4.9	4.9	4.7	4.4	4.0	–0.9
Other uses	15.7	15.9	16.5	16.7	16.5	16.2	0.6
World	**98.7**	**101.0**	**105.6**	**108.3**	**109.9**	**110.6**	**11.9**

Source: OPEC.

Figure 3.13
Oil demand growth by sector, 2018–2040



* *Marine bunkers, rail and domestic waterways.*
Source: OPEC.

Significant demand growth is also expected in the aviation sector. This is projected to be the fastest growing sector, with oil demand growing at 1.5% p.a. on average. Translated to incremental barrels, the aviation sector is expected to add around 2.4 mb/d to future oil demand, rising from 6.5 mb/d in 2018 to 8.9 mb/d in 2040. Some growth is also projected in the marine sector, as well as in rail and domestic waterways. The average rate of growth, however, is much slower than in aviation, at 0.8% p.a. and 0.7% p.a., respectively. Demand in the marine sector was revised downward in this year's Outlook on the basis that more LNG-powered vessels are anticipated than was assumed in past editions of the WOO.

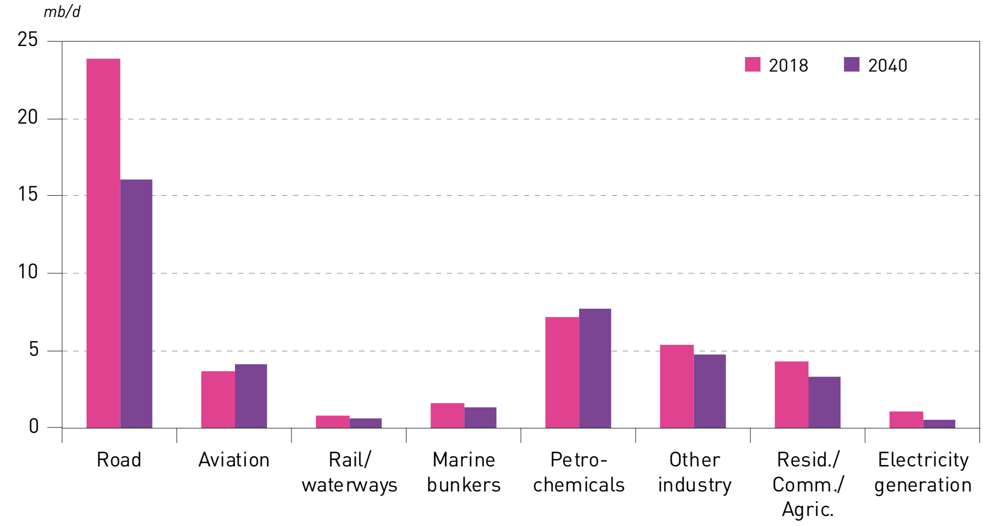
In non-OECD countries, the industrial use of oil is projected to grow in both the petrochemical and other industry sectors. However, growth in petrochemicals (+3.5 mb/d) will be much stronger compared to the 'other industry' (+1.3 mb/d). Moreover, this growth is expected to decelerate, even in non-OECD countries, as the structure of economies gradually moves from being industry-oriented towards being more service-oriented. The net effect of these trends is that the global demand increase in 'other industry' is forecast to be 0.8 mb/d between 2018 and 2040, while demand in the petrochemical sector is expected to increase by 4.1 mb/d over the same period.

The remaining two consuming sectors – residential/commercial/agriculture and electricity generation – show diverging trends. The first one is set to grow over the forecast period, driven by strong demand in non-OECD countries. In contrast, electricity generation is the only sector where demand is forecast to decline at the global level. This is a result of increasing competition from natural gas, as well as from renewables. The projected demand decline for electricity generation is close to 1 mb/d, reaching an outright demand level of 4 mb/d by 2040.

Overall changes in sectoral oil demand for the major regions between 2018 and 2040 are summarized in Figures 3.14 and 3.15. In the OECD, oil demand is projected to grow in only two sectors: aviation and petrochemicals. All other sectors are set to see demand decline, with the largest drop projected for road transportation (–7.9 mb/d). In addition to this, more than 1 mb/d of demand is also forecast to be eliminated in the residential, commercial and agriculture sector, as efficiency improvement measures target this sector in most countries.

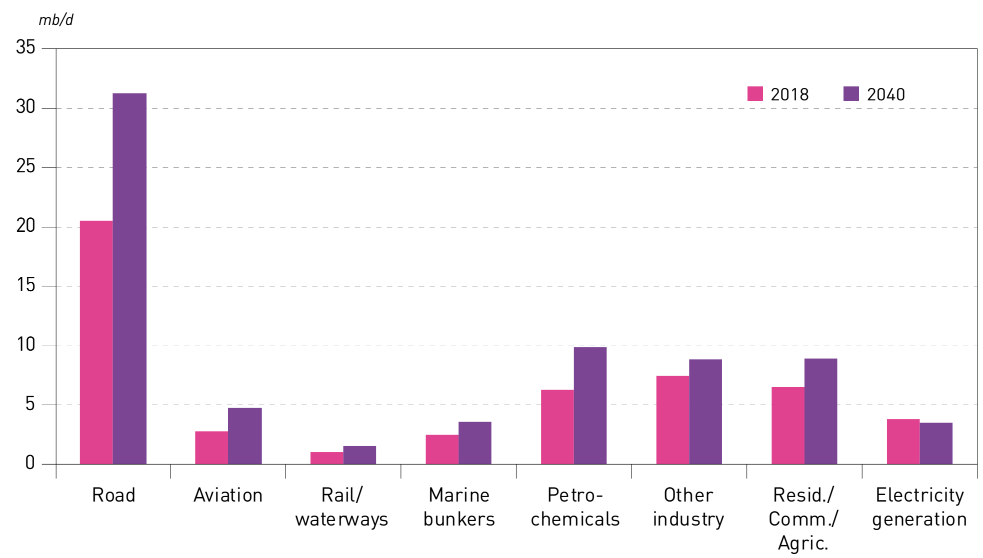
The picture is rather different in the non-OECD region where all but the electricity sector see demand expand. Growth is particularly strong in the road transportation (+10.7 mb/d) and

Figure 3.14
Sectoral oil demand in the OECD region, 2018 and 2040



Source: OPEC.

Figure 3.15
Sectoral oil demand in non-OECD countries, 2018 and 2040



Source: OPEC.

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petrochemical (+3.6 mb/d) sectors. The former is driven by a massive expansion of the car fleet and strong growth in the use of commercial vehicles, reflecting population growth, solid GDP numbers and a rapid expansion of the middle class.

The latter reflects strong future demand for petrochemical products and the fact that Asian countries, especially, will take advantage of this development to further advance their strong position in the industry. Significant demand increases are also projected in the residential, commercial and agriculture sector (2.4 mb/d) and the aviation sector (2 mb/d).

3.3.1 Road transportation

The invention of the ICE and its widespread use in the road transportation sector revolutionized the movement of goods and passengers and helped spur the rapid development of economic activity and an increase in productivity. Oil-based liquids are the traditional energy carriers in the transport sector, with gasoline and diesel still the primary fuels used around the world in a majority of vehicles. As a result, the road transportation sector accounted for 45% of global oil demand in 2018.

However, the future of road transportation, and in, particular, oil demand related to this sector, is clouded with a number of uncertainties. An increasing penetration of AFVs, supported by policies aimed at increasing their use, as well as the improving fuel efficiency of ICEs, has already started to curb oil demand. Expanding urbanization has also seen carpooling, ride hailing and car sharing gaining in importance, though the net effect of these modern services on future oil demand remains to be seen. Moreover, a growing reliance on public transportation systems in certain parts of the world also plays a role.

Nonetheless, oil demand in the road transportation sector is projected to surpass 47 mb/d by 2040, driven by growing vehicle fleets, in line with population growth, coupled with rising economic activity in developing countries. A different picture is emerging in OECD regions, which have already attained or are tending towards vehicle saturation levels, alongside a faster transition to more efficient vehicles and a higher penetration of AFVs.

Vehicle stock

To a large extent, future oil demand in the road transportation sector will mirror developments in global vehicle stocks in terms of both size and composition. To date, the expansion in the number of vehicles at the global level, has always more than compensated for the effects of fuel efficiency improvements on oil demand. Recent sales data, as well as projections for the forecast period indicate, however, that this could change, at least in some regions.

At the global level, it is estimated that new car sales fell marginally in 2018 compared to 2017 (by –0.5%), but still remained above 96 million. Strong growth in many non-OECD countries, such as India, Brazil, Thailand, most South East Asian countries and Russia was offset by falling sales in other major markets, China and Europe, in particular.

Despite a decline, China remained by far the largest car market, followed by the US and Japan. Stalling sales in Germany and strong growth in India over 2018 resulted in India becoming the fourth largest global vehicle market. Moreover, as strong sales of new vehicles in India are expected to continue, it is very likely that India will become the third largest market soon.

Apart from the total number of vehicles, three important observations can be made about car sales in 2018:

- The share of SUVs in new sales has continued to rise. In 2018, SUVs accounted for more than 36% of all new registrations. Compact and midsize SUVs remained the most popular.

- A key feature of European car sales in 2018 was the significant drop in the share of diesel cars, in line with a rapid shift in consumer sentiment. Uncertainties related to the ongoing discussion about banning diesel cars from major city centres, a diminishing price advantage in several countries and the effects of the diesel emission scandal have outweighed the efficiency benefits of diesel cars. However, this drop in sales was not equally spread across all European countries.

- BEVs sales rose to 1.26 million in 2018, setting a new record. In relative terms, this represents an increase of 74% compared to 2017, by far the largest increase among all car categories. Strong sales in the US and increased sales in Europe, as consumers there were looking for alternatives to diesel cars, contributed to growth. However, the main increase was in China, where almost 800,000 new BEVs were sold in 2018. Including 2018 sales of PHEVs, more than one million BEVs and PHEVs were sold in China and more than two million globally.

Turning to the outlook, Table 3.4 shows the estimates for the regional stock of passenger cars through to 2040. At the global level, the total vehicle fleet is estimated to grow by around 835 million passenger cars between 2018 and 2040. The large majority of the increase (773 million cars) will likely come from non-OECD countries and is tightly linked to the rise of the middle class.

China alone is expected to see some 438 million of passenger cars on its roads, around 279 million more than in 2018. Significant increases in the number of passenger vehicles are also projected for Other Asia and India, adding some 160 million and 124 million, respectively. Global stock levels are anticipated to see an average growth rate of 2.5% p.a., while the rate in China will be around 4.7% p.a. The highest growth rate, however, is projected for India, at 8.2% p.a. This is due to the relatively low baseline of existing stock levels and the projected high GDP growth rates.

Table 3.4
Number of passenger cars

millions

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	281.3	286.9	300.4	312.8	323.6	332.8	51.6
OECD Europe	256.5	258.4	261.4	263.8	265.7	266.9	10.5
OECD Asia Oceania	93.8	94.2	94.8	95.0	94.8	94.2	0.4
OECD	**631.5**	**639.5**	**656.6**	**671.6**	**684.1**	**694.0**	**62.5**
Latin America	78.1	81.4	89.5	97.2	104.3	110.6	32.5
Middle East & Africa	35.5	39.3	50.3	63.9	80.5	100.5	65.0
India	26.6	32.1	50.4	76.3	110.3	150.7	124.1
China	158.6	183.9	253.5	325.1	388.9	437.8	279.1
Other Asia	68.9	78.8	108.2	143.9	184.6	228.5	159.6
OPEC	51.9	57.8	74.1	91.9	110.7	130.1	78.2
Russia	35.4	37.1	40.9	44.2	46.9	49.1	13.7
Other Eurasia	46.6	49.1	54.9	59.9	64.0	67.4	20.8
Non-OECD	**501.6**	**559.6**	**721.9**	**902.3**	**1,090.0**	**1,274.6**	**773.0**
World	**1,133.2**	**1,199.1**	**1,378.5**	**1,573.9**	**1,774.2**	**1,968.6**	**835.4**

Source: OPEC.

Compared to the non-OECD, high levels of car ownership in OECD regions prevent a significant increase in the number of cars. Nevertheless, between 2018 and 2040, the number of passenger cars is still estimated to increase by 63 million, with OECD Americas accounting for most of this.

A somewhat different pattern is expected for commercial vehicles. The number of commercial vehicles is anticipated to increase by around 220 million, rising from 236 million in 2018 to 457 million in 2040 (Table 3.5). This represents average annual growth of 3%, which is higher than in the passenger car segment. Moreover, growth is spread among a wider range of regions, including OECD Americas and Europe, as the increase in the commercial vehicle fleet is related more to trade and economic growth.

Table 3.5
Number of commercial vehicles

millions

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	39.0	40.6	44.5	48.6	53.0	57.3	18.3
OECD Europe	41.0	42.6	46.8	51.8	57.1	62.8	21.9
OECD Asia Oceania	25.6	25.5	25.8	26.1	26.2	26.4	0.8
OECD	**105.5**	**108.7**	**117.1**	**126.4**	**136.3**	**146.5**	**40.9**
Latin America	20.5	21.9	26.0	30.6	35.5	40.8	20.3
Middle East & Africa	15.8	17.2	21.5	26.6	32.9	41.0	25.2
India	15.5	18.0	24.9	33.7	44.7	58.6	43.1
China	26.8	29.3	36.8	45.6	55.2	65.3	38.5
Other Asia	26.7	29.2	36.1	43.5	51.2	59.0	32.3
OPEC	14.6	16.7	19.4	22.6	26.4	30.9	16.3
Russia	6.0	6.1	6.2	6.3	6.4	6.6	0.6
Other Eurasia	4.8	5.1	5.9	6.7	7.6	8.6	3.8
Non-OECD	**130.7**	**143.6**	**176.9**	**215.6**	**259.8**	**310.9**	**180.1**
World	**236.2**	**252.3**	**294.0**	**342.0**	**396.1**	**457.3**	**221.1**

Source: OPEC.

In the non-OECD grouping, the number of commercial vehicles is expected to continue growing at healthy rates over the forecast period, ranging from 0.4% p.a. in Russia to 6.2% p.a. in India. Besides India, the majority of the increase comes from China and Other Asia. As a result, China is expected to become the largest market for commercial vehicles, surpassing OECD Europe towards the end of the forecast period. A significant increase in commercial vehicles is also projected in OECD Americas (+18 million) and OECD Europe (+22 million). Contrary to these regions, OECD Asia Oceania and Russia are expected to witness only a very small increase, both below one million.

Vehicle fleet composition

As already mentioned, car markets across the world have witnessed only limited changes in the vehicle fleet composition in recent decades, especially when considering the total fleet. Some countries have experienced an expansion in natural gas vehicles (NGVs) on the back of abundant gas resources, government support and relatively lower gas prices. Nevertheless, the dominance of ICEs has remained untouched and it has not been impacted by the emergence of any new technology.

In the past few years, however, electric mobility has started to visibly change the landscape of the vehicle fleet composition, mainly in China, parts of Europe and in the US. These regions witnessed significant growth in the sales of EVs in 2018. In China, EV sales, including both BEVs and PHEVs, increased by 90% to more than one million, or 4% of all new registrations. This made China the largest market for EVs.

Strong BEV sales in **China** were supported by direct subsidies in the range of an average $10,000 per vehicle in 2018. However, these subsidies have been significantly reduced in 2019, with the government having stated its intention to halt incentives by 2020. The highlights of the changed policy are:

- Automobile manufacturers producing over 30,000 cars must manufacture fleets with an average fuel consumption of 42 miles per gallon (mpg) by 2020, and 54.5 mpg by 2025;

- Manufacturers that fail to satisfy the fuel economy measures will be required to buy credits from other companies or reduce production of non-compliant vehicles;

- Increased subsidies for EVs with a range of at least 180 miles per charge matched with significantly lower subsidies for EVs with a range from 90–180 miles. EVs with a range below 90 miles will no longer receive any subsidies; and

- The subsidy for an EV with a battery pack density over 140 watt hour per kilogramme (Wh/kg) will be boosted by an additional 20%, battery pack densities lower than 120 Wh/kg will receive 40% less in subsidies, while EVs with battery pack densities under 105 Wh/kg will no longer be eligible for any subsidy from the government.

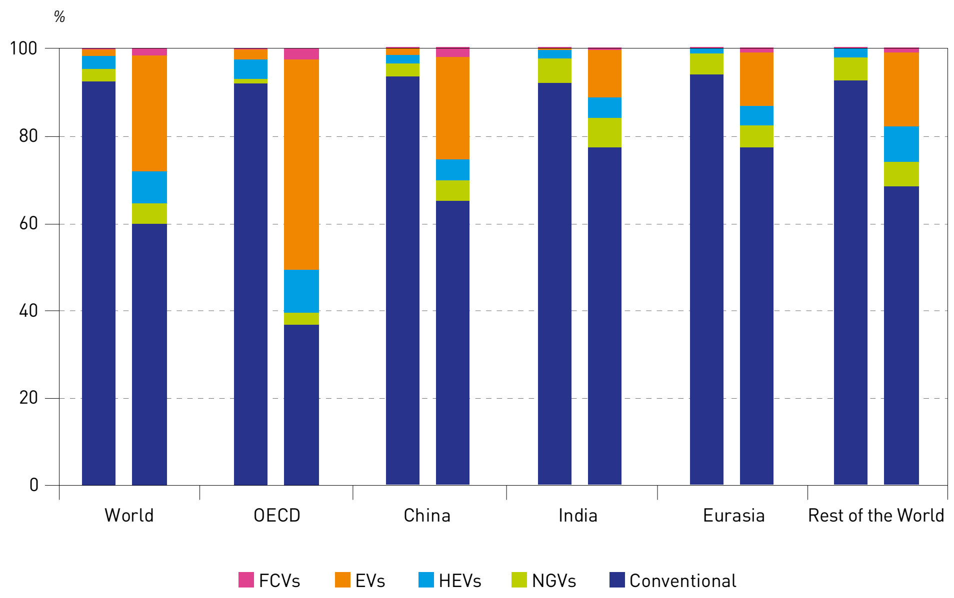
The effects of this change are expected to be manifold. One immediate effect is that direct subsidies will be reduced to $2,000–$9,000 per electric car depending on its mileage. This, combined with the fuel economy requirements, will likely lead to some consolidation of the Chinese car industry as manufacturers of low-range BEVs will not be able to compete. At the same time, the financial burden of these subsidies will gradually be transferred from the government to the car industry, which will in turn create a push to lower the cost of BEVs.

The net effect will likely be somewhat lower sales over 2019, as has already been indicated by sales figures for the first quarter of the year. However, more sustainable sales growth is expected to occur after the transitional period. The change in Chinese policy on BEV subsidies has also increased the government's focus on developing the necessary charging infrastructure. This is also true of policy developments in Europe and in the US.

EV sales in **Europe** increased by 33% y-o-y in 2018, which translates to about 400,000 new added units. It is noteworthy that BEV sales in Norway have expanded significantly with new registrations of EVs nearing a 50% share of total passenger vehicle registrations. This is faster than in any other country due to evolving policy incentives, making Norway the global leader in the penetration of EVs. Norway registered close to 60,000 new EVs in 2018, while the government anticipates that the majority of passenger cars in the country will be electric by 2025. Impressive growth was also observed in the **OECD Americas**. EV sales in the US soared to a record 79% y-o-y increase in 2018. However, despite these high growth numbers, the share of EVs is still below 2% of total passenger vehicle sales in both OECD Europe and OECD Americas.

Looking ahead, Figure 3.16 presents the summary of expected structural changes in the regional sales of passenger vehicles over the forecast period. Clearly, the largest shift in most regions, and in the OECD and China, in particular, is that between conventional ICE vehicles and EVs. At the global level, the share of EV sales is projected to rise to more than 26% in 2040. Moreover, a minor increase in new sales is also projected for NGVs and fuel cell vehicles (FCVs). Despite this expansion, however, ICEs (including HEVs) are still estimated to account for two thirds of all passenger vehicles sold in 2040.

Figure 3.16
Shares of new passenger car sales by powertrain, 2018 and 2040



Source: OPEC.

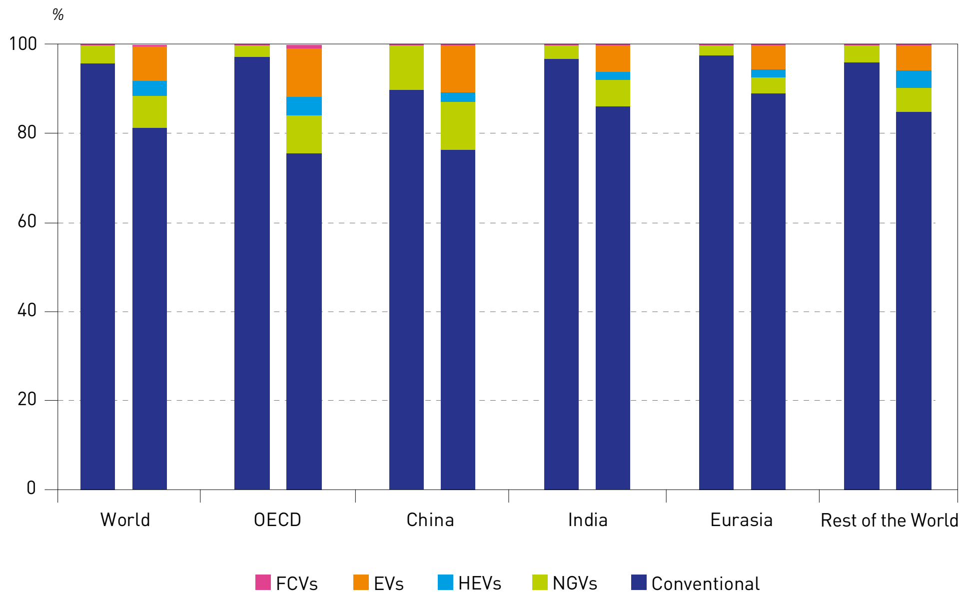
Moreover, there are still expected to be wide regional differences in car sales in 2040. The highest share of EVs sales is expected in the **OECD**, with EVs expected to account for almost half of all new passenger cars in 2040. This region will be followed by **China** where almost one quarter of new registrations are projected to be EVs. The electrification of road transportation in other regions will likely progress far less quickly. In **Other non-OECD countries** (excluding China and India) the share is expected be around 17%, with Eurasia about 12% and India at 11%.

In the segment of commercial vehicles, the shifting fleet composition dynamics are more muted than for passenger cars. There are two main reasons for this. Firstly, heavy-duty vehicles use primarily diesel engines that tend to be relatively efficient. Moreover, supporting infrastructure for diesel engines is well developed in most parts of the world. Secondly, there are limited options for alternative powertrains, especially for heavy-duty vehicles despite the fact that battery-driven prototypes of trucks and experimental tracks of electrified highways already exist. In the foreseeable future, electrification is an option for light-duty vehicles and buses, especially on fixed transport routes in city centres. Moreover, some potential for increased sales exists for NGVs - these have already been able to capture a noticeable share of new sales, especially in China and India.

Therefore, conventional vehicles are expected to continue to dominate the sales of commercial vehicles over the forecast period. As presented in Figure 3.17, the share of ICE-based vehicles in all sales of commercial vehicles is projected to only gradually decline from almost 96%

in 2018 to 81% by 2040. This drop is mainly the result of a rising number of EVs and HEVs in the commercial segment, to nearly 8% and 3% in 2040, respectively. Another reason is the rise of NGVs, which are anticipated to increase from around 4% in 2018 to more than 7% in 2040. These numbers are broadly unchanged from the WOO 2018 projections as no new technology developments nor policy measures have provided additional arguments for a significant departure from the trends outlined in the 2018 publication.

Figure 3.17
Shares of new commercial vehicle sales by powertrain, 2018 and 2040



Source: OPEC.

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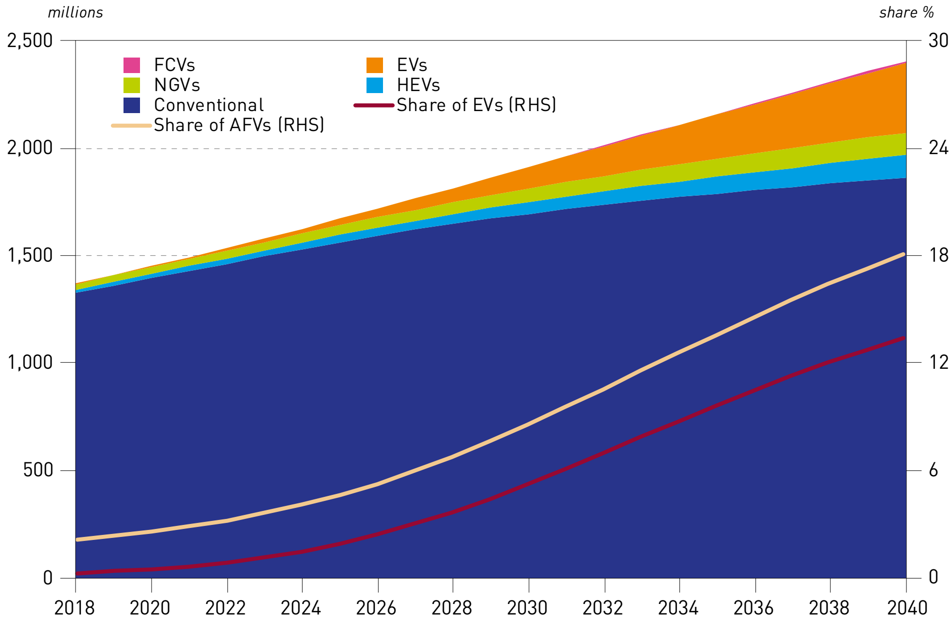
This argument also applies to regional trends where, in respect to commercial vehicles, it is mostly downward revisions to GDP growth that are affecting the size of the vehicles stock, rather than its composition. The two regions with the most visible change in the structure of future sales are the OECD and China. In the **OECD**, the share of EV sales in this segment is projected be close to 11% by 2040. Sales of NGVs are also estimated to increase significantly, by around 6 pp. Moreover, HEVs will likely account for a share of more than 4% by 2040. This then leads to a decline in the sales of conventional vehicles to a level of around 76%. This compares to the more than 97% recorded in 2018. A similar change is also projected in **China**. In this country, however, the share of NGVs is expected to be higher than in the OECD.

A somewhat lower share of AFVs is projected in **India**, but the country is still on a growth trajectory with shares expected to reach around 6% for both EVs and NGVs by 2040. Similar figures are also projected for the group of **Other developing countries**.

The implications of the outlined trends in new vehicle sales, for both passenger cars and commercial vehicles, on the changing composition of the global vehicle fleet is presented in Figure 3.18. It is worth emphasizing that structural changes in the global vehicle fleet will be rather smooth and much slower than the change in the composition of new sales. This is due to the large existing base of almost 1.4 billion vehicles currently on the road and the relatively long life span of the average vehicle. Obviously, the turnover of new vehicles is faster in developed regions, especially in the OECD, and slower in developing countries. Therefore, oil-based vehicles will constitute the large majority of all vehicles over the entire forecast period. Their share will gradually decline, nevertheless, it is still estimated to be over 80% by 2040.

Figure 3.18
Composition of the global vehicle fleet, 2018–2040



Source: OPEC.

EVs are gradually expected to become the second largest group of vehicles. Currently, NGVs are the largest alternative category. Their position, however, will likely be overtaken by EVs sometime towards 2030. The incremental number of EVs is estimated to accelerate in the second part of the forecast period, hence, their share will also grow significantly. Recent projections indicate that more than 320 million EVs will be on the roads by 2040, which corresponds to a 13% share of the global fleet. The large majority of EVs are forecast to be passenger cars, some 305 million. In relative terms, this represents 15% of all passenger cars in 2040.

Combining the growth of all AFVs – EVs, NGVs and FCVs – results in a higher shift in the penetration curve, but it is not expected to dramatically change the general pattern. This is because the increase in the share of NGVs is rather limited, and this category will account for only around 4% of the total fleet in 2040.

An even slower expansion is projected for FCVs, which are forecast to remain a niche market over the forecast period, except in **OECD Asia Oceania**. This view could potentially change in the years to come as China considers giving more support for the development of FCVs and related infrastructure. The new development plan is for about 50,000 FCVs to be on the road by 2025. To make this feasible, China plans additional investments into Research & Development (R&D) efforts in FCV technology. It remains to be seen, however, to what extent this technology will be able to compete with other transportation options.

Outlook for oil demand in road transportation

Future oil demand in the road transportation sector will be driven by a combination of factors, including changes in the vehicle fleet, its composition, efficiency improvements in oil-based vehicles and average vehicle miles travelled (VMT). At the global level, oil demand in the road transportation sector (Table 3.6) is forecast to increase by 2.9 mb/d between 2018 and 2040, from 44.4 mb/d to 47.3 mb/d.

The net result of the interplay between these factors at the regional level is also presented in Table 3.6, and underscores a starkly contrasting picture at the regional level. Oil demand in the **non-OECD** region is projected to expand significantly (+10.7 mb/d) whereas a considerable decline (–7.8 mb/d) is expected in the **OECD**.

Table 3.6
Oil demand in the road transportation sector by region *mb/d*

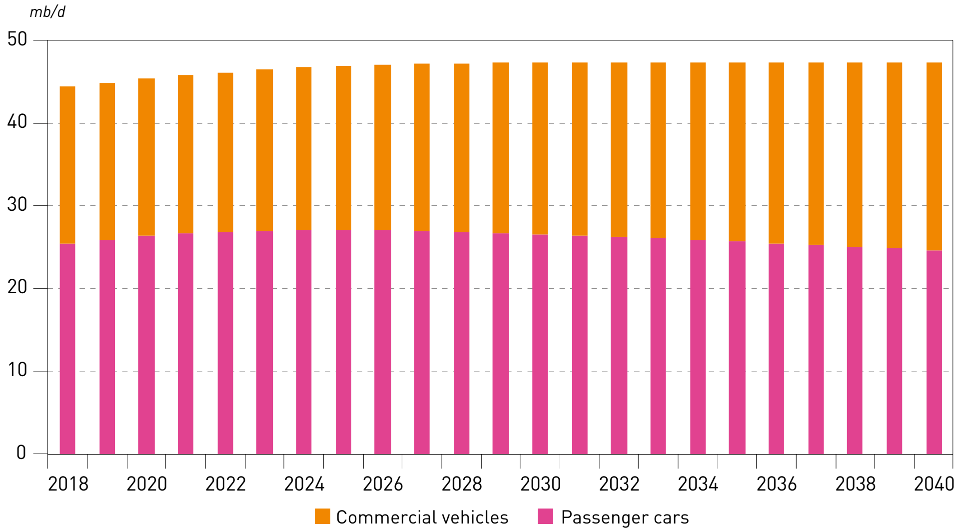
	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	14.3	14.4	13.7	12.5	11.2	10.0	–4.4
OECD Europe	6.8	6.7	6.4	5.8	5.1	4.5	–2.3
OECD Asia Oceania	2.8	2.7	2.6	2.2	1.9	1.6	–1.2
OECD	**23.9**	**23.8**	**22.7**	**20.5**	**18.2**	**16.0**	**–7.8**
Latin America	2.8	2.9	3.1	3.1	3.2	3.2	0.4
Middle East & Africa	1.9	2.0	2.3	2.6	2.9	3.3	1.4
India	1.9	2.0	2.7	3.4	4.2	5.1	3.2
China	5.2	5.5	6.2	6.8	7.3	7.5	2.2
Other Asia	3.4	3.5	4.0	4.5	5.0	5.3	2.0
OPEC	3.2	3.4	3.7	4.0	4.3	4.5	1.3
Russia	1.2	1.2	1.2	1.2	1.2	1.1	0.0
Other Eurasia	0.9	1.0	1.1	1.2	1.2	1.3	0.3
Non-OECD	**20.5**	**21.6**	**24.3**	**26.8**	**29.2**	**31.3**	**10.7**
World	**44.4**	**45.4**	**47.0**	**47.3**	**47.4**	**47.3**	**2.9**

Source: OPEC.

The second observation relates to plateauing oil demand in this sector in the last decade of the forecast period. In the period to 2030, expected strong growth in the vehicle fleet will result in expanding oil demand, in spite of improvements in fuel efficiency and the increased penetration of AFVs. This, however, will likely change in the latter part of the forecast period as growth in the fleet size will decelerates and expanding AFV sales, along with continued efficiency improvements in ICEs limit oil demand growth.

This effect is much more pronounced if passenger cars are considered separately from the fleet of commercial vehicles. As shown in Figure 3.19, oil demand from passenger cars will reach a plateau earlier and will even begin to decline after the mid-2020s. During this period, however, the number of commercial vehicles is expected to continue increasing, especially in developing countries, which will compensate for the losses from the passenger car segment. Moreover, the effect of better fuel efficiency in commercial vehicles is much lower (compared to passenger

Figure 3.19
Oil demand in the road transportation sector by segment, 2018–2040



Source: OPEC.

cars) as diesel engines remain dominant and the prospects for further efficiency improvements is limited.

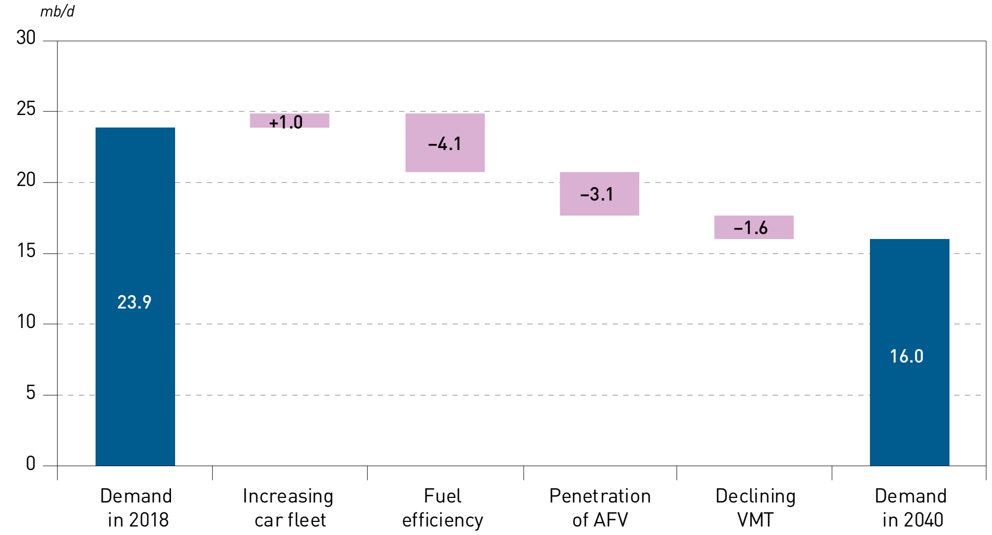
Finally, Figures 3.20 and 3.21 provide another perspective to the distinct dynamics of developments in the road transport sector in the OECD and non-OECD regions. The figures show the major factors impacting the overall change in oil demand between 2018 and 2040, with a focus on changes in the vehicle fleet, fuel efficiency, penetration of AFVs and VMT.

Figure 3.20 presents the effect of these factors on changing oil demand in the **OECD**. The overall fleet size in this region is expected to increase by only 100 million vehicles, which would result in around 1 mb/d of incremental demand by 2040. However, this potential demand increase will be more than offset by improving fuel efficiency, which is estimated to reduce oil demand by around 4.1 mb/d over the forecast period. It should be noted that improving fuel efficiency has the largest impact on oil demand of all the highlighted factors, which is also the case in the non-OECD countries grouping.

In addition to efficiency, potential oil demand in the OECD will be further reduced by AFVs. The oil consumption substituted by alternative fuels in this case is in the range of more than 3 mb/d. Finally, declining VMT is expected to result in a demand reduction of 1.6 mb/d by 2040. VMT is expected to fall due to several factors, *inter alia* saturation levels, changes in the population age structure, the further development of public transport systems and the expansion of car sharing.

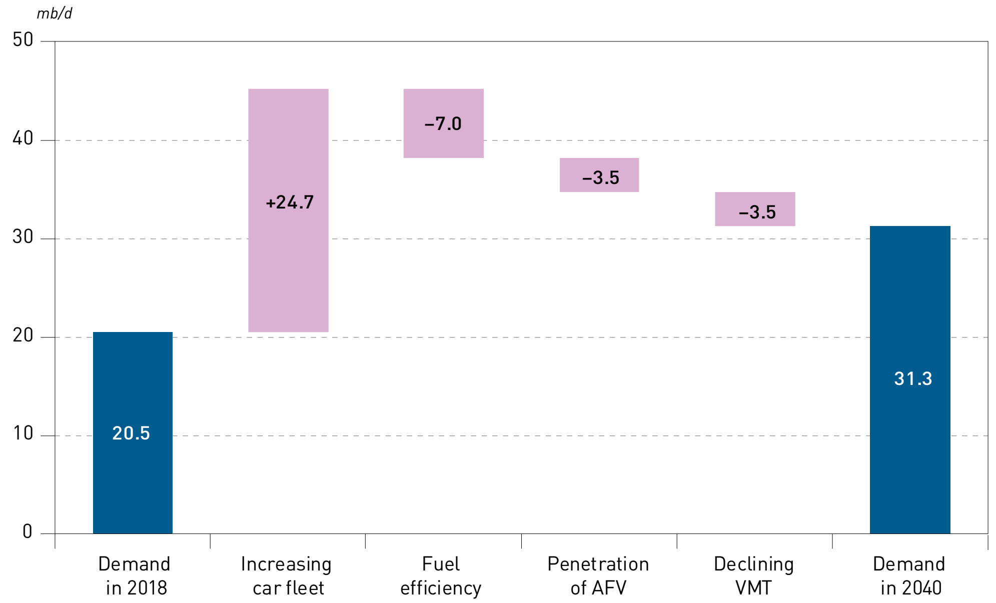
In the **non-OECD** region, as presented in Figure 3.20, the large increase of the vehicle fleet has the potential to increase oil demand by almost 25 mb/d by 2040, for the reasons discussed earlier in this chapter. However, the actual oil demand growth projected is 10.7 mb/d between 2018 and 2040. This is because efficiency improvements are expected to limit demand growth by 7 mb/d and the penetration of AFVs by an additional 3.5 mb/d by the end of the forecast period. Finally, lower-average annual VMT will likely further reduce sectoral demand by another 3.5 mb/d. All told, oil demand in the road transportation sector in the non-OECD is estimated to reach 31.3 mb/d by 2040.

Figure 3.20
Demand in road transportation in the OECD, 2018 and 2040



Source: OPEC.

Figure 3.21
Demand in road transportation in non-OECD countries, 2018 and 2040



Source: OPEC.

3.3.2 Aviation

Most signposts in the aviation industry point in the direction of future growth. Freight markets typically follow increasing economic activity. Higher economic activity also leads to an expanding middle class which, in turn, supports passenger air travel. At the same time, huge investments are being made across all continents to expand the necessary infrastructure, including new airports and aircraft fleets. A combination of these factors results in significant potential for future oil demand growth in this sector. This potential is, however, partly offset by improving efficiency, not only for new aircraft, but also the better management of the freight load, optimized routes and air traffic systems.

In terms of air freight, the IATA estimates that this will grow by 4.4% p.a. on average over the next five years on a tonne-kilometre basis (Air freight 5-year forecast, IATA, March 2019). This is slightly lower than its previous estimate, which reflects slower growth in global economic activity. This expansion in air freight is expected to decelerate further in the longer-term , in line with the assumed trends in regional and global GDP growth.

Similar growth levels are also expected in the segment of air passenger traffic. The main reason for this forecast is the anticipated growth in the propensity to travel, especially in non-OECD countries where the overwhelming majority of countries are still in the category of those where the average annual number of flights per capita is below one. This creates huge growth potential once the middle class expands and air travel becomes affordable. India and Indonesia are two great examples in this respect. According to the IATA forecast, India will become the third largest market for air traffic by 2024, and Indonesia is expected to take the fourth position sometime around 2030.

Undoubtedly, this sector's growth will only be possible if large and timely investment into required infrastructure takes place. Reviewing the long list of existing projects for new airports and orderbooks for new aircrafts, especially in Asia, leaves little doubt that infrastructure expansion is keeping up.

Besides recent additions, such as Van Don International Airport in Vietnam and Istanbul Airport in Turkey, the list of large airport projects includes China's Beijing Daxing International Airport and Hong Kong's Chep Lap Kok, Long Thanh International in Vietnam, Berlin Brandenburg in Germany and the expansion of the Louis Armstrong New Orleans International in the US, to name just a few. In fact, according to the Civil Aviation Administration of China (CAAC), China alone aims to construct more than 200 new airports by 2035 to meet growing demand for air transport in the country.

It should not be expected, however, that oil demand in the aviation sector will grow proportionally to the increase in passenger traffic and freight transport. On the contrary, a significant part of the potential increase will be offset by various fuel-saving measures. These includes higher load factors, better navigational equipment and, more importantly, improving fuel economy in future aircraft. Indeed, besides security, fuel efficiency has always been the main target of technical innovation in the aviation sector.

In recent years, several innovations have contributed to lower specific fuel consumption, such as the aerodynamic properties of wings, the extended use of carbon fibre reinforced compounds and new lightweight, but resistant metal alloys that substantially reduce aircraft weight. Moreover, electrification is also underway in air transportation, although at a substantially slower pace than in road transportation.

To a significant extent, technology developments and efficiency measures are increasingly being impacted by energy policies that target the decarbonization of the industry. These policies are set at both the national and international level. The two leading targets for the aviation sector – set by ICAO and IATA – are a cap on net aviation CO_2 emissions (carbon-neutral growth) from 2020 and a reduction in net aviation CO_2 emissions of 50% by 2050 (compared to 2005 levels). It remains to be seen, however, just what future measures will be adopted to realize these targets.

Considering all of the mentioned factors, oil demand in the aviation sector is expected to grow by 2.4 mb/d during the forecast period, from 6.5 mb/d in 2018 to 8.9 mb/d in 2040. The regional breakdown of demand in the sector are provided in Table 3.7.

Mirroring growth in per capita income levels, as well as the projected regional air traffic expansion, most of the incremental oil demand in this sector is expected to come from the **non-OECD** region. This is estimated at 2 mb/d between 2018 and 2040. Out of this, around 56%, or 1.1 mb/d, is associated with air traffic in Other Asia, India and China. Some growth is also projected for OPEC (+0.3 mb/d), Latin America and Russia (+0.2 mb/d each). The lowest demand increase will likely take place in the Middle East & Africa (+0.15 mb/d) and Other Eurasia (+30 tb/d), despite the great potential for expansion that exists, in particular, in Africa. However, support for infrastructure is lagging, and expansion will be challenging.

Compared to the non-OECD, the potential for future demand growth is much lower in the **OECD**. This region's growth is estimated at 0.4 mb/d over the forecast period, as the OECD represents a mature market where growth is somewhat constrained by infrastructure capacity.

Table 3.7
Oil demand in the aviation sector by region

mb/d

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	1.9	1.9	2.0	2.0	2.1	2.1	0.2
OECD Europe	1.3	1.3	1.4	1.4	1.4	1.4	0.2
OECD Asia Oceania	0.5	0.5	0.6	0.6	0.6	0.6	0.1
OECD	**3.7**	**3.8**	**4.0**	**4.0**	**4.2**	**4.1**	**0.4**
Latin America	0.3	0.3	0.4	0.4	0.5	0.5	0.2
Middle East & Africa	0.3	0.3	0.3	0.3	0.4	0.4	0.2
India	0.2	0.2	0.3	0.3	0.4	0.5	0.4
China	0.6	0.7	0.8	0.9	0.9	0.9	0.3
Other Asia	0.8	0.8	0.9	1.0	1.1	1.2	0.4
OPEC	0.4	0.4	0.5	0.6	0.6	0.7	0.3
Russia	0.2	0.2	0.3	0.3	0.4	0.4	0.2
Other Eurasia	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Non-OECD	**2.8**	**2.9**	**3.4**	**4.0**	**4.4**	**4.8**	**2.0**
World	**6.5**	**6.7**	**7.5**	**7.9**	**8.6**	**8.9**	**2.4**

Source: OPEC.

3.3.3 Marine bunkers

Currently the most pressing issue in the marine bunkers sector is the IMO regulation mandating that the sulphur content in marine fuels be lowered to a maximum 0.5% on a weight basis, effective 1 January 2020. As discussed earlier in section 3.1.1, this regulation will likely be a disruptive event for the shipping and oil refining sectors. Building upon this analysis, this section will focus on the major long-term trends and factors affecting oil demand in the marine shipping industry.

In broad terms, future oil demand in this sector will depend on a combination of three primary factors, namely growth in international seaborne trade, marine transport efficiency improvements and fuel substitution, especially due to the increasing penetration of LNG vessels.

Seaborne trade is primarily driven by the level of global economic growth. The base assumption adopted in this Outlook is that global GDP will expand by an average 3.3% p.a. over the forecast period, which should provide a solid basis for increasing trade. How much of this growth translates into additional oil demand in this sector depends on the progress of technology improvements on vessels engines, hull and propeller design, optimized operating modes and the potential substitution by other sources of energy.

The IMO, in an effort to reduce emissions in the marine sector, adopted mandatory energy-efficiency measures in 2011, effective as of 1 January 2013. The target is to achieve 30% efficiency improvements, by 2025, for all new ships compared to those built in 2014. The main tools to enforce the regulation are the Energy Efficiency Design Index (EEDI), mandatory for new ships, and the Ship Energy Efficiency Management Plan, mandatory for all ships. Moreover, the IMO's Marine Environment Protection Committee (MEPC) also announced its intention to reduce GHG emissions from international marine transport by at least 50% by 2050, compared to 2008 levels. Obviously, any measures adopted to reach this target would also significantly affect future oil demand.

From an oil demand perspective, the main engine propelling the vessel is the most important component of a ship as it consumes most of the fuel used on a vessel's journey. Large vessels traditionally have a large two-stroke or four-stroke reciprocating piston engine. The efficiency of these engines has reached levels close to, or even beyond 50%.

In general, four-stroke engines are used when comfort (low vibrations) is important; a typical example would be a cruise ship. Here, the engine is increasingly being used to drive a generator producing electric power, which in turn is used to power the strong electric motors spinning the ship's propeller(s). The overall efficiency of this system – encompassing the main engine, generator and electric motor – can currently reach as high as 45%. Such powertrains are quite expensive and are, therefore, only used when comfort and flexibility is important. More information about this and other technologies can be found in Chapter 7.

Large merchant vessels, such as container vessels, bulk carriers, tankers and other purpose-built ships, on the other hand, typically employ slow-moving two-stroke engines that are directly coupled to the propeller without intermediate gears or other devices. These two-stroke engines have a far simpler design and are currently the most efficient ICEs, with typical efficiency levels between 48% and 52%.

One method to improve fuel efficiency and reduce fuel costs is the use of WHR units, which are widely available on the market. Current WHR units use thermal energy coming mainly from the hot exhaust gases of the engine, but also from the jacket and oil cooling water. They can add around 10% of additional power which is typically used to operate auxiliary devices on board. Reefer and freezer containers or controlled atmosphere containers, for example, are becoming increasingly important, but require a substantial amount of electricity for their built-in cooling, freezing and atmosphere conditioning devices that may be provided by WHR units.

Another measure to reduce fuel consumption that has been adopted in recent years is slow steaming. Before the 2008/2009 financial crisis, vessels were generally expected to move as quickly as possible, especially container ships. Today, however, the typical average velocity has dropped from 26 knots (kn) (48 km/h) to 21kn (39 km/h) or even lower. The propeller thrust needed to overcome water resistance changes considerably with velocity, and as a consequence, fuel consumption can be reduced by around 25% to 35% per day. However, a slower ship also needs more time to get to its destination and the fuel and cost savings are lower when referring to the specific fuel consumption per tonne-mile.

Special attention in the design stage is also needed to reduce the associated flow resistance generated from moving an enormous mass of water around the ship's hull. This, as well as propeller design, provide another area of efficiency improvement. Modern propellers for large vessels are usually tailor-made, based on extensive analysis of how true-to-scale models behave in fluid flow tanks and increasingly through analysis of computer simulations and AI concepts. Propeller conversion efficiency has already reached levels beyond 90%. High-speed ferries – often designed as multiple-hull ships, such as catamarans and trimarans – increasingly use water-jet systems.

Another critical issue affecting future oil demand will be the speed at which LNG vessels are adopted by the shipping industry. These are often seen as an important element in efforts to reduce emissions in the marine sector. Additional support for the use of LNG as a bunker fuel could emerge if a ban on open-loop scrubbers is considered. This would certainly make the widespread adoption of LNG more likely, as it may be used not only at high sea, but also within areas with stringent emission regulations such as Emission Control Areas (ECAs).

However, the current lack of reliable bunkering facilities remains an obstacle to a widespread adoption of LNG, despite an increasing number of ports that are now providing LNG bunkering services. This may be overcome in the future, but as it stands, there is a 'chicken and egg'-type challenge. Nevertheless, nearly all modern large engines powering maritime vessels today are either delivered as dual-fuel or can be refitted for LNG operations with minimal effort.

Accounting for all these factors, Table 3.8 presents oil demand in the marine bunkers sector over the forecast period. At the global level, oil demand is projected to increase by 0.8 mb/d,

Table 3.8
Oil demand in the marine bunkers sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	0.5	0.5	0.5	0.5	0.5	0.4	–0.1
OECD Europe	0.8	0.8	0.8	0.8	0.7	0.7	–0.1
OECD Asia Oceania	0.3	0.3	0.3	0.2	0.2	0.2	–0.1
OECD	**1.6**	**1.6**	**1.6**	**1.5**	**1.4**	**1.3**	**–0.3**
Latin America	0.3	0.3	0.3	0.3	0.4	0.4	0.2
Middle East & Africa	0.1	0.1	0.2	0.2	0.2	0.2	0.1
India	0.0	0.0	0.0	0.0	0.1	0.1	0.0
China	0.2	0.2	0.3	0.3	0.3	0.4	0.1
Other Asia	1.2	1.2	1.3	1.4	1.5	1.6	0.5
OPEC	0.5	0.5	0.6	0.6	0.6	0.6	0.2
Russia	0.1	0.2	0.1	0.1	0.1	0.1	0.0
Other Eurasia	0.1	0.1	0.1	0.1	0.2	0.2	0.0
Non-OECD	**2.5**	**2.6**	**3.0**	**3.2**	**3.4**	**3.6**	**1.1**
World	**4.1**	**4.2**	**4.5**	**4.7**	**4.8**	**4.9**	**0.8**

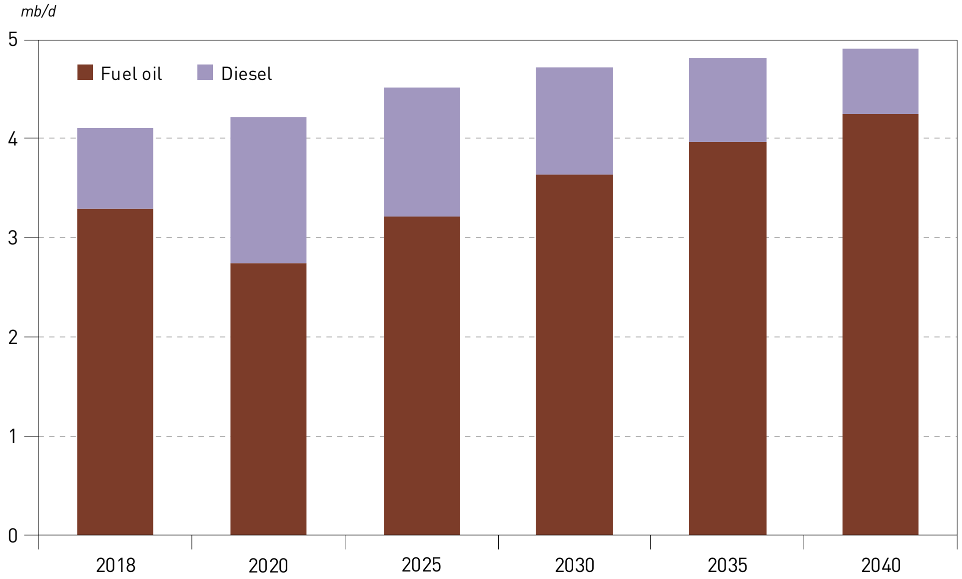
Source: OPEC.

from 4.1 mb/d in 2018 to 4.9 mb/d in 2040. All of the demand growth in the long-term will likely come from **non-OECD countries**, especially in Asia, the Middle East and Latin America. In these regions, the growth in seaborne trade is expected to more than outweigh assumed efficiency improvements and fuel substitution. However, demand for marine bunker fuels in India, Russia and Other Eurasia is currently fairly limited, totalling just 0.3 mb/d. Therefore, the growth potential is also low, with the counterbalancing effects of increasing trade and improved efficiencies.

The story is different in the **OECD** region. Demand for marine bunker fuels in this region is projected to remain flat throughout the next decade, before starting a slow decline thereafter. The end effect is that demand is seen declining by around 0.3 mb/d between 2018 and 2040.

Figure 3.22 presents the changing demand structure in the marine sector in terms of refined products. In 2018, around 80% of this sector's demand was for heavy fuel oil. However, this is projected to change significantly in 2020 with the introduction of the IMO regulations, with the share of fuel oil estimated to drop to 65% and the share of diesel increasing. This shift will nonetheless be relatively short-lived, as the growing penetration of scrubbing technology and the increased availability of LSFO over time will support the use of fuel oil.

Figure 3.22
Product demand in the marine bunkers sector, 2018–2040



Source: OPEC.

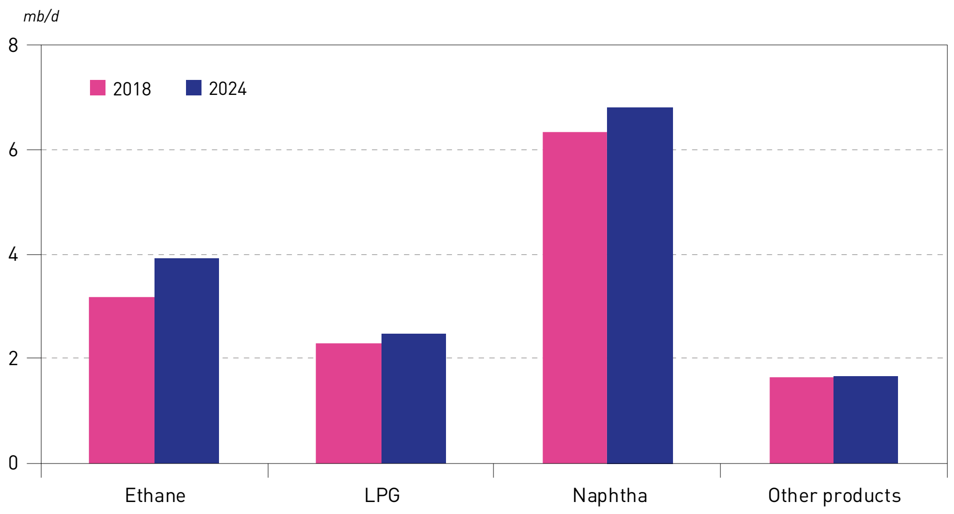
It should be noted that the return of fuel oil will likely result in it not only fully regaining its share in marine bunkers, but also reaching levels close to 90% by 2040. This is somewhat more than anticipated in the WOO 2018. There are two reasons for this. Firstly, overall demand in the marine sector was revised downward on the basis of lower economic growth and an assumed higher penetration of LNG vessels. Secondly, this Outlook assumes a higher number, and a faster penetration, of installed scrubbers as open-loop scrubbers seem to be a viable option. This reduces the need for additional diesel demand in the sector and provides support to residual fuel oil. Needless to say, this assumption is subject to further review and provides an element of uncertainty for future projections.

3.3.4 Petrochemicals

Recent developments in the petrochemical industry warrant a closer look at the medium-term prospects before discussing the long-term outlook. Medium-term developments in this sector will largely be driven by strong demand for petrochemical products and the growing availability of relatively cheap feedstock, especially in North America. These have led to a number of new projects being developed and several of them are already at an advanced stage of construction. The global petrochemical industry has performed exceptionally well over the last few years and this trend is likely continue over the medium-term with substantial capacity additions likely to take place, especially in China and in the US.

As presented in Figure 3.23, the largest incremental demand in the petrochemical sector over the medium-term (2018–2024) is projected for ethane (+0.8 mb/d), as ethane-based capacity additions will dominate the sector's expansion.

Figure 3.23
Oil demand in the petrochemical sector by product, 2018 and 2024



Source: OPEC.

In the **US**, ample ethane availability at lower prices has encouraged the country's petrochemical industry to expand capacity at existing plants and to build new steam crackers in the past few years. This trend is expected to continue, particularly over the next two-to-three years. Around seven million tonnes of ethylene capacity is likely to be added in the US before the end of 2021. The major projects expected to come online over this period include the Sasol, Lotte Chemical and Shintech projects in Louisiana, US, and the Bayport Polymers, Formosa Plastics and DuPont projects in Texas, US. Much of the investment is geared toward exporting plastics products. There are also several projects scheduled for completion for the second half of the medium-term; however, these are still in the early stages of planning or construction and are, therefore, less certain and are more likely to see delays.

Naphtha demand will also increase, driven primarily by capacity additions in Asia and the Middle East. In **China** alone, more than 5 million tonnes (mt) of new capacity will be naphtha-based. Apart from China, some naphtha-based capacity additions are also likely to take place in other Asian countries, namely India, South Korea, Malaysia, Thailand and the Philippines.

In the **Middle East**, about 50% of additional capacity shall likely be based on naphtha. Additional projects in the region exist in IR Iran, Kuwait and Oman. In Saudi Arabia, Saudi Aramco and SABIC have announced their selection of Yanbu as the site for the Crude Oil to Chemicals Complex (COTC) project, which is expected to produce 9 mt per year of chemicals and base oils, bringing a new business model to the industry. However, the project's start-up year has shifted to 2025.

In **Russia**, the list of proposed projects totals up to more than 3 mt of additional capacity, but it is unlikely that all of the projects will be completed within the medium-term horizon. From a feedstock perspective, the plans are to use a combination of ethane and naphtha, supplemented by LPG.

The net effect of these developments is that incremental oil demand in the petrochemical sector is expected to be in the range of 1.5 mb/d between 2018 and 2024. Of this, around 0.5 mb/d will likely take place in OECD Americas, 0.3 mb/d in China, 0.2 mb/d each in Other Asia and OPEC, and some 0.1 mb/d in India, Russia and OECD Europe. In terms of feedstock, around 0.8 mb/d of the incremental demand is for ethane, 0.5 mb/d for naphtha and 0.2 mb/d for LPG.

Strong demand growth in the petrochemicals sector is expected to continue beyond the medium-term, although some deceleration is likely. The long-term demand trends for this sector are presented in Table 3.9. It shows average demand growth expanding at a solid 1.2% p.a. on average over the entire forecast period. This compares to the 1.7% average growth projected over the medium-term. Nonetheless, this is the second fastest growth rate at the sectoral level, behind aviation.

In terms of incremental demand, this represents an increase of 4.1 mb/d at the global level, from the 13.4 mb/d observed in 2018 to a forecasted level of 17.6 mb/d in 2040. It is worth emphasizing that, in volume terms, this is the largest incremental demand among all sectors, even more than

Table 3.9
Oil demand in the petrochemical sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	3.3	3.5	3.9	4.0	4.0	3.9	0.6
OECD Europe	1.8	1.8	1.9	1.8	1.8	1.7	–0.1
OECD Asia Oceania	2.1	2.0	2.0	2.0	2.0	2.0	0.0
OECD	**7.2**	**7.4**	**7.7**	**7.9**	**7.9**	**7.7**	**0.5**
Latin America	0.3	0.3	0.4	0.4	0.4	0.4	0.1
Middle East & Africa	0.0	0.1	0.1	0.1	0.1	0.1	0.1
India	0.4	0.5	0.6	0.7	0.9	1.0	0.6
China	1.9	1.9	2.2	2.4	2.5	2.6	0.8
Other Asia	1.3	1.4	1.6	1.7	1.9	2.1	0.7
OPEC	1.3	1.3	1.4	1.8	2.2	2.6	1.3
Russia	1.0	1.0	1.1	1.1	1.1	1.1	0.1
Other Eurasia	0.0	0.0	0.1	0.1	0.1	0.0	0.0
Non-OECD	**6.3**	**6.6**	**7.3**	**8.3**	**9.1**	**9.9**	**3.6**
World	**13.4**	**14.0**	**15.1**	**16.2**	**17.0**	**17.6**	**4.1**

Source: OPEC.

for the road transportation sector, which has traditionally been the source of the largest demand increase.

The bulk of this incremental demand is forecast to come from Asia, OPEC and OECD Americas. In fact, these three regions are anticipated to account for around 95% of incremental demand and close to 70% of oil demand in the petrochemical sector by 2040. **Asia** alone will likely absorb 7.7 mb/d of oil products in this sector by the end of the forecast period. The concentration of the petrochemicals industry in these regions is driven by two major factors – demand for petrochemical products, mostly as an intermediate material for production of finished products and feedstock availability.

In **OECD Americas**, almost all of the additional sectoral demand is anticipated to be satisfied by ethane. The use of 'other products' is even anticipated to decline as oil-based products used as an energy source are substituted by cheaper natural gas. A similar trend is also expected in **OPEC** countries where the relative weight of ethane is expected to increase too. Out of a total sectoral growth of 1.3 mb/d between 2018 and 2040, ethane is forecast to increase by 1 mb/d. Some growth in OPEC Member Countries is also expected in the use of LPG (and marginally naphtha), as new petrochemical projects in OPEC's African Member Countries develop.

The composition of petrochemical feedstock in Asian countries differs significantly from those in OPEC and OECD Americas. In 2018, naphtha accounted for 70% of the total petrochemicals demand in Asia. The share of naphtha is expected to increase by 2 pp in the period to 2040, to reach 3.3 mb/d. This clearly illustrates the fact that Asia's petrochemical industry will remain dominated by naphtha, despite some growth in ethane demand.

The outlook for the petrochemical sector in the other two OECD regions is somewhat different. Oil demand for petrochemicals in **OECD Europe** is anticipated to be stagnant, and Europe is not expected to benefit from cheap feedstock despite some plans for ethane and propane imports from the US. Strong competition from other regions will dictate European petrochemical choices in the future as mature demand and domestic constraints may trigger a sector rationalization. The same issues are also relevant for **OECD Asia Oceania**, with the exception of South Korea, where some growth in its petrochemical sector likely. In total, however, demand for oil products in the petrochemicals sector of both regions is expected to decline marginally over the forecast period.

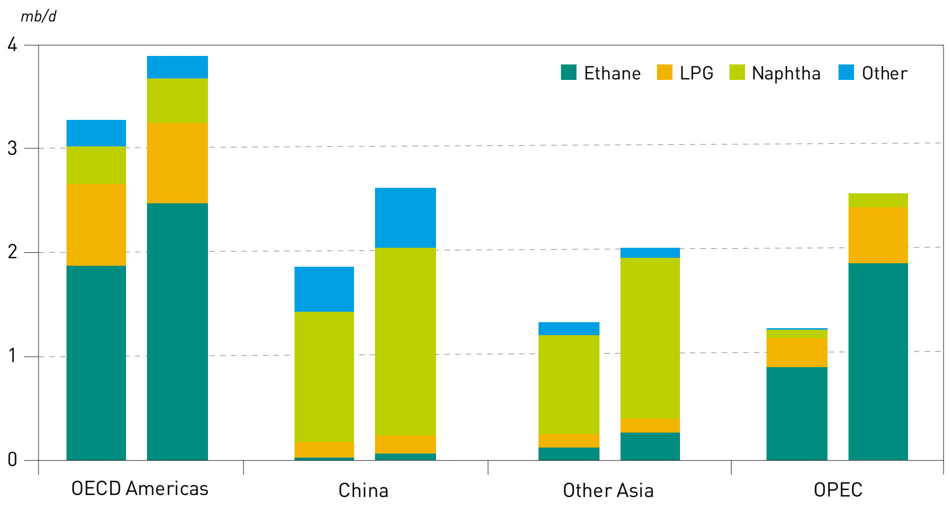
Some minor demand growth is projected in **Russia**, **Latin America** and the **Middle East & Africa**. However, demand increments in these regions are only in the range of 0.1 mb/d, and hence, have limited impact on the sector's overall demand. To complete the picture, Figure 3.24 summarizes trends in the petrochemical industry from the perspective of major oil products, mainly for feedstock purposes, but also for energy use, and key demand regions.

Finally, it is important to emphasize the uncertainties related to the prospects for petrochemicals. On the one hand, the petrochemicals demand outlook is changing fundamentally with projections being revised upward y-o-y. This raises the question as to how future petrochemicals demand growth stands in relation to economic growth. On the other hand, environmental concerns and increasing consumer awareness raise questions as to what extent the use of plastics and polymers is sustainable and how it fits into a circular economy.

Traditionally, the power generation and transportation sectors, in particular road transportation, were at the top of the agenda for policymakers. However, a growing awareness of the proliferation of plastics in the environment has been catching the attention of policymakers with a focus on the need to address this issue through a set of policy measures, such as banning specific single-use plastics, plastics recycle and waste management.

Plastics consumption has increased significantly over the last two decades. It is estimated that nearly half of all plastic ever manufactured has been made since 2000. Strong growth consumption

Figure 3.24
Regional demand in the petrochemical sector by products, 2018 and 2040



Source: OPEC.

has been especially the case for single-use plastics, such as grocery bags, packaging, bottles, straws, containers, cups and cutlery.

Developments have led more than 100 countries to introduce measures to limit this growth. Even though policies have been mostly limited to certain products thus far, such as plastic bags, it does signal the evolution of more comprehensive policies aimed at reducing plastic waste and replacing single-use plastics with alternatives. Policies include the recent EU decision to ban specific single-use plastics by 2021. This also includes an ambitious target of collecting and re-using or recycling 90% of plastic bottles by 2029, as well as several other measures aiming at reducing plastic waste.

Recycling is also gaining focus. For example, the 'New Plastics Economy Global Commitment' was announced in October 2018. It unites over 350 businesses, governments, and other organizations around the world in efforts to eliminate unnecessary plastic items and "to innovate to ensure 100% of plastic packaging can be easily and safely reused, recycled or composed by 2025".

There has also been a rising emphasis on plastic waste management. Recently, a landmark UN Plastic Waste Pact was reached by 186 countries (excluding the US). The pact would legally bind the countries to monitor and track the movement of plastic waste outside their borders. No country would be able to send unmanageable amounts of plastic waste to private waste-handling companies without the consent of the receiving countries' government. With all of the mentioned efforts, including shifting consumer behaviour to use plastics more responsibly and in an environmentally sustainable manner, it is evident that will affect the use of oil as a petrochemical feedstock, although it remains to be seen in what manner and to what extent.

3.3.5 Other sectors

Two other demand sectors stand out: 'other industry' (representing the industry sector excluding petrochemicals) and a combination of the residential, commercial and agriculture sectors. The baseline demand in both of these sectors is significantly higher than for the rail, domestic waterways and the electricity generation sectors. Moreover, incremental demand over the forecast period is also much higher.

The largest incremental demand among other sectors is projected for the residential, commercial and agriculture sector, at 1.4 mb/d between 2018 and 2040. Oil demand in this sector totalled 10.8 mb/d in 2018 and is projected to reach 12.2 mb/d by 2040 (Table 3.10). This overall demand increase, however, masks strong, distinct trends for specific regions, primarily declining demand in the OECD and growth in the non-OECD.

Table 3.10
Oil demand in the residential/commercial/agriculture sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	1.8	1.7	1.7	1.7	1.5	1.4	–0.4
OECD Europe	1.7	1.6	1.6	1.5	1.4	1.3	–0.4
OECD Asia Oceania	0.9	0.8	0.8	0.8	0.7	0.6	–0.3
OECD	**4.3**	**4.2**	**4.2**	**4.0**	**3.6**	**3.3**	**–1.0**
Latin America	0.7	0.7	0.8	0.9	1.0	1.0	0.3
Middle East & Africa	0.7	0.7	0.8	0.9	1.0	1.0	0.4
India	1.0	1.1	1.3	1.5	1.6	1.7	0.7
China	2.1	2.2	2.4	2.6	2.8	2.9	0.8
Other Asia	0.8	0.8	0.8	0.9	0.9	0.9	0.1
OPEC	0.5	0.5	0.6	0.7	0.6	0.6	0.1
Russia	0.3	0.3	0.3	0.3	0.3	0.3	0.0
Other Eurasia	0.3	0.3	0.4	0.4	0.4	0.4	0.0
Non-OECD	**6.5**	**6.8**	**7.4**	**8.0**	**8.5**	**8.9**	**2.4**
World	**10.8**	**11.0**	**11.6**	**12.1**	**12.2**	**12.2**	**1.4**

Source: OPEC.

In the **OECD**, oil in this sector has faced strong competition from gas and electricity for many decades. This can be observed in the clear downward trend with demand declining from above 8 mb/d in 1970s to recent levels of slightly above 4 mb/d. Moreover, declining demand is expected to continue, mostly driven by efficiency gains, such as better insulation and efficiency standards.

This trend will also be supported by a further switch towards natural gas and renewables, such as the use of solar and heat pumps by households. Several OECD countries provide incentives to increase the use of renewable energy in residential and commercial buildings, enforce stringent standards for household appliances and have tightened building codes for new construction. Examples of such policy measures are the Energy Performance of Buildings Directive of the European Commission targeting 'nearly zero energy buildings' by the end of 2020. As a result, OECD oil demand in this sector is anticipated to decline by 1 mb/d between 2018 and 2040.

Contrary to the OECD, oil demand in **non-OECD countries** in the residential, commercial and agriculture sector is projected to increase by 2.4 mb/d to reach a level of 8.9 mb/d in 2040. This is mainly related to expected developments in China, India and the Middle East & Africa where the largest demand increases are projected.

In India and the Middle East & Africa, in particular, this demand increase in the residential, commercial and agriculture sectors will be driven by rising incomes and increasing urbanization levels that will continue to stimulate a switch away from traditional fuels such as wood for cooking and heating to commercial fuels, including oil products. Moreover, the agriculture sector is also set to experience a major change in developing regions that contribute to future oil demand.

From the perspective of refined products, it is not surprising that the use of ethane/LPG is expected to account for most of the increase in sectoral demand, reaching 6 mb/d by 2040. This fuel category competes directly with traditional fuels for cooking, but also with kerosene, which is set to decline over the forecast period. The use of gasoil/diesel is expected to increase in developing countries. This, however, will be almost entirely offset by declines in the OECD and Russia.

Oil use in rail and domestic waterways is the lowest among all sectors considered in this Outlook. Moreover, more than half of it is concentrated in only two regions, OECD Americas and China (Table 3.11). In the case of the OECD Americas, the majority of demand is linked to diesel used for rail transport. This is also the case for all other regions, with the exception of China, where a larger part of demand relates to domestic waterways.

Table 3.11
Oil demand in the rail and domestic waterways sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	0.5	0.5	0.5	0.5	0.5	0.4	–0.1
OECD Europe	0.2	0.2	0.2	0.1	0.1	0.1	0.0
OECD Asia Oceania	0.1	0.1	0.1	0.1	0.1	0.0	–0.1
OECD	**0.8**	**0.8**	**0.8**	**0.7**	**0.6**	**0.6**	**–0.2**
Latin America	0.1	0.1	0.1	0.1	0.2	0.2	0.1
Middle East & Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	0.1	0.1	0.1	0.1	0.1	0.1	0.0
China	0.6	0.6	0.7	0.7	0.8	0.8	0.3
Other Asia	0.1	0.1	0.2	0.2	0.2	0.2	0.1
OPEC	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Russia	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other Eurasia	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-OECD	**1.0**	**1.0**	**1.2**	**1.3**	**1.4**	**1.5**	**0.5**
World	**1.8**	**1.8**	**1.9**	**2.0**	**2.1**	**2.1**	**0.3**

Source: OPEC.

Currently, around one-third of the global rail network is electrified. However, there are significant regional disparities in the rate of electrification. While in OECD Europe around 60% of the railway network is electrified, in the US, which drives oil demand for the OECD Americas region, less than 1% of the railway network is electrified. China also has a high share of electrification in its rail sector, close to 70%. This explains the country's relatively low oil demand in this sub-sector.

In the **US**, rail electrification is not expected to increase significantly over the forecast period. Therefore, relatively stable oil demand in the sector results from the offsetting effects of increasing freight traffic and improved efficiency. Moreover, part of the demand in this region – in the range of 0.5–0.6 mb/d during the first half of 2019 – is linked to moving crude oil from remote producing areas to refineries or export hubs. In the future, however, this is expected to decline somewhat as increased pipeline infrastructure over the medium-term and declining domestic crude production over the long-term will likely limit the use of oil for this purpose.

In **China**, the use of a large network of waterways and the longest navigable rivers and canals in the world have kept oil demand rising in this sub-sector. According to the Asian Development Bank (ADB) report 'Promoting inland waterway transport in the People's Republic of China', China has a coastline of 18,000 km and a navigable inland waterway system totalling 126,300 km. Despite the huge waterway infrastructure system that has been developed over centuries, it has still not achieved its full potential in respect to both its size and its utilization. Therefore, the expectation is for a continued expansion in domestic waterway traffic in China, both for passengers and freight, which will support oil demand growth over the forecast period.

In addition to China, some demand growth is also projected in other developing countries due to increasing passenger and freight traffic demand, particularly in the rail sub-sector.

In total, oil demand in the rail and domestic waterways sector is expected to show steady growth to reach 2.1 mb/d by 2040. This is an increase of around 0.3 mb/d *versus* 2018. The sectoral product outlook is not likely to change significantly from its current structure as gasoil/diesel will continue to account for most of the demand. Gasoline and residual fuel are only expected to be used marginally.

Oil demand in the electricity generation sector has been on a declining path for decades and it is very likely that this will continue in the decades ahead. In 1990, the electricity sector accounted for more than 11% of total oil demand. This share has since decreased significantly, accounting for less than 5% in 2018. Recent projections indicate that this share will further decline to well below 4% by the end of the forecast period.

Oil demand for electricity generation is expected to shrink by 0.9 mb/d by 2040 to reach 4 mb/d (Table 3.12). While the use of gasoil/diesel is expected to remain relatively stable at around 1.5 mb/d, most of the decline will be in the use of residual fuel, dropping from 2 mb/d in 2018 to 1.5 mb/d in 2040, and other products from 1.2 mb/d to 0.9 mb/d. Part of this reduction includes the substitution of crude oil used directly for power generation in several countries. This is the result of strong competition from alternative sources of electricity, such as natural gas, renewables and nuclear, and a policy in several OPEC countries to benefit from the value-added use of available oil resources. Therefore, the largest demand decline in this sector is expected in OPEC countries (–0.5 mb/d).

On the other hand, some growth is expected in the Middle East & Africa and India on the back of improving electricity access and energy poverty alleviation policies. The adoption of these policies on a larger scale could potentially provide some opportunities for the use of oil to generate electricity. Oil-based decentralized power generation does not need to establish extensive grid networks and is suitable for integrating a variety of alternative technologies, such as wind, solar, water, hydropower, or stationary fuel cells.

Moreover, oil could play an increasing role in enhancing grid stability or providing back-up capacity for regions where natural gas logistics are difficult, or where the supply of other sources of energy is intermittent. Additional room for oil-based power generation could be offered in countries with high oil refining and conversion capacities. The combination of power generation, for example, from petcoke gasification, with either the production of petrochemicals or cogeneration (or both), is interesting from the viewpoint of very low feedstock costs. Moreover, this could also be applicable to other low-value products that result from refining processes.

Table 3.12
Oil demand in the electricity generation sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	0.3	0.3	0.3	0.2	0.2	0.1	–0.1
OECD Europe	0.3	0.3	0.3	0.2	0.2	0.2	–0.1
OECD Asia Oceania	0.5	0.5	0.4	0.3	0.3	0.2	–0.3
OECD	**1.1**	**1.1**	**0.9**	**0.8**	**0.6**	**0.5**	**–0.5**
Latin America	0.5	0.5	0.5	0.5	0.5	0.5	0.0
Middle East & Africa	0.6	0.6	0.7	0.7	0.8	0.9	0.3
India	0.2	0.2	0.2	0.2	0.2	0.2	0.1
China	0.2	0.2	0.2	0.2	0.2	0.2	0.0
Other Asia	0.5	0.5	0.5	0.4	0.4	0.4	–0.1
OPEC	1.7	1.6	1.7	1.6	1.4	1.2	–0.5
Russia	0.2	0.2	0.2	0.2	0.1	0.1	0.0
Other Eurasia	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Non-OECD	**3.8**	**3.8**	**4.0**	**3.9**	**3.7**	**3.5**	**–0.3**
World	**4.9**	**4.9**	**4.9**	**4.7**	**4.4**	**4.0**	**–0.9**

Source: OPEC.

Turning to the 'other industry' sector, major oil consumption trends in this sector are fairly similar to those discussed earlier for the residential, commercial and agriculture sectors, although the weighting of contributing regions differs.

Demand projections (Table 3.13) for this sector are closely linked to economic growth and the structure of economies. Normally, as a country moves through the early stages of development, the industrial sector expands and its share in the economy increases. Therefore, the largest incremental demand over the forecast period is projected for India (+0.5 mb/d), the Middle East & Africa (+0.3 mb/d) and OPEC (+0.3 mb/d).

However, as a country moves further down the development path and income levels increase, the share of the industrial sector tends to decline, in favour of the services sector. This is clearly already the case for China where oil demand in 'other industry' is likely to experience no growth over the next few years, before it starts to decline in the longer-term .

Another important element that shapes sectoral demand is road construction and maintenance. In the OECD, the road network is already well developed and only limited expansion has been seen in the last few years. Therefore, oil here is mostly consumed for road maintenance. In this respect, the outlook for non-OECD countries stands in stark contrast to the OECD. In most developing countries, the need for expanding road infrastructure is significant which, in turn, will support demand for asphalt, bitumen and other related products.

In the OECD region, oil demand in the 'other industry' sector is expected to revert to a declining path, following a temporary boost observed in the past few years as industry benefited from lower oil prices. Looking ahead, however, the shrinking weight of the industrial sector, technology and policy-driven efficiency improvements, and fuel switching towards natural gas, is expected to result in a demand reduction of around 0.6 mb/d over the forecast period.

Table 3.13
Oil demand in the 'other industry' sector by region *mb/d*

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
OECD Americas	3.0	3.0	3.0	2.9	2.8	2.8	–0.2
OECD Europe	1.5	1.5	1.3	1.4	1.4	1.3	–0.1
OECD Asia Oceania	0.9	0.9	0.8	0.8	0.7	0.6	–0.2
OECD	**5.3**	**5.4**	**5.1**	**5.0**	**4.9**	**4.7**	**–0.6**
Latin America	0.9	0.9	0.9	1.0	1.0	1.0	0.1
Middle East & Africa	0.6	0.6	0.7	0.8	0.8	0.9	0.3
India	1.0	1.0	1.1	1.2	1.3	1.4	0.5
China	2.0	2.0	2.0	1.8	1.8	1.8	–0.1
Other Asia	0.9	1.0	1.0	1.1	1.1	1.1	0.2
OPEC	1.3	1.3	1.5	1.6	1.6	1.6	0.3
Russia	0.5	0.5	0.5	0.5	0.5	0.5	0.0
Other Eurasia	0.4	0.4	0.5	0.5	0.5	0.5	0.1
Non-OECD	**7.5**	**7.6**	**8.0**	**8.4**	**8.7**	**8.8**	**1.3**
World	**12.8**	**13.0**	**13.1**	**13.4**	**13.6**	**13.6**	**0.8**

Source: OPEC.

3.4 Long-term oil demand outlook by product

This sub-section provides some insight into demand for the major categories of refined products as shown in Table 3.14. Light products are grouped into three categories: ethane/LPG, naphtha and gasoline (including ethanol). Middle distillates are grouped into two categories: jet/kerosene (including jet kerosene and domestic kerosene) and diesel/gasoil (including biodiesel). Finally, residual fuel oil (including refinery fuel oil) and 'other products' (including bitumen, lubricants, waxes, still gas, coke, sulphur, direct use of crude oil) account for the heavy part of the refined barrel.

The largest demand increase among all major products is projected for ethane/LPG, at 3.3 mb/d between 2018 and 2040. Strong growth for these two products is linked to the petrochemical and residential sectors. Most of the ethane demand growth is expected to take place in the petrochemical sector, especially in OECD Americas and in OPEC. In terms of incremental LPG demand, the largest part is expected to come from the residential sector in developing countries as a result of the adoption of energy poverty alleviation measures.

Naphtha is used almost exclusively as a petrochemical feedstock. Its average demand growth rate of 1.2% p.a. mirrors overall growth in this sector. In terms of volume, this represents 1.9 mb/d of additional demand by the end of the forecast period when total demand is expected to reach 8.3 mb/d. Most of the demand will be concentrated in Asian countries, with the largest increments projected for Other Asia (+0.6 mb/d) and China (+0.5 mb/d). The rest of the incremental demand is forecast to be spread between India, OECD Asia Oceania, Russia, OPEC and Africa.

In terms of the gasoline demand outlook, this is entirely driven by developments in the road transportation sector, discussed in detail earlier in this chapter. Two major observations are worth emphasizing in this respect. The first one relates to the contrasting regional outlook for this product, where strong growth in developing countries is broadly offset by demand declines in the

Table 3.14
Long-term oil demand by product

mb/d

	2018	2020	2025	2030	2035	2040	Growth 2018–2040
Ethane/LPG	11.7	12.2	13.2	14.0	14.6	15.0	3.3
Naphtha	6.4	6.5	6.9	7.5	7.9	8.3	1.9
Gasoline	26.0	26.6	27.8	27.8	27.6	27.5	1.5
Light products	**44.0**	**45.3**	**47.9**	**49.3**	**50.1**	**50.7**	**6.7**
Jet/kero	7.3	7.5	8.3	8.7	9.3	9.5	2.2
Gasoil/diesel	29.0	30.1	30.7	31.1	31.2	31.0	2.0
Middle distillates	**36.4**	**37.7**	**38.9**	**39.8**	**40.5**	**40.5**	**4.1**
Residual fuel	7.1	6.7	7.0	7.3	7.5	7.5	0.4
Other products	11.2	11.3	11.6	11.8	11.9	11.8	0.6
Heavy products	**18.3**	**18.0**	**18.7**	**19.2**	**19.3**	**19.3**	**1.0**
World	**98.7**	**101.0**	**105.6**	**108.3**	**109.9**	**110.6**	**11.9**

Source: OPEC.

OECD. The net effect is sluggish average growth of around 0.3% p.a. over the forecast period. In terms of volume, this translates to 1.5 mb/d of incremental demand between 2018 and 2040.

Equally important is the observation that gasoline growth not only decelerates over the next decade, but it is estimated to start to decline after 2030. The overall drop between 2030 and 2040 is marginal, but it indicates a potential change in the trend for one of the key refined products. This is a result of the overall road transportation demand trends where improving fuel efficiency and the increasing penetration of AFVs, primarily EVs, broadly offset the potential demand increase resulting from the expansion in the number of passenger vehicles.

For middle distillates, demand in this product group is dominated by diesel/gasoil. In the long-term, demand for diesel/gasoil is expected to increase by close to 2 mb/d to reach 31 mb/d in 2040. This expectation is driven by a number of factors. On the positive side, growing requirements for transportation services in the non-OECD grouping will lead to expanding fleets of trucks and buses, as well as primarily diesel-driven light-duty vehicles. Some demand growth is also projected in the rail and domestic navigation sectors. This is further supported by the industry, residential and agriculture sectors, while the marine sector is forecast to provide only a temporary boost to diesel demand.

However, as oil demand in most of these sectors is strongly linked to GDP growth, the assumed slower GDP growth in this Outlook provides weaker support to diesel demand. Moreover, diesel demand growth is partially offset by the expected demand reduction in the road transportation sector, especially in European countries.

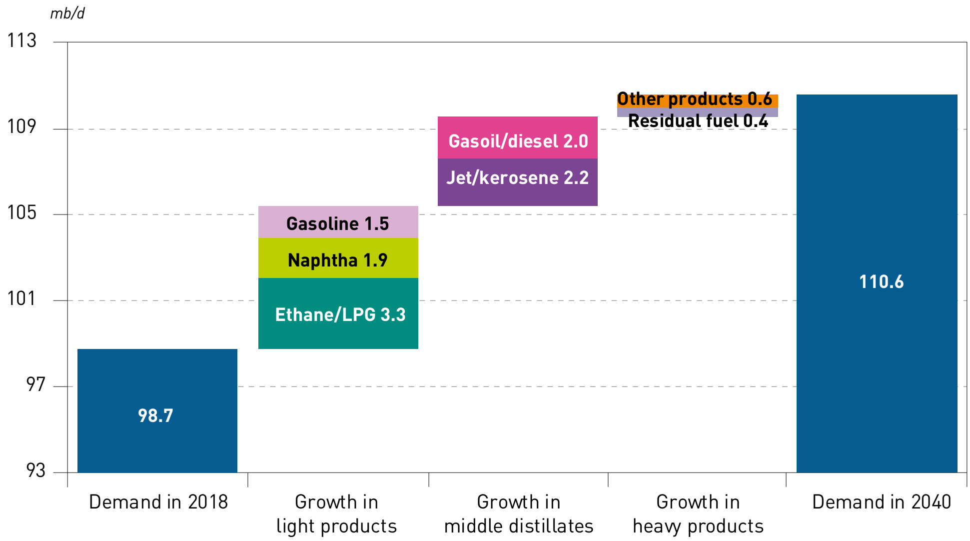
Relatively slow growth in gasoil/diesel will be partially compensated by strong growth in jet/kerosene. The growth in this product group is comparable to naphtha, averaging 1.2% p.a. between 2018 and 2040, an additional 2.2 mb/d of demand by 2040. This comes almost exclusively from the fast-growing aviation industry, with its reliance on jet kerosene. Some growth is also projected in domestic kerosene, used mostly for lighting, heating and cooking in developing countries. However, at the global level, demand for domestic kerosene is forecast to decline due to a switch to alternative fuels, including LPG, in most regions, which more than compensates for growth in some developing countries.

Demand for residual fuel oil is anticipated to move within a relatively narrow range of around 0.8 mb/d over the forecast period. As discussed earlier, its demand is expected to drop sharply in 2020 due to IMO regulations limiting sulphur content. Thereafter, a smooth recovery is anticipated as the shipping industry increases its use of scrubbers. This recovery, however, is subdued by expected developments in other sectors, such as electricity generation, refining, rail and domestic waterways. In total, demand for residual fuel oil is expected to increase by just 0.4 mb/d between 2018 and 2040.

A similar level of demand increase is also projected for the group of 'other products' (+0.6 mb/d). Moreover, because of the diversity of products included in this group, the overall demand increase is the result of diverging trends for specific products, ranging from demand growth for bitumen/asphalt, lubricants and petcoke to an anticipated decline in the direct use of crude oil to produce electricity.

The summary of the major trends discussed in this sub-chapter is presented in Figure 3.25. It shows that more than half of the incremental oil demand over the forecast period is expected to be satisfied by light products, which account for 6.7 mb/d out of a total demand growth of 11.9 mb/d. The demand for middle distillates is expected to increase by 4.1 mb/d, which is anticipated to be almost equally shared between gasoil/diesel and jet/kerosene. Some growth (+1 mb/d) is also projected for heavy products.

Figure 3.25
Demand growth by product category in the long-term



Source: OPEC.

Liquids supply

Key takeaways

- Medium-term non-OPEC total liquids supply is expected to increase by 9.9 mb/d, rising from 62.4 mb/d in 2018 to 72.2 mb/d in 2024, or average growth of 1.6 mb/d p.a.

- Production in the latter period of the medium-term has been revised up by an average 3.0 mb/d, as a result of a higher 2018 baseline (+0.8 mb/d), a more robust 2019–2020 short-term outlook (revised up by an average 1.2 mb/d) and stronger prospects for both US tight oil and other key non-OPEC production sources.

- The main driver of medium-term non-OPEC supply growth remains overwhelmingly US tight oil, but Brazil, Norway, Canada, Guyana and Kazakhstan will also likely contribute.

- US tight oil supply is seen expanding sharply in the medium-term, rising by 6.7 mb/d, but it is expected to begin to slow thereafter, showing only modest increases and peaking at 17.4 mb/d in 2029. By 2040, US tight oil production is seen at 14.5 mb/d. Tight oil production elsewhere has potential, but it is expected to remain at relatively modest volumes.

- Offshore crude oil production will likely see a revival of fortunes in the medium-term, as output grows again in mature producing areas such as the North Sea and the US Gulf of Mexico, in addition to strong growth in new areas including Brazil's pre-salt and Guyana. In the period 2018–2024, crude output in these regions is expected to contribute nearly 25% of non-OPEC liquids supply growth.

- In terms of liquid types, crude oil (including tight crude) is anticipated to contribute 6.8 mb/d, or 68% of non-OPEC supply growth in the medium-term, NGLs another 1.8 mb/d, or 19%, with the remainder made up of global biofuels, refinery processing gains and other liquids. In the long-term to 2040, crude oil is forecast to decline by 3 mb/d, while NGLs and other sources continue to grow.

- Over the long-term, total non-OPEC supply is projected to hit a high point of 72.6 mb/d in 2026 and gradually decline to 66.4 mb/d by 2040. After the expected US tight oil peak, only four countries are expected to show meaningful output growth, namely Qatar, Brazil, Canada and Kazakhstan. Virtually all other non-OPEC producers are projected to see a decline in long-term liquids production.

- Global cumulative upstream investment requirements will need to be in the range of $8.1 trillion over the entire forecast period. Especially in the earlier years, the lion's share of this investment will need to be made in OECD countries, due to the strong projected contribution from North America, in particular, US tight oil and Canadian oil sands. OPEC's required investment share, by contrast, will rise in the long-term.

This Chapter describes the outlook for liquids supply from 2018–2040. As in previous editions of the WOO, the medium-term projections for 2018–2024 and the longer-term outlook are discussed separately, due to the different methodologies employed. The medium-term view relies upon a bottom-up approach, identifying upstream project start-ups, their progress and the underlying decline in mature fields, while the long-term outlook is based upon an assessment of the available resource base. US tight oil is also modelled and discussed separately.

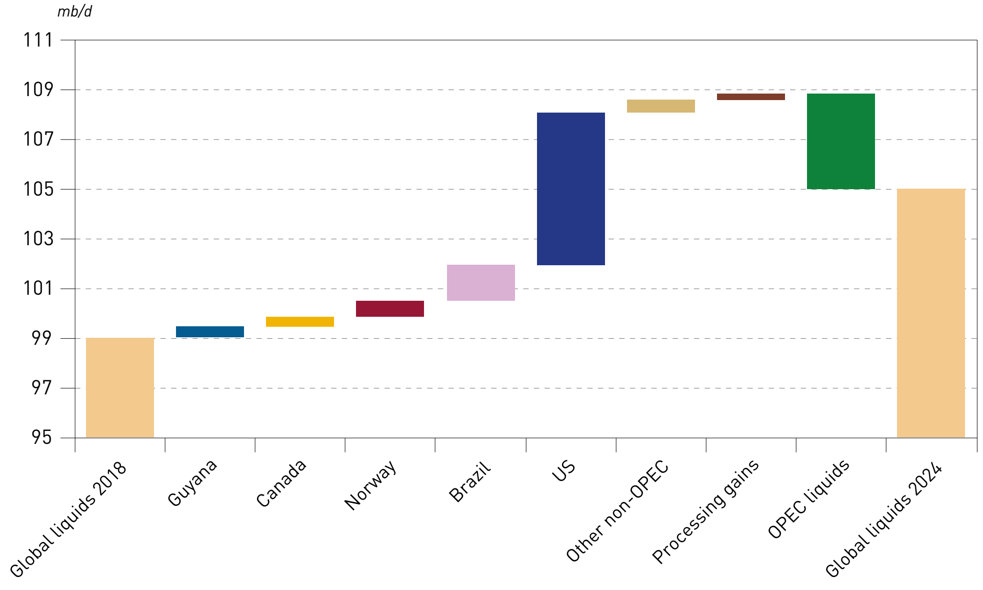
It is important to note that all supply figures quoted in this publication reflect Qatar having left OPEC on 1 January 2019. Naturally, this has led to a revision of the baseline for OPEC and non-OPEC oil production assessments, as well as forecasts, which should not be confused with actual changes to the outlook.

4.1 Medium-term outlook for liquids supply

Total non-OPEC liquids supply, including crude oil, NGLs, biofuels, other liquids and refinery processing gains, is projected to grow from 62.4 mb/d in 2018 to 72.2 mb/d in 2024, or by 9.9 mb/d, with global liquids supply in 2024 estimated at 105 mb/d (Figure 4.1 and Table 4.1). Upward revisions to the historical baseline and the short-term outlook for non-OPEC supply have resulted in a higher starting point which, combined with upward-revised projections for US tight oil and other sources of non-OPEC supply growth, means that medium-term incremental supply is moderately higher than the 8.6 mb/d assessed in the WOO 2018. On average, non-OPEC total liquids supply is seen increasing by 1.6 mb/d p.a. from 2019–2024, thus continuing to outstrip annual demand growth over the period.

The drivers of this continued strong non-OPEC supply growth are the return of modest increases in upstream investment and healthy demand. US tight oil production growth may have seen its strongest year in 2018, but it is nonetheless expected to continue at a healthy pace, with total US liquids making up just over 60% of the estimated medium-term non-OPEC supply growth. Moreover, there also appears to be a cyclical recovery in non-US, non-OPEC supply prospects in

Figure 4.1
Composition of medium-term global oil liquids supply growth, 2018–2024



Source: OPEC.

line with the recovery in oil prices, investment and activity, which had all dropped as a result of the sharp crude price decline in the period 2014–2016. The subsequent rebalancing of the market and the return of more stability is due in no small part to the success of the Declaration of Cooperation.

Non-OPEC supply, after expanding by a record 2.9 mb/d in 2018, is projected to experience above-average growth in 2019 and 2020, largely as US tight oil production continues to soar. However, growth is seen returning to more moderate levels thereafter. US liquids supply growth,

Table 4.1
Medium-term global liquids supply outlook

mb/d

	2018	2019	2020	2021	2022	2023	2024	Change 2018–2024
US	16.7	18.6	20.3	21.5	22.1	22.6	22.8	6.2
of which: tight oil	*10.2*	*12.0*	*13.8*	*15.1*	*16.0*	*16.5*	*16.9*	*6.7*
Canada	5.2	5.2	5.3	5.4	5.4	5.5	5.6	0.4
of which: oil sands	*2.9*	*2.9*	*3.0*	*3.0*	*3.1*	*3.1*	*3.2*	*0.3*
Mexico & Chile	2.1	1.9	1.8	1.9	1.9	1.9	2.0	–0.1
OECD Europe	3.8	3.8	3.9	4.2	4.5	4.6	4.5	0.7
OECD Asia Oceania	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.1
OECD	**28.2**	**30.0**	**31.9**	**33.4**	**34.5**	**35.1**	**35.4**	**7.2**
Latin America	5.2	5.4	5.8	6.1	6.4	6.7	7.0	1.8
Middle East	3.2	3.2	3.2	3.3	3.3	3.4	3.5	0.3
Africa	1.5	1.6	1.6	1.6	1.6	1.7	1.7	0.1
China	4.0	4.1	4.1	4.1	4.0	4.1	4.0	0.0
Other Asia	3.6	3.5	3.5	3.4	3.4	3.4	3.4	–0.2
Russia	11.3	11.4	11.5	11.5	11.5	11.5	11.5	0.1
Other Eurasia	3.1	3.0	3.0	3.0	3.1	3.1	3.2	0.2
Non-OECD	**31.9**	**32.2**	**32.7**	**33.1**	**33.4**	**33.9**	**34.3**	**2.4**
Processing gains	**2.3**	**2.3**	**2.4**	**2.4**	**2.4**	**2.5**	**2.5**	**0.2**
Non-OPEC	**62.4**	**64.4**	**66.9**	**68.9**	**70.3**	**71.5**	**72.2**	**9.9**
Crude	44.0	45.5	47.2	48.8	49.9	50.5	50.8	6.8
of which: tight crude	*7.0*	*8.3*	*9.7*	*11.0*	*11.7*	*12.1*	*12.4*	*5.4*
NGLs	9.9	10.4	10.9	11.1	11.3	11.5	11.7	1.8
of which: unconventional NGLs	*3.7*	*4.2*	*4.7*	*4.9*	*5.1*	*5.3*	*5.6*	*1.9*
Global biofuels	2.5	2.5	2.6	2.7	2.7	2.8	2.9	0.4
of which: fuel ethanol	*1.8*	*1.9*	*1.9*	*1.9*	*2.0*	*2.0*	*2.1*	*0.3*
of which: biodiesel	*0.7*	*0.7*	*0.7*	*0.7*	*0.8*	*0.8*	*0.8*	*0.1*
Other liquids	3.7	3.7	3.8	3.9	4.0	4.2	4.4	0.6
of which: GTLs	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.4*	*0.1*
of which: CTLs	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.2*
of which: others incl. Canadian oil sands	*3.3*	*3.3*	*3.3*	*3.4*	*3.4*	*3.5*	*3.6*	*0.3*
Total OPEC liquids	**36.6**	**35.0**	**34.4**	**33.5**	**32.9**	**32.7**	**32.8**	**–3.8**
Stock change*	**0.3**	**–0.5**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	
World	**99.0**	**99.4**	**101.3**	**102.3**	**103.3**	**104.2**	**105.0**	**6.0**

* *Stock change assumptions reflect commercial stock inventories, development of Strategic Petroleum Reserves (SPR), and the rising need for stocks as refinery capacity expands.*

Source: OPEC.

predominantly driven by tight crude and unconventional NGLs, is projected to contribute just over 60% of total non-OPEC supply in the medium-term. Within the US, Gulf of Mexico offshore production, as well as production in Alaska, is also expected to contribute barrels.

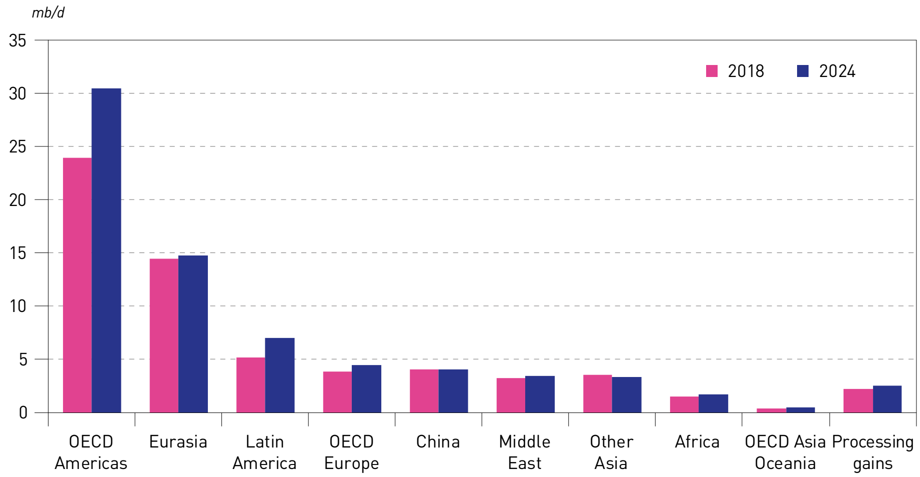
However, even as the growth rate in the US begins to slow from high levels, a cluster of sizeable upstream projects in other non-OPEC countries is expected to come online as a result of final investment decisions taken since prices stabilized from 2016. In sum, this will result in slower, but still impressive growth over most of the latter half of the medium-term.

Non-OPEC countries with major new projects coming online include Brazil, where a steady stream of new fields is set to start up; Guyana, a newcomer to the club of oil producing nations; as well as mature producers such as Norway, Canada, Qatar and Kazakhstan. At the same time, the previously pronounced natural declines for some mature producers, such as China, Mexico and the UK, have to some extent been halted due to policy shifts and/or favourable upstream investment conditions.

4.1.1 Non-OPEC liquids supply growth by region

Regionally, the strongest growth in non-OPEC liquids supply comes from OECD Americas, which contributes a full 6.5 mb/d of incremental production (Figure 4.2). Most of this is from the US, but growth is also expected in Canada, while output in Mexico and Chile is expected to remain flat. Latin America is anticipated to be another source of substantial incremental production, some 1.8 mb/d, comprised of higher output from Brazil, Guyana and Argentina. OECD Europe, Eurasia and non-OPEC Middle East will also likely see gains. The only region expected to see a small decline in output is Other Asia, essentially non-OECD Asia, excluding China.

Figure 4.2
Medium-term non-OPEC liquids supply outlook by region

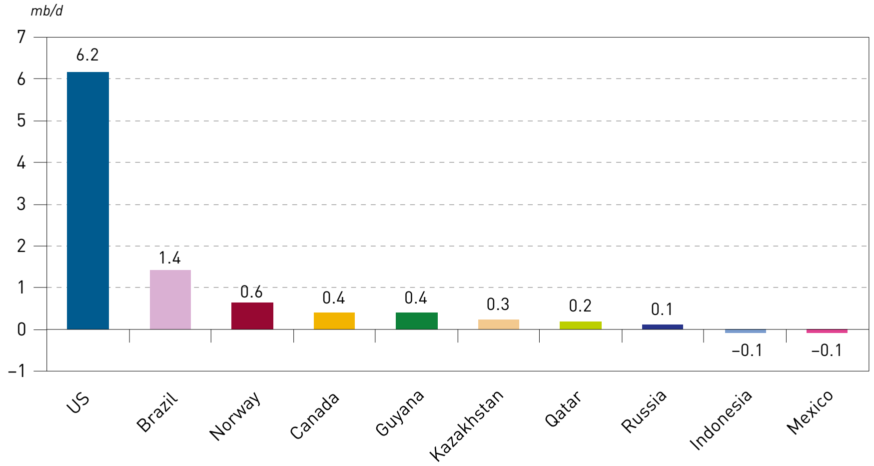


Source: OPEC.

In terms of individual countries' contributions to non-OPEC medium-term liquids supply growth, the US is projected to be by far the largest contributor, with 6.2 mb/d out of a total 9.9 mb/d (Figure 4.3). Other major contributors include Brazil, Norway and Canada. Compared to the WOO 2018, a slightly larger group of other countries, including Guyana, Kazakhstan, Qatar, Russia and others, will also make likely modest contributions to overall liquids output.

Two other observations are noteworthy in comparing the outlook to the WOO 2018. First, the order and composition of non-OPEC contributions has changed slightly, with Norway moving up the ranking, and Guyana and Qatar joining the list. Second, in this publication's non-OPEC supply medium-term outlook, there are virtually no countries with pronounced output declines.

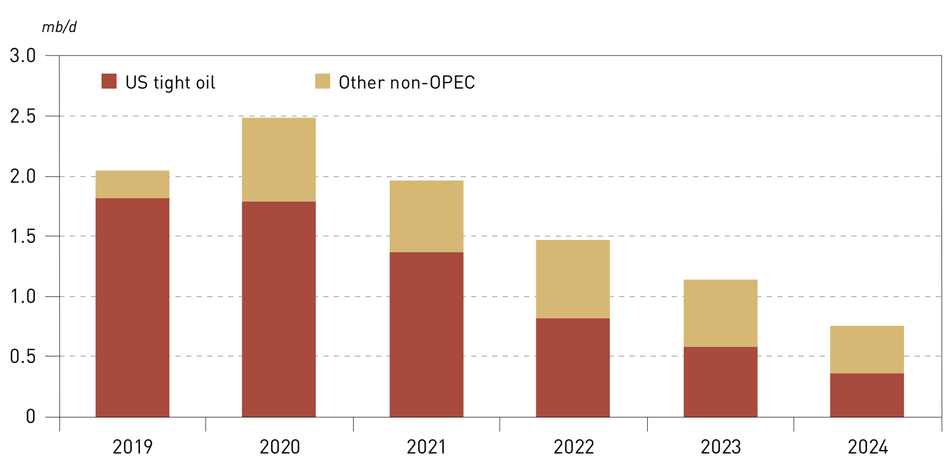
Figure 4.3
Selected contributors to non-OPEC total liquids change, 2018–2024



Source: OPEC.

While the overall contribution from the US is large, its incremental supply makes up a slightly lower 62% of total non-OPEC supply growth, *versus* the roughly two-thirds projected in the WOO 2018. A key element is that the robust US supply growth in 2018 (2.3 mb/d, mostly from tight oil) is now part of the baseline and not the medium-term growth projections. As US tight oil growth is projected to slow over the medium-term, while the supply outlook for other non-OPEC countries has been revised upwards, the relative share of US growth declines throughout the 2019–2024 period (Figure 4.4).

Figure 4.4
Composition of non-OPEC annual medium-term liquids supply growth



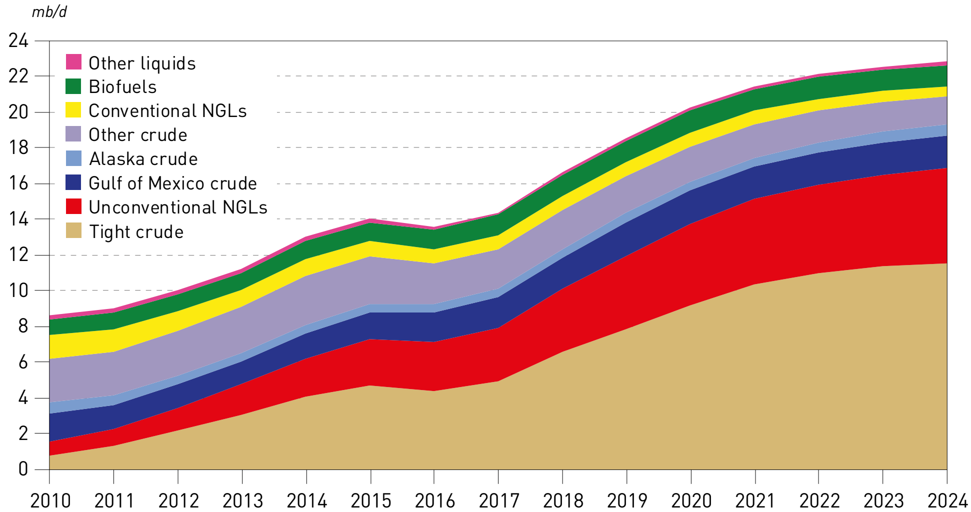
Source: OPEC.

In particular, a number of large fields outside the US are expected to come online and/or ramp up output in 2019–2024. These include Johan Sverdrup in Norway, with the first phase due to have 440 tb/d of capacity, various large pre-salt fields in Brazil, including Buzios 3, Buzios 4, Lula Norte and others, and first oil at Guyana's new Liza field.

US

US liquids supply will remain the fastest-growing source of non-OPEC barrels in the medium-term. It is projected to increase by 6.2 mb/d, from 16.7 mb/d in 2018 to 22.8 mb/d in 2024 (Figure 4.5 and Table 4.2). This is overwhelmingly driven by tight oil, with increases for both tight crude and unconventional NGLs related to shale gas output. In total, tight oil is expected to grow by 6.7 mb/d in the medium-term, rising to 16.9 mb/d, which would correspond to nearly 75% of estimated US oil production. In contrast, other US conventional onshore crude production is projected to decline by 0.6 mb/d. Conventional NGLs output is forecast to fall by 0.2 mb/d, while production of biofuels and other liquids is expected to remain flat.

Figure 4.5
US total liquids supply in the medium-term



Source: OPEC.

While tight oil will remain immensely important to the US and overall non-OPEC supply growth (US and other tight oil developments will be discussed in section 4.3), it is worth pointing out that current projections indicate that it may have seen its strongest annual growth in 2018, when it increased by 2.2 mb/d. The 2019–2024 period is expected see slower, albeit still sizeable, growth, averaging 1.1 mb/d p.a., ahead of an expected peak in the late 2020s.

Moreover, while tight oil is overwhelmingly driving US liquids supply, it is by no means the only source of growth. Following several years of stagnation after the Macondo/Deepwater Horizon accident in 2010, and the resulting temporary drilling moratorium, US offshore production in the Gulf of Mexico has seen a recovery, and is projected to increase by 0.1 mb/d in the medium-term to reach 1.8 mb/d in 2024 (Figure 4.6).

Several large new projects are expected to start up in the medium-term period, including Shell's Appomattox, which came online in the first half of 2019. It is the first deepwater field in the Norphlet Formation, which extends into the Eastern Gulf, a virtually untapped area east of where

Table 4.2
US total liquids supply over the medium-term

mb/d

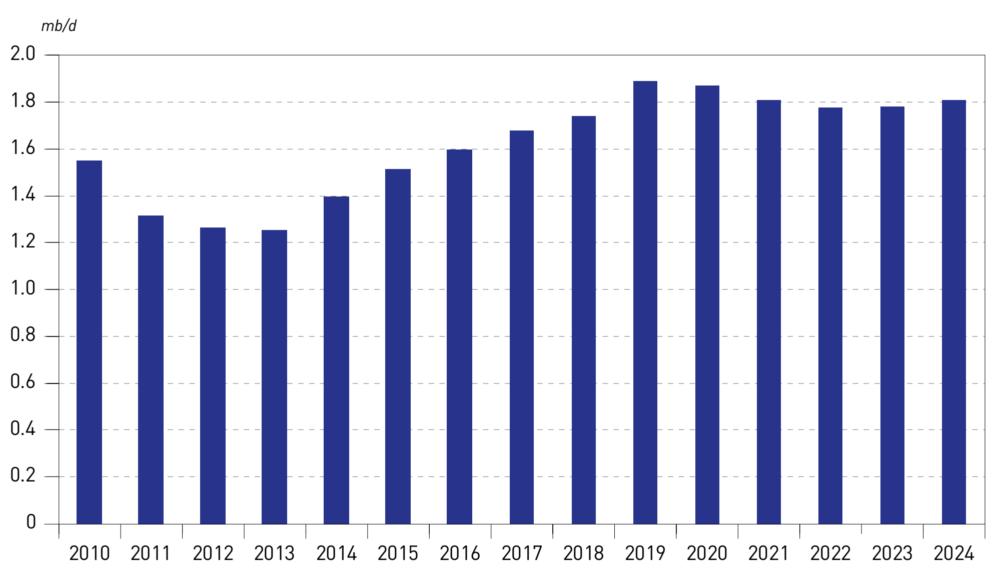
	2018	2019	2020	2021	2022	2023	2024	Change 2018–2024
US tight oil	10.2	12.0	13.8	15.1	16.0	16.5	16.9	6.7
of which: tight crude	*6.6*	*7.9*	*9.2*	*10.4*	*11.0*	*11.4*	*11.5*	*4.9*
of which: unconventional NGLs	*3.6*	*4.1*	*4.6*	*4.7*	*4.9*	*5.2*	*5.4*	*1.8*
US Gulf of Mexico crude	1.7	1.9	1.9	1.8	1.8	1.8	1.8	0.1
US Alaska crude	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.2
US other crude	2.2	2.1	2.0	1.9	1.8	1.7	1.6	–0.6
US other NGLs	0.8	0.8	0.8	0.7	0.7	0.6	0.5	–0.2
US biofuels	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.0
US other liquids	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0
Total US liquids production	**16.7**	**18.6**	**20.3**	**21.5**	**22.1**	**22.6**	**22.8**	**6.2**

Source: OPEC.

most offshore production has historically taken place. Appomattox is slated to produce 125 tb/d at its peak.

Alaskan crude oil production is projected to rise by 0.2 mb/d as several new fields are developed, with total output reaching 0.6 mb/d in 2024. Advances in drilling techniques are contributing to

Figure 4.6
US Gulf of Mexico offshore crude oil production



Source: OPEC.

the development of untapped resources. Horizontal wells with multiple laterals can now extend several miles from existing drilling pads. ConocoPhillips has reportedly achieved a 5-mile long well using this technique which, given seasonal above-ground issues in Alaska, means that wells can be more easily drilled from existing gravel pads and then reach out to tap into reservoirs offshore.

Furthermore, the National Petroleum Reserve in Alaska (NPRA), an area long off-limits to oil companies, is expected to be tapped for the first time in the medium-term period. ConocoPhillips is set to start up a cluster of fields, including Willow, Bear and Narwhal, with a collective peak capacity of 120 tb/d. Moreover, the current administration is expected to hold lease sales in 2020 for drilling in the Alaskan National Wildlife Refuge (ANWR), another very large area to the east of the NPRA that was also previously off-limits to drillers.

However, it should be noted that the NPRA, in particular, will need new infrastructure to link up with the Trans-Alaska Pipeline System (TAPS), which carries oil produced on Alaska's Northern Slope to the southern port of Valdez, from where barrels are shipped to the US West Coast and other markets. Moreover, future administrations may take a more critical position *vis-à-vis* the opening up of as-yet-protected Alaskan acreage.

With regard to the potential to allow drilling in other untapped coastal areas, a US court ruled at the end of March 2019 that the current administration's reversal of an offshore drilling moratorium in parts of the Arctic and sections of the Atlantic Coast was unlawful. The previous administration had protected large parts of the outer continental shelf, including the Chukchi and Beaufort Seas in the Arctic offshore in Alaska, as well as a large part of the Atlantic Coast. The court ruled that only Congress has the right to reverse these orders.

In contrast to tight liquids supply, offshore and Alaskan oil, other conventional US onshore crude production is projected to decline by 0.6 mb/d. Conventional NGLs output is forecast to fall by 0.2 mb/d, while production of biofuels and other liquids is expected to remain flat.

Canada

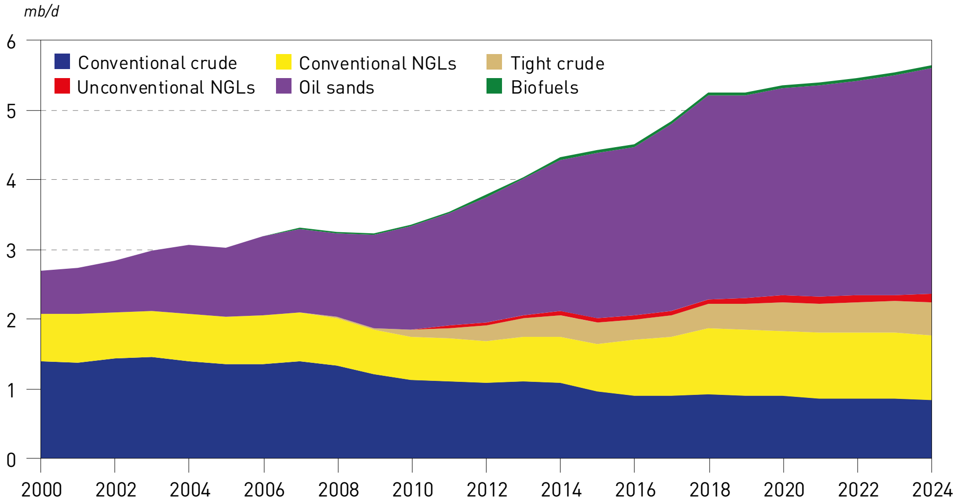
Canada is projected to see its total liquids production grow from 5.2 mb/d in 2018 to 5.6 mb/d in 2024 (Figure 4.7). Most of this growth, around 0.3 mb/d, will stem from rising oil sands production. This is set to grow from 2.9 mb/d in 2018 to 3.2 mb/d in 2024. Incremental output will likely come from further increases at existing projects, including Fort Hills, Horizon and Christina Lake. In the latter years of the medium-term period, additional volumes are expected to come from the Kirby and West Ells projects.

In November 2018, the Aspen project was the first greenfield oil sands project to be sanctioned since the 2014 oil price downturn. The project has a planned capacity of 75 tb/d and first oil is targeted for 2022. However, operator Imperial Oil has already suggested that it might delay the start up.

This demonstrates the increasingly challenging economic and policy environment the Canadian oil sands sector finds itself in – squeezed by lower-cost US tight oil and constrained by export capacity limits following delays to planned pipeline projects. These constraints have, in turn, widened differentials to international benchmark crudes, thus depressing domestic Canadian prices. In late 2018, the Province of Alberta took the unusual step of mandating a production shut-in to bring down inventories and support differentials. It first forced an adjustment of 325 tb/d, which has since been partially eased.

Even though the TransMountain pipeline recently received the go-ahead to triple its capacity to around 885 tb/d, thus expanding the flow of Albertan barrels to the West Coast, this will likely

Figure 4.7
Canada total liquids supply



Source: OPEC.

take until 2022 to materialize. The expansion of the Line 3 pipeline into the US Great Lakes region is expected to be completed in 2021, but the fate of the Keystone XL pipeline is still up in the air, meaning that export infrastructure constraints will remain a concern.

Regarding the latter, a US federal judge has blocked its construction, assessing that the US administration had not sufficiently taken environmental findings into consideration. However, the US president subsequently issued a new permit for the pipeline in March 2019, leaving the situation somewhat unclear.

These challenges illustrate why Canadian oil sands – while remaining an important source of non-OPEC supply growth – have seen future growth expectations revised successively downwards, and why growth depends almost exclusively on smaller modular additions to existing projects.

This Outlook assumes that shut-in Albertan production will gradually return over the course of 2020. In addition to growth from oil sands, another 180 tb/d of tight crude and unconventional NGLs is expected to be added in the medium-term period. Conventional crude and NGLs production are projected to decline by a modest 0.1 mb/d.

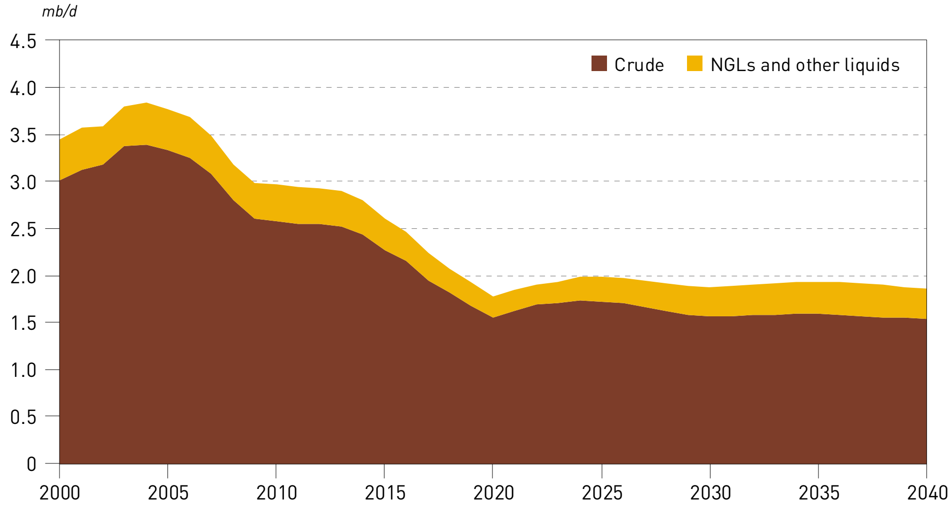
Mexico

In late 2013, Mexico changed its constitution to allow for a comprehensive package of energy reforms, bringing an end to 75 years of a national monopoly on oil and gas production. Suffering from declining crude oil output and falling exports, and rising costly refined product imports, the government of the time pushed through a major constitutional change with a view towards opening up the sector, creating competition for the national oil company Petróleos Mexicanos (Pemex), and encouraging significant investment into its oil sector.

Central to this was the liberalization of the upstream sector, where crude production had been falling steadily since a peak in 2004. Nevertheless, almost six years on, while some steps towards opening up Mexico's energy sector have been taken, the energy reform is expected to have only a relatively muted effect. Several acreage auctions have been held, and seen significant, if modest bidding, but new upstream auctions have now been put on hold for up to three years.

As a result, Mexico is projected to see production levels stabilize, halting the decline it has seen in recent years over the medium-term, as some initial benefits of the 2013 energy reform filter through (Figure 4.8). Foreign companies have been active in exploring Mexican upstream acreage, and a handful of final investment decisions (FIDs) have been taken. The latter will likely result in modest volumes of new production coming online, including the Eni-operated Area 1 cluster of fields, which is expected to add around 90 tb/d in the shallow waters of Campeche Bay from 2019/2020. They will be the first new oil fields developed by an outside operator.

Figure 4.8
Mexico total liquids supply in the long-term



Source: OPEC.

PanAmerican is scheduled to bring the first barrels to market from the 30 tb/d Hokchi field in 2021. Finally, Talos is expected to start output at its Zama field, with 110 tb/d of capacity around 2023.

At the same time, the new administration is once again putting the onus on Pemex. A re-orientation towards building on its strengths, experience and existing infrastructure in shallow-water (and to a lesser extent, onshore) appears to make sense, as may the concurrent move away from higher-risk unconventional (such as tight oil) and deepwater assets (such as the Perdido belt). The authorities have made bold claims that these measures can boost oil production by 300 tb/d by 2020.

The plan for doing so would involve accelerated development of what the government considers low-hanging fruit by drilling 500 wells – three times the number drilled in 2018 – at 20 new fields. It also assumes a constant high rate of new discoveries as more investment is ploughed in.

Furthermore, bureaucratic red tape would be slashed, with the regulatory process to receive permits for new upstream projects, at least those to be developed by Pemex, cut to 50 days from 270 days. In turn, Pemex hopes to bring new discoveries onstream within 1.3 years, as compared to the currently typical five years. By following this strategy (and presumably including some non-Pemex-developed fields in their calculations), the government claims that Mexican crude oil production will recover to 2.5 mb/d or more by 2024, when President Obrador is due to leave office.

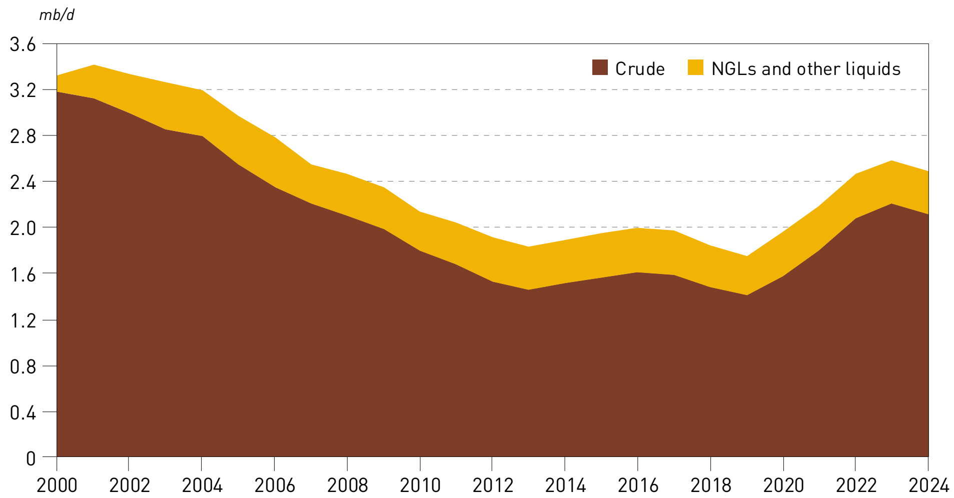
In this publication's assessment, a combination of investment at existing assets and bringing onstream new oil fields will indeed halt the decline that Mexican oil production has experienced since 2004, when it pumped 3.8 mb/d (3.4 mb/d crude; 0.4 mb/d NGLs). Production is projected to fall from an average total liquids output of 2.1 mb/d in 2018 to a low of 1.8 mb/d in 2020–2021, and then recover to 2.0 mb/d by 2024, after which it is expected to hold steady throughout the remainder of the decade and beyond.

However, it should be stressed that there remains upside potential. Pemex may succeed in focusing on its strengths and eventually farm out operating stakes in other fields to external parties. Undoubtedly, the resource potential is there, with large tight oil formations and deepwater assets contiguous to similar assets in the US, as well as refining hubs and thirsty markets close at hand. If some of the foreign-operated greenfields provide visible and measurable success, then auctions and further investments may recommence.

Norway

Norway is the third-largest source of non-OPEC supply growth in the medium-term, with total liquids supply seen rising from 1.9 mb/d in 2018 to 2.5 mb/d in 2024 (Figure 4.9). The entire increase comes from crude production.

Figure 4.9
Norway total liquids supply



Source: OPEC.

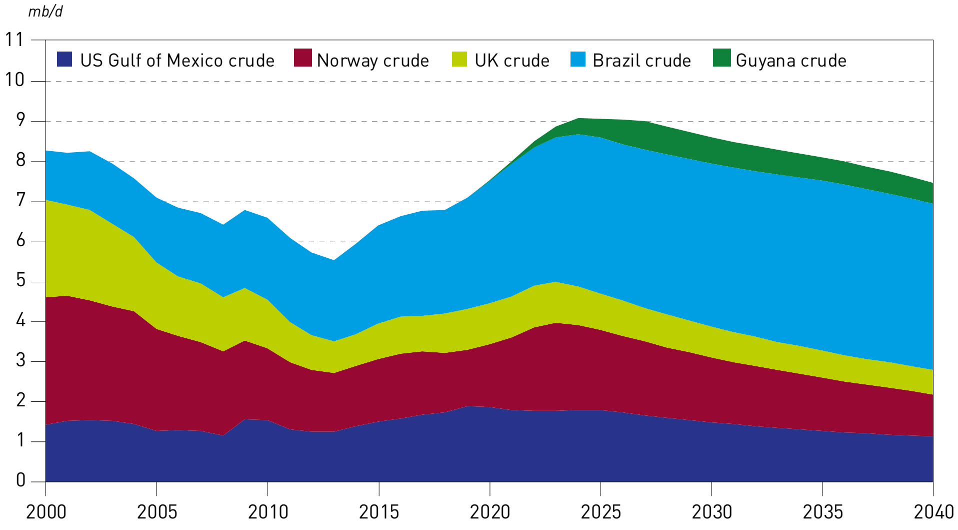
A number of large new fields are planned to come online, and operators in Norway have also proven adept at extending the life of existing fields through improved drilling and other techniques, as well as numerous tie-backs of new wells to existing infrastructure.

Since peaking at 3.4 mb/d in 2001, Norway's oil production has more or less been in a steady decline, as fields mature and large new finds have proven difficult. However, after being forced to cut costs and become more efficient following the 2014/2015 price downturn, a string of new field projects has been sanctioned, of which a critical mass will come online in the period to 2024.

This is part of a broader trend in which mature offshore areas around the globe are experiencing something of a renaissance, and it is most pronounced in Norway (Figure 4.10). This is manifesting itself in large new discoveries being brought online, including the giant Johan Sverdrup field, one of the largest North Sea projects ever to start up. It is on track to deliver first barrels in late-2019, and capacity should ramp up to 440 tb/d in the first phase of the project. A later phase, due to start up in 2022, should add a further 220 tb/d.

The operator, Equinor, has made some striking claims that hint at the field's potential, including cost savings of 30% since the project was given the go-ahead in 2015. An efficient and relatively fast process of bringing it online since then, alongside the use of cutting-edge techniques such as digitalization, permanent reservoir modelling, and EOR methods, among others, is expected to result in a very high recovery rate of 70%.

Figure 4.10
Crude oil output in selected offshore producing areas



Source: OPEC.

Besides Johan Sverdrup, 2020, in particular, should see a string of other projects starting up, including the smaller Martin Linge, Njord and Trestakk fields. In the latter years of the medium-term period, the Johan Castberg field will likely add another 200 tb/d, and the redevelopment of the Snorre field another 70 tb/d.

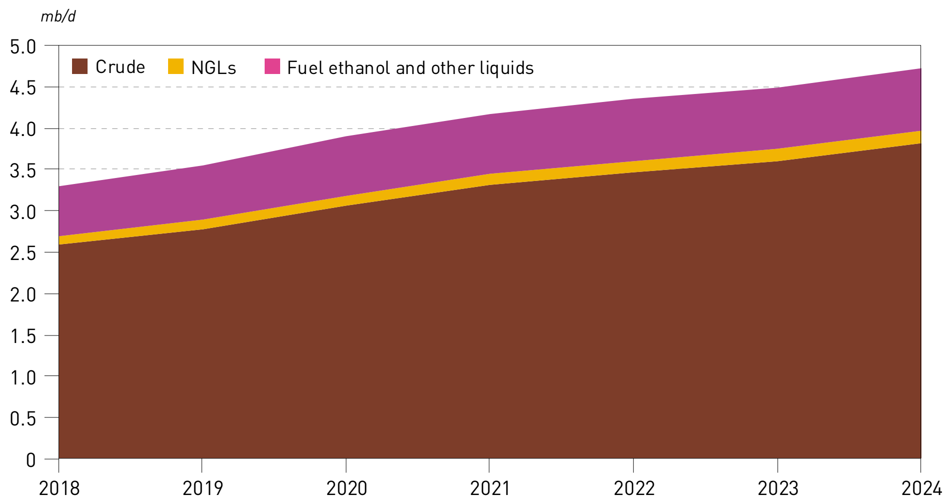
After boosting Norwegian liquids supply by 2024 to heights not seen since 2008, the longer-term project pipeline looks bleaker, and output is likely to decline again due to a lack of investment. In particular, northern waters, including the Barents Sea, remain relatively underexplored. Only two fields, Snoehvit and Goliat, are currently producing oil and gas there, and Johan Castberg is the only field in that area due to start up in the medium-term.

The Norwegian Labour Party – currently the opposition – recently changed its long-held supportive stance and turned against exploratory drilling around the disputed Lofoten Islands in the Norwegian Arctic. This may mean that another prospective area remains off-limits to drillers, further hampering future supply growth, as several billion barrels of oil are expected to remain under these waters.

Brazil

The second most important source of non-OPEC liquids supply growth is expected to be Brazil, where production is projected to increase from 3.3 mb/d in 2018 to 4.7 mb/d in 2024 (Figure 4.11). This is in part the result of the previous government's reforms, which allowed companies other than Petrobras to operate pre-salt fields, reduced local-content rules, and allowed for frequent offshore acreage auctions. It is also a testament to the numerous large-scale projects in the country's pre-salt deepwater acreage in the Santos Basin, expected to come to fruition within the next years.

Figure 4.11
Brazil total liquids supply



Source: OPEC.

A sizeable production increase of 0.2 mb/d is already expected in 2019, with the start-ups of several floating production, storage and offloading ('FPSO') vessels that were originally due to come online in 2018. These include, among others, the Buzios 3 and Buzios 4 vessels, each with 150 tb/d of capacity. They would follow their Buzios 1 and Buzios 2 namesakes, which were brought onstream in 2018. Other projects include Lula Extremo Sul, Berbigao, Lula Norte, Tartaruga Verde/Mestica and Atapu, all of which are expected to start and/or ramp up production in 2019 or 2020.

A second phase, in the latter part of this publication's medium-term horizon, should see a further cluster of projects come online, including more 100–200 tb/d capacity FPSOs, making for strong growth. This second round is expected to include projects, such as the first and second phases of the large Libra field, Lula Oeste, Parque das Baleias, and others.

In the meantime, the current government has plans to further reform the country's energy sector. These include gas market liberalization, plans for Petrobras to sell off some assets, including, notably some refineries, as well as incentives to develop unconventional resources.

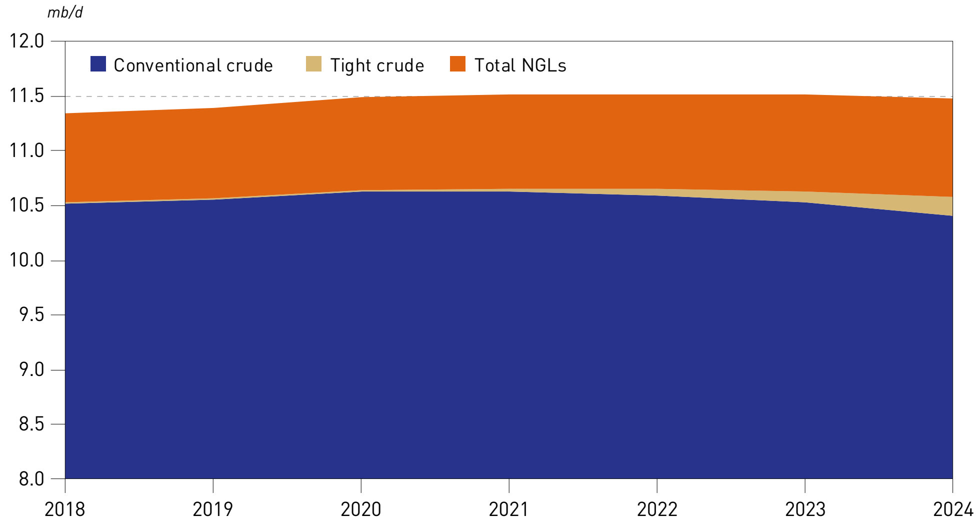
The 16th regular acreage bidding round and sixth pre-salt production-sharing auction are expected to be held in late-2019. Areas up for bidding may include the much-anticipated sale of oil in the so-called 'transfer-of-rights' areas, previously allocated to Petrobras. These developments would serve to sustain further growth beyond the mid-2020s.

Lastly, Brazilian biofuels production is projected to increase by 0.2 mb/d in the medium-term, rising to 0.8 mb/d. Of this, 0.6 mb/d is fuel ethanol.

Russia

Total liquids production in Russia is expected to grow by a modest 0.1 mb/d, from 11.3 mb/d in 2018 to 11.5 mb/d in 2024 (Figure 4.12). The modest emergence of tight crude will likely be off-set by slightly lower conventional crude output, while NGLs production is projected to rise by 0.1 mb/d.

Figure 4.12
Russia total liquids supply



Source: OPEC.

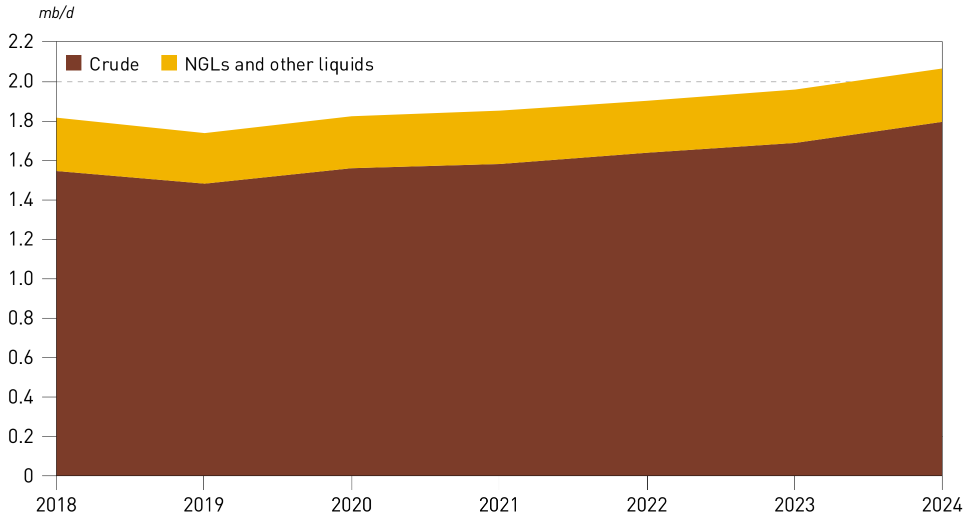
Against a very large and mature base, there are relatively few greenfield projects set to come online in this period. New projects starting up, or where ramp-up continues, include Kuyumbinskoye, Tagulskoye and Lodochnoye in Eastern Siberia, and Russkoye, Spilmana, Vinogradov and the Erginskiy cluster of fields in Western Siberia, the latter of which is expected to add 175 tb/d.

A key determinant for longer-term Russian supply will be how upstream and other taxes are applied. The implementation of a new tax, the so-called Excess Profit Tax, began this year on a trial group of fields with collective output of around 440 tb/d. A positive evaluation of this new tax might see it progressively extended to more fields, which, in addition to other incentives for remote, expensive or difficult-to-produce fields, could result in higher liquids production than projected in this outlook. The Russian government has spoken about the need to open new frontier areas, including tight oil, offshore production, and Arctic acreage – so far all largely untapped.

Kazakhstan

Kazakhstan is projected to see total liquids supply rise from 1.8 mb/d in 2018 to 2.1 mb/d in 2024 (Figure 4.13). Phase one of the giant Kashagan oil field has reached full capacity at around 370 tb/d, and its operator has spoken of the potential to add another 100 tb/d by debottlenecking.

Figure 4.13
Kazakhstan total liquids supply



Source: OPEC.

The other main source of medium-term growth will be the start-up of volumes from the Tengiz Future Growth Project. This will ultimately add another 260 tb/d to the existing field's 600+ tb/d capacity, starting from 2022. Further expansion of the country's three largest field complexes – Kashagan, Tengiz and Karachaganak, is less certain, and would take place beyond the medium-term horizon.

Others

Guyana, a small country in north-eastern South America, will join the club of oil producers with its first barrels from offshore fields expected in 2020. Development plans for a string of large discoveries there, initially around the Liza field, but now extending to other areas, have firmed up, and a timetable has been drafted for the start-up of large FPSOs. In its first phase, Liza is set to add 120 tb/d from 2020, followed by Liza 2 in 2022 (200 tb/d), and Liza 3 in 2024 (180 tb/d). Collectively, this means total oil production will rise from zero in 2018 to around 0.4 mb/d in 2024 and continue to rise thereafter.

A number of further discoveries have been made in the Stabroek block, including Snoek, Turbot, Ranger, Pacora and others, and operator ExxonMobil, in conjunction with partners Hess and China National Offshore Oil Corporation (CNOOC), is confident about bringing further large projects online in the coming years. This should result in Guyana becoming the fifth-largest source of non-OPEC supply growth in the medium-term, with potential for further upside revisions as projects receive the go-ahead.

The **UK** is expected to see total liquids production stay flat at 1.1 mb/d between 2018 and 2024, albeit briefly rising to 1.2 mb/d at points in the intervening years. Faced with the prospect of heavy decline rates, the UK government lowered taxes in the oil sector after prices fell in 2014/2015 to ensure that activity continued. This, combined with cost-saving efficiencies and project optimization, as well as the use of 'Big Data' techniques, has seen a number of projects in the UK offshore sector continue to move forward.

The further ramp-up at BP's Clair Ridge expansion in the West of Shetlands area has brought additional capacity online in 2019, while a clutch of other fields including the gas/condensate Culzean project, Lancaster, Cheviot and the Mariner heavy oil field will add more capacity, albeit offset by strong natural declines. Despite potentially promising reserves, this Outlook does not expect any shale gas or related liquids to be developed in the UK, as drilling faces strong popular resistance.

China is projected to see its liquids supply stay flat at 4.0 mb/d over the medium-term, albeit temporarily rising to 4.1 mb/d. Worried by several years of relatively steady decline from a peak of 4.4 mb/d in 2015, the government has ordered major state oil companies to increase their upstream investment. They have done so – reports estimate that the 'Big 3' consisting of China National Petroleum Corporation (CNPC), Sinopec and CNOOC will collectively raise their upstream capex by around 15%. As a result, this Outlook estimates that production declines will be halted, even though only a short-lived output rise is expected.

4.1.3 Non-OPEC supply growth by type

Crude oil (including tight crude) is expected to make up 6.8 mb/d, or around 70%, of the full 9.9 mb/d of incremental medium-term non-OPEC supply. NGLs (including unconventional gas liquids derived from shale gas) is estimated to contribute 1.8 mb/d, or nearly 20%. Other liquids are set to add 0.6 mb/d, or 6%, of which half is from Canadian oil sands. Biofuels and refinery processing gains are anticipated to account for the remainder. Around 80%, or 5.4 mb/d, of the headline crude number is due to higher tight crude supply.

Much of the growth is expected to come early in the forecast horizon, with non-OPEC supply projected to expand by an average of 2.3 mb/d in 2019/2020. This will be followed by slower average growth of around 1.3 mb/d in the latter years of the medium-term, as US tight oil growth decelerates and the bulk of large new upstream projects given the green light today come online.

In line with expectations for a rapid increase in tight crude oil supply, the bulk of new NGLs supply is projected to come from the shale sector. Stronger production of unconventional NGLs in the US accounts for more than 90% of the total growth in non-OPEC NGLs supply over the medium-term. Marginal increases in NGLs production are also expected in Russia, Qatar and Latin America.

4.1.4 Other liquids supply (excluding biofuels)

Non-OPEC other liquids supply, which comprises a variety of unconventional liquids including Canadian oil sands, GTLs, CTLs and others (but excludes biofuels), is projected to grow by over 0.6 mb/d in the medium-term, from 3.7 mb/d in 2018 to 4.4 mb/d in 2024. Half of this incremental supply is expected to stem from Canadian oil sands, which are set to expand by 0.3 mb/d in this period.

GTLs and CTLs supply is anticipated to grow by 0.1 mb/d and 0.2 mb/d, respectively, the former as new natural gas supply and related LNG trains come on-stream in Qatar, bringing with them more related liquids. Meanwhile, China is the dominant source of additional CTLs supply, with production expected to approximately double in the medium-term period to 0.2 mb/d in 2024.

4.1.5 Biofuels supply

Non-OPEC liquid biofuels supply is projected to grow from 2.5 mb/d in 2018 to 2.9 mb/d in 2024. Fuel ethanol, which makes up around 70% of total biofuels supply, is seen growing by 0.3 mb/d in the medium-term. Growth is spread among only a handful of countries that are already the largest producers of the fuel, including the US, Brazil and China.

Brazil and China essentially have policies in place that support further growth in domestic supply and blending. In mid-2019, the current US administration announced the year-round sale of E15, a gasoline blend with a 15% share of ethanol, in theory allowing for higher sales of the fuel. Previously, sales of E15 had been limited to summer months in order to prevent excessive evaporation.

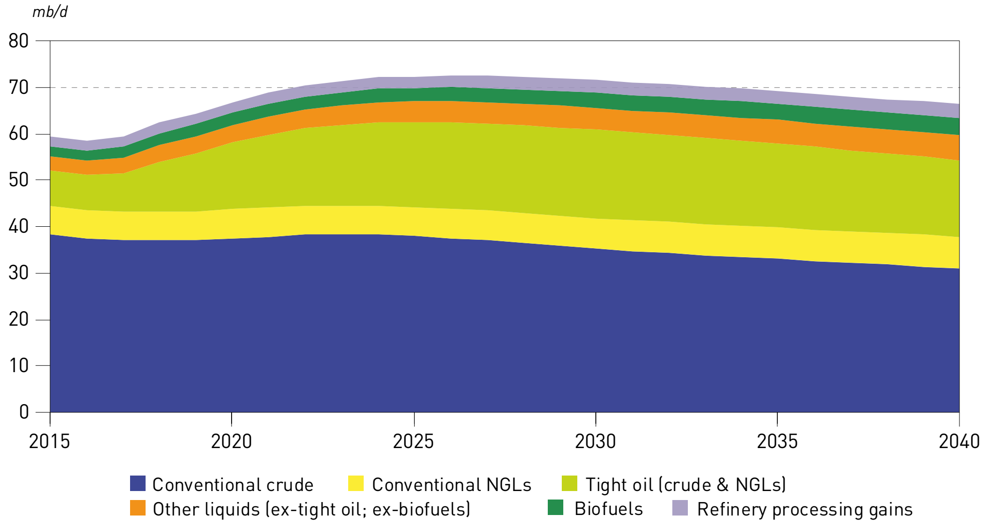
4.2 Long-term outlook for liquids supply by region and type

Beyond the medium-term horizon of 2024, non-OPEC supply in aggregate is only forecast to grow for another two years, before peaking at 72.6 mb/d in 2026 (Figure 4.14). To a large extent this is due to US supply peaking at around the same time, at 22.8 mb/d in the 2024–2026 period. Thereafter, other sources of non-OPEC supply growth are even more limited, with just four countries providing increments of 0.5 mb/d or more. These include Qatar, where supply is expected to increase by 0.7 mb/d, and Brazil, Canada and Kazakhstan, each with growth of 0.5 mb/d in the 2024–2040 period (Figures 4.15 and 4.16).

Meanwhile, other countries expected to provide incremental barrels in the medium-term are also projected to see production peak and decline post-2024. Besides the US, these include Norway, China, the UK and Russia, as well as some other smaller producers.

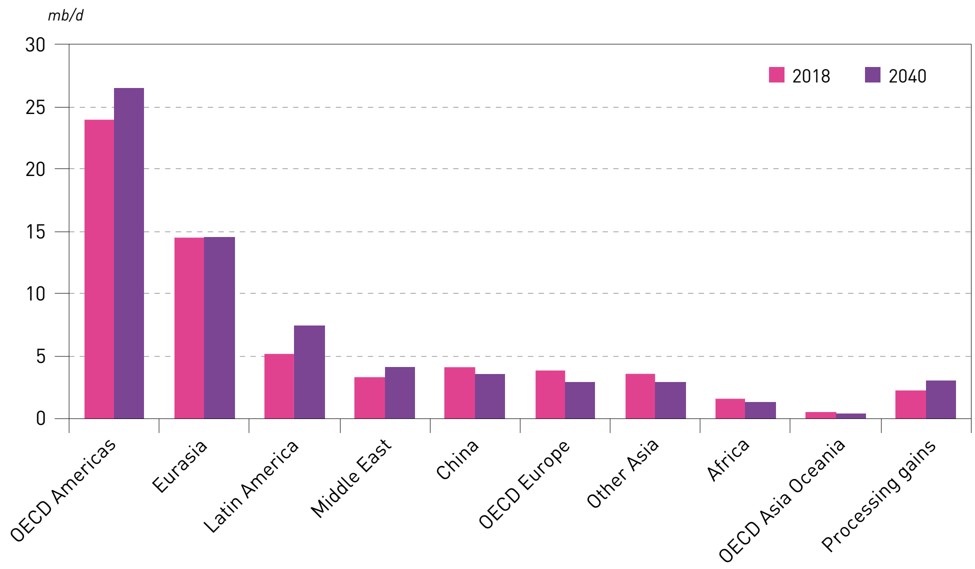
However, the picture is slightly different when considering non-OPEC supply growth over the entire 2018–2040 period. Including the growth prospects within the initial medium-term period, this results in non-OPEC supply growth being led by Brazil, with 1.9 mb/d, followed by the US, with 1.8 mb/d, Canada and Qatar, with incremental supply of 0.9 mb/d each, and lastly, Kazakhstan and Guyana, with supply higher by 0.8 mb/d and 0.5 mb/d, respectively. Meanwhile, output declines are most evident in Norway (–0.5 mb/d), Russia, China, the UK and Colombia (each –0.4 mb/d) in the long-term.

Figure 4.14
Long-term non-OPEC liquids supply outlook by type, 2015–2040



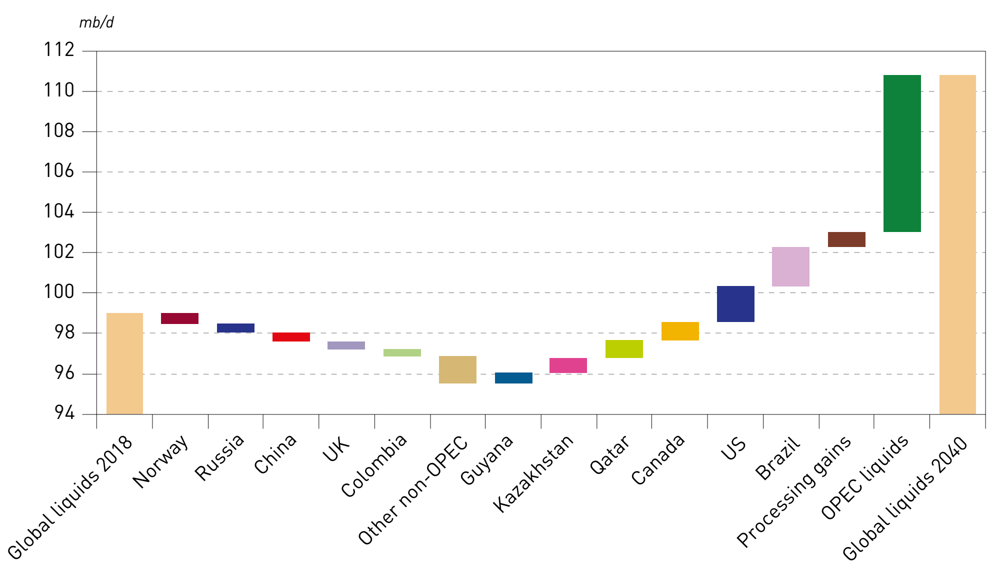
Source: OPEC.

Figure 4.15
Long-term non-OPEC liquids supply outlook by region, 2018–2040



Source: OPEC.

Figure 4.16
Composition of long-term global liquids supply growth, 2018–2040



Source: OPEC.

4.2.1 Long-term outlook for crude

In terms of types of liquids, the long-term non-OPEC supply growth picture is quite different from the medium-term. Total crude oil, including tight crude, is actually seen declining by 3.0 mb/d between 2018 and 2040 (Table 4.3), even though US tight crude production is set to increase by 1.9 mb/d. With the exceptions of Brazil, which will grow a healthy 1.5 mb/d; Kazakhstan, with

Table 4.3
Long-term global liquids supply outlook by region

mb/d

	2018	2019	2020	2025	2030	2035	2040	Change 2018–2040
US	16.7	18.6	20.3	22.8	22.2	20.5	18.5	1.8
of which: tight oil	*10.2*	*12.0*	*13.8*	*17.0*	*17.3*	*16.3*	*14.5*	*4.4*
Canada	5.2	5.2	5.3	5.7	5.9	6.1	6.1	0.9
of which: oil sands	*2.9*	*2.9*	*3.0*	*3.3*	*3.5*	*3.7*	*3.9*	*1.0*
Mexico & Chile	2.1	1.9	1.8	2.0	1.9	1.9	1.9	–0.2
OECD Europe	3.8	3.8	3.9	4.3	3.7	3.3	2.9	–0.9
OECD Asia Oceania	0.4	0.5	0.5	0.5	0.4	0.3	0.3	–0.1
OECD	**28.2**	**30.0**	**31.9**	**35.3**	**34.1**	**32.1**	**29.7**	**1.4**
Latin America	5.2	5.4	5.8	7.2	7.6	7.7	7.5	2.3
Middle East	3.2	3.2	3.2	3.6	4.0	4.1	4.1	0.9
Africa	1.5	1.6	1.6	1.7	1.5	1.4	1.3	–0.2
China	4.0	4.1	4.1	4.0	3.9	3.7	3.6	–0.4
Other Asia	3.6	3.5	3.5	3.4	3.3	3.1	2.9	–0.7
Russia	11.3	11.4	11.5	11.4	11.1	11.0	10.9	–0.4
Other Eurasia	3.1	3.0	3.0	3.4	3.4	3.5	3.6	0.5
Non–OECD, excl. OPEC	**31.9**	**32.2**	**32.7**	**34.6**	**34.8**	**34.4**	**33.8**	**1.9**
Processing gains	**2.3**	**2.3**	**2.4**	**2.5**	**2.7**	**2.8**	**3.0**	**0.7**
Non-OPEC	**62.4**	**64.4**	**66.9**	**72.4**	**71.5**	**69.3**	**66.4**	**4.0**
Crude	44.0	45.5	47.2	50.6	48.0	44.7	41.0	–3.0
of which: tight crude	*7.0*	*8.3*	*9.7*	*12.6*	*12.7*	*11.6*	*10.0*	*3.0*
NGLs	9.9	10.4	10.9	11.9	12.8	13.2	13.3	3.4
of which: unconventional NGLs	*3.7*	*4.2*	*4.7*	*5.7*	*6.3*	*6.6*	*6.5*	*2.8*
Global biofuels	2.5	2.5	2.6	2.9	3.3	3.5	3.8	1.3
of which: fuel ethanol	*1.8*	*1.9*	*1.9*	*2.1*	*2.3*	*2.4*	*2.5*	*0.7*
of which: biodiesel	*0.7*	*0.7*	*0.7*	*0.9*	*1.0*	*1.1*	*1.3*	*0.6*
Other liquids	3.7	3.7	3.8	4.4	4.8	5.1	5.3	1.6
of which: GTLs	*0.2*	*0.2*	*0.2*	*0.4*	*0.4*	*0.5*	*0.5*	*0.3*
of which: CTLs	*0.3*	*0.3*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.4*
of which: others incl. Canadian oil sands	*3.3*	*3.3*	*3.3*	*3.6*	*3.8*	*4.0*	*4.2*	*0.9*
Total OPEC liquids	**36.6**	**35.0**	**34.4**	**33.4**	**37.0**	**40.8**	**44.4**	**7.8**
Stock change*	**0.3**	**–0.5**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	
World	**99.0**	**99.4**	**101.3**	**105.8**	**108.5**	**110.2**	**110.8**	**11.8**

* *Stock change assumptions reflect commercial stock inventories, development of Strategic Petroleum Reserves (SPR), and the rising need for stocks as refinery capacity expands.*

Source: OPEC.

production higher by 0.7 mb/d; and Guyana, at 0.5 mb/d, virtually all other non-OPEC countries are expected to see their crude oil output decline. All three countries witnessing increases will benefit from significant new resources being developed.

Expected crude oil output declines are most pronounced in China (–1.0 mb/d), Russia (–0.7 mb/d), Norway, Colombia, the UK and Indonesia (each –0.4 mb/d) and Mexico and India (each –0.3 mb/d).

4.2.2 Long-term outlook for other liquids supply (incl. NGLs, biofuels, GTLs, CTLs and other)

In contrast to the picture painted for crude oil, the other sources of liquids supply, including NGLs, biofuels and other liquids, are all projected to experience long-term growth. NGLs are expected to grow by 3.4 mb/d between 2018 and 2040, largely driven by unconventional NGLs from shale plays. In turn, most of this is seen stemming from the US, where natural gas production is projected to rise steadily as associated gas grows, in part as a result of tight oil development, and in part due to strong demand from the petrochemicals sector and LNG export terminals. Other long-term sources of NGLs supply growth include Qatar (0.6 mb/d) and Russia (0.2 mb/d).

4.3 Global outlook for tight oil supply

4.3.1 Tight oil developments in the US

The US tight oil sector has continued to defy expectations, with supply having risen by an unprecedented 2.2 mb/d in 2018. Tight crude accounted for 1.6 mb/d of that and unconventional NGLs another 0.6 mb/d. Meanwhile, the medium-term outlook for US tight oil production has been revised upwards, in part due to a sizeable baseline adjustment of more than 1 mb/d for 2018 and a higher short-term outlook for 2019–2020, as well as due to stronger projected growth potential. Combined, US tight crude and unconventional NGLs production is seen growing by 6.7 mb/d, from 10.2 mb/d in 2018 to 16.9 mb/d in 2024. Of this, 4.9 mb/d is tight crude, and 1.8 mb/d is unconventional NGLs output (Table 4.4).

Table 4.4
US tight oil supply outlook

mb/d

	2018	2019	2020	2021	2022	2023	2024	Change 2018–2024
US tight crude	6.6	7.9	9.2	10.4	11.0	11.4	11.5	4.9
US unconventional NGLs	3.6	4.1	4.6	4.7	4.9	5.2	5.4	1.8
US total tight oil	**10.2**	**12.0**	**13.8**	**15.1**	**16.0**	**16.5**	**16.9**	**6.7**

Source: OPEC.

This pronounced increase, however, masks the fact that medium-term annual growth is projected to slow for a variety of reasons. Much has already been written about pressure to maintain capital discipline leading to lower investment from independent producers, and this continues to be the case. Moreover, parent-child well interference, as drilling is more and more concentrated in the same acreage; infrastructure constraints preventing more oil (and gas) from reaching refineries or export hubs; and a declining, or at best flat, rig count, are expected to play a role.

It should also be noted that in this drilling-intensive sector, where well output declines rapidly, record-high production and growth result in even-higher incremental volumes being needed just to maintain production, let alone for continued growth. All of these factors lend support to a more critical view of US tight oil production and its potential for further growth at the rapid pace observed in 2018.

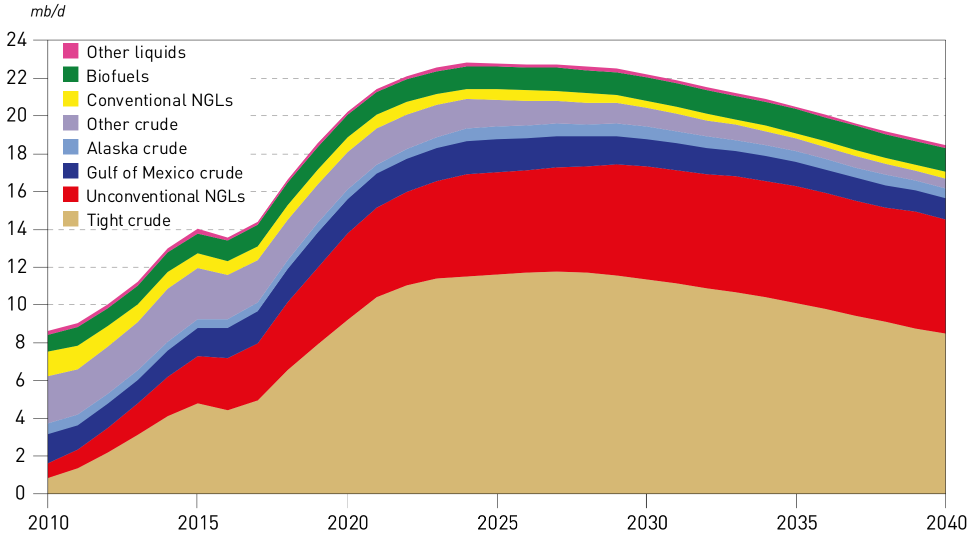
At the same time, despite all of these factors, production figures have continued to rise, as efficiency gains in drilling and completion eke out more production per well while reducing costs. It has meant that breakeven levels have continued to decline and output continues to rise despite a flat-to-declining rig count. Infrastructure constraints, especially in the Permian Basin straddling the Texas/New Mexico border, have not proven to be a major bottleneck when measured against production growth in the past year. In any case, pipeline constraints should be resolved by the end of 2019, according to most estimates.

Moreover, oil majors' belated interest in the tight oil sector, ExxonMobil and Chevron's much-touted growth ambitions, and the recent bidding war for independent Anadarko, suggest that a phase of consolidation may be starting. This would be expected to bring further efficiency gains as activity becomes more like mass production in other industrial sectors. Increasingly large, contiguous acreage allows for more strategic, integrated planning of how to develop resources, something the largest oil companies excel in.

Majors can also rely upon their balance sheets to finance development, thus enabling them to take a longer-term view on growth. Moreover, they have the opportunity to vertically integrate their tight oil production with their refining, petrochemicals and export capacities, thus becoming less price-sensitive. Lastly, with the resource base being constantly revised up from the already large estimates, the prospect of further growth and a lengthy plateau phase in US tight oil production remains a possible outcome.

As a result, US tight oil is projected to continue growing modestly in the latter half of the 2020s, cumulatively rising by another 0.5 mb/d until 2029, when supply is projected to peak at 17.4 mb/d, or around three-quarters of total US liquids production. Tight crude is expected to peak slightly earlier, at 11.8 mb/d, in 2027, while US unconventional NGLs supply is expected to continue to grow to reach a plateau of around 6.2 mb/d in the mid-2030s (Figure 4.17).

Figure 4.17
US total liquids supply outlook over the long-term

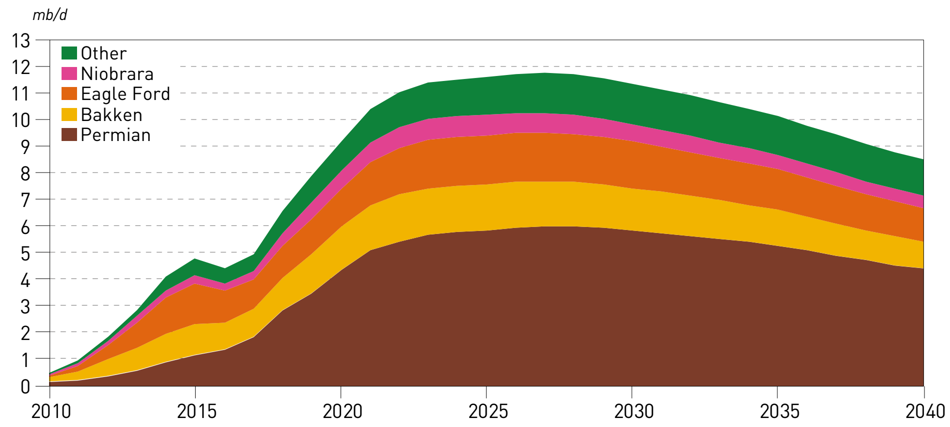


Source: OPEC.

US tight crude oil production by basin

Looking at major producing areas, the Permian Basin will remain by far the most prolific and will continue to see the strongest growth (Figure 4.18). Tight crude production in the Permian is projected to rise from 2.8 mb/d in 2018 to a peak of 6.0 mb/d in 2027/28, thus making up around half of the overall growth in tight crude. The Bakken and Eagle Ford Basins are expected to grow roughly in tandem, each rising to a plateau of 1.8 mb/d in the mid-2020s. Niobrara and other producing regions will see more modest medium-term growth.

Figure 4.18
US tight crude supply outlook by major basin

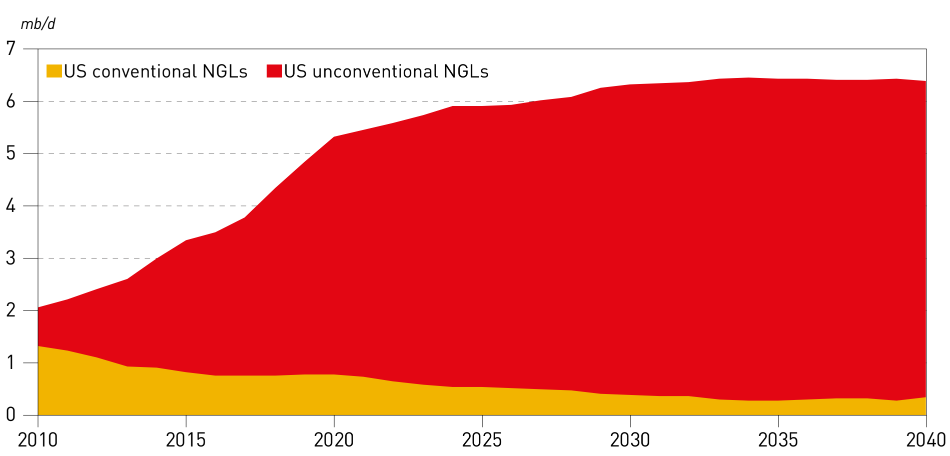


Source: OPEC.

US unconventional NGLs

Unconventional NGLs output is forecast to see steady growth, rising from levels of 3.6 mb/d in 2018 to 5.4 mb/d in 2024, and to a peak of 6.2 mb/d in the early 2030s. This growth is mainly associated with rising natural gas production, especially from shale plays, but also from associated gas (Figure 4.19).

Figure 4.19
US NGLs supply outlook by type



Source: OPEC.

4.3.2 Tight oil developments outside of the US

Outside the US, tight oil production remains relatively modest, except in Canada, where output is expected to rise from 0.4 mb/d in 2018 to 0.8 mb/d by the early 2030s (Table 4.5). Canada is the first country outside the US to see large-scale development of tight oil resources, which already account for nearly 10% of total Canadian liquids output. The Duvernay and Montney formations in Alberta and British Columbia could rival the most prolific US tight oil fields.

Argentina, owner of the potentially very prolific Vaca Muerta formation in Neuquén province, is projected to see tight oil production rise from 0.1 mb/d in 2018 to around 0.4 mb/d by 2030, and to 0.6 mb/d in the long-term. There is also significant upside potential as a wider field of companies shows investment interest. The Vaca Muerta play in the Neuquén Basin is almost triple the size of the highly prolific Permian Basin and one of the largest deposits in the world.

Table 4.5
Global long-term tight oil supply outlook *mb/d*

	2018	2019	2020	2025	2030	2035	2040	Change 2018–2040
US	10.2	12.0	13.8	17.0	17.3	16.3	14.5	4.4
Canada	0.4	0.5	0.5	0.7	0.8	0.7	0.7	0.3
Russia	0.0	0.0	0.0	0.3	0.4	0.4	0.5	0.5
Argentina	0.1	0.1	0.1	0.3	0.4	0.5	0.6	0.5
Bahrain	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
China	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Total	**10.7**	**12.5**	**14.4**	**18.3**	**19.0**	**18.2**	**16.5**	**5.8**

Source: OPEC.

Russia sees total tight liquids rising from virtually nothing today to 0.2 mb/d in the medium-term, mostly from the Bazhenov formation, and then to 0.5 mb/d in the long-term. Although it has many other prospects such as the Abalak, Khadum and Domanik Suites, Western Siberia's Bazhenov is poised to drive growth due to well established infrastructure. However, sectoral sanctions are limiting necessary technology required to develop tight oil projects.

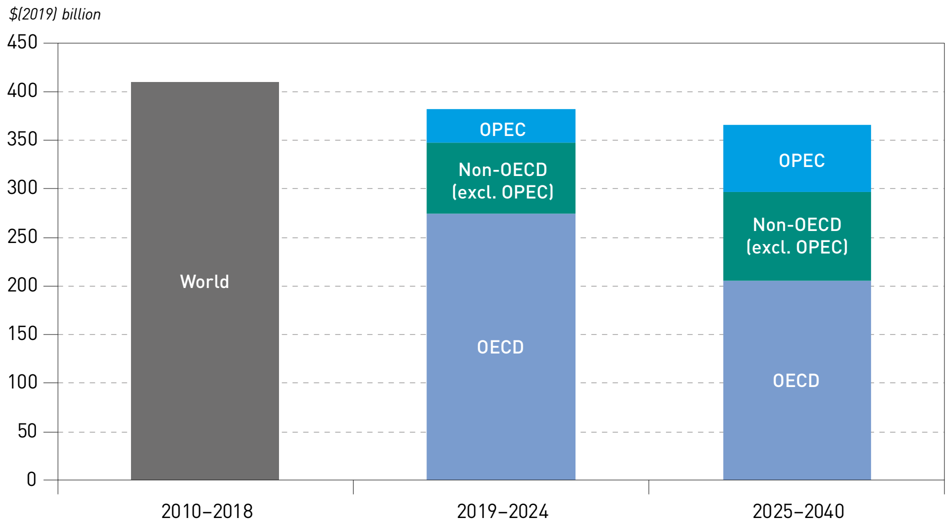
Bahrain and **China** meanwhile, despite having a lot of potential, are only expected to see relatively modest production levels of around 0.1 mb/d respectively by the 2030s. China ranks third in the world in terms of technically recoverable tight oil resources, trailing behind Russia and the US. The country's four western major basins are projected to lead growth in tight oil production. Development is forecast for marginal growth due to difficult geology within these basins.

4.4 Upstream investment requirements

In the medium- and long-term, upstream investment will need to be sustained to ensure steady production growth to meet projected demand increases, as well as to offset natural decline in oil fields. On average, requirements are projected to be $382 billion p.a. in the medium-term period, and a slightly lower $366 billion p.a. for 2025–2040 (Figure 4.20).

The breakdown of these investment requirements by major region indicates that OECD countries will be called on to make the lion's share of investments, around 72%, in the medium-term period, reduced slightly to an average 56% in the latter years. This is due to the larger volumetric contribution of barrels, especially in the medium-term, as well as higher average costs of upstream development. By contrast, OPEC's implied annual investment requirements share will be quite low at 9% in 2019–2024, rising to 19% in the longer-term as demand for OPEC crude

Figure 4.20
Annual upstream investment requirements



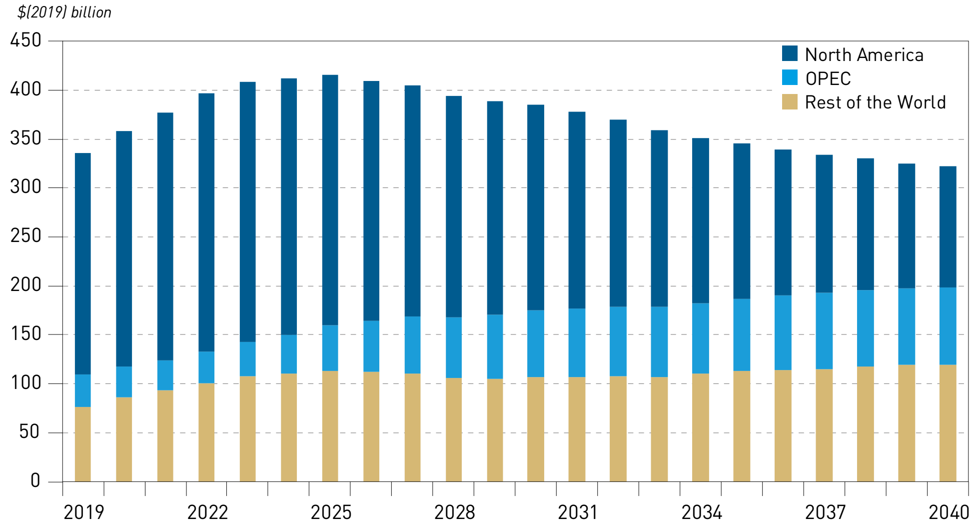
Source: OPEC.

rises. Non-OECD countries' share, excluding OPEC, is projected to average 19% in the medium-term, rising to 25% in 2025–2040.

The OECD's relatively large share is in turn due to North America's significant contribution to adding barrels, stemming from US tight oil and, to a lesser extent, from Canadian oil sands (Figure 4.21). The high average cost of developing certain North American upstream assets also plays a role, notably for deepwater in the US and unconventional production in Canada.

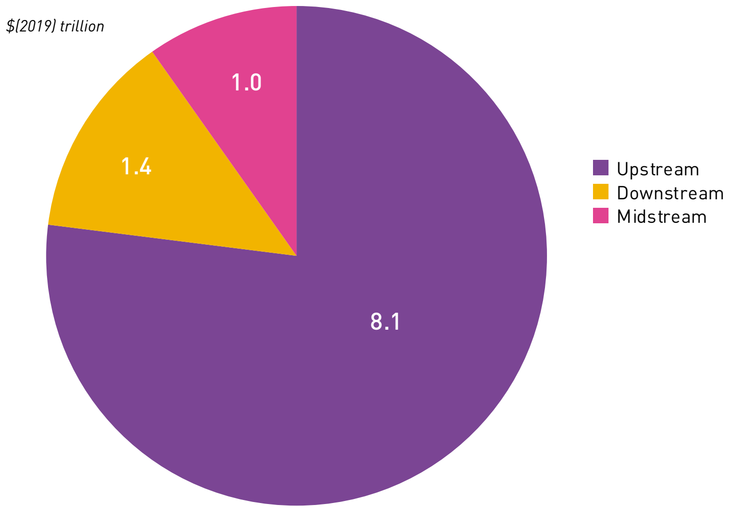
Cumulatively, the projected global total upstream investments required to sustain production according to this publication's outlook are expected to sum up to $8.1 trillion (in 2019 dollars). In addition, around or slightly above $1.4 trillion will be required in the global downstream sector (more details provided in Chapter 5), as well as another $1 trillion in the global midstream sector. Combined, this indicates that nearly $10.6 trillion of investment will be needed globally over the long-term in order to sustain projected oil supply needs (Figure 4.22). This will require a supportive price environment, as well as the necessary regulatory and fiscal framework to facilitate this investment.

Figure 4.21
Annual upstream investment requirements by major region, 2019–2040



Source: OPEC.

Figure 4.22
Cumulative oil-related investment requirements by sector, 2019–2040



Source: OPEC.

Refining outlook

Key takeaways

- The medium-term outlook projects crude distillation capacity additions of 7.95 mb/d between 2019 and 2024, with over 70% of the additions in the Asia-Pacific (4 mb/d) and the Middle East (1.7 mb/d).

- Almost 70% of the additions are projected to occur in the first three years of the outlook, with a significant drop in additions in the latter years of the medium-term.

- The potential for incremental crude runs based on refinery additions are estimated at 7.7 mb/d by 2024. This is almost 4 mb/d higher relative to incremental refinery product demand, highlighting a significant build-up of excess capacity.

- The largest surplus is expected for the Middle East, followed by the US & Canada, China and Europe. While refineries in the Middle East and the US & Canada are likely to increase product exports, refineries in Europe could come under pressure in the medium-term. The only region that shows a capacity deficit in the medium-term is Latin America, indicating the possibility for increasing product imports.

- Total primary refining capacity (including condensate splitters) additions between 2019 and 2040 are projected at 16.5 mb/d, mostly in developing regions. Following oil demand growth trends, the average addition rate is projected to slow significantly in the long-term, to less than 0.5 mb/d p.a. between 2035 and 2040, down from an average of almost 1.9 mb/d in 2019 and 2020.

- Total refinery closures of 2.1 mb/d are estimated for the period 2019–2025, mostly in Europe and the US & Canada. However, further closures, around 5 mb/d, will be required in the long-term due to projected declining refinery utilization rates, mostly in developed regions.

- In the long-term, 8.8 mb/d of new conversion unit capacity, 18 mb/d of desulphurization and 5.2 mb/d of new octane unit capacity is projected to come online.

- Investment in the three downstream categories is estimated at $1.4 trillion in the period 2019–2040; $275 billion for known medium-term projects, $230 billion for additions in the long-term and $890 billion for maintenance and replacement.

- Despite rising optimism about the implementation of the 2020 IMO Sulphur Rule, next year's fuel switch continues to be a major refining sector challenge. This is particularly focused on the fuel mix in the bunker sector and the resulting impact on crude price spreads and product differentials.

- Given the long-term slowdown in required refining capacity, it will become increasingly difficult to justify building large new refineries. The period after 2030 could see capacity additions coming primarily from debottlenecking and the upgrading of existing facilities instead of building new plants.

This Chapter takes the oil supply and demand projections in this Outlook and examines how various factors could impact the global refining sector over the medium- and longer-term . It first presents an assessment of current 'base' capacity, projects, announced and further anticipated closures. These three factors combined lead to the assessed net available capacity by year from 2019–2024, the period covered in the review of medium-term developments.

It then compares the potential product output from projected capacity additions by year from 2019–2024 with the incremental 'call on refining' each year as driven by product demand growth, in order to assess the balance between incremental refining potential and incremental refining required. To arrive at the net 'call on refining', the analysis takes into account non-crude supply – that is, NGLs, GTLs/CTLs and biofuels. Increases in these supply streams reduce the level of incremental refined products needed. The resulting global and regional balances are then presented and reviewed.

The Chapter also presents the long-term outlook based on modelling cases from 2024–2040. Compared to the medium-term assessment, this represents a somewhat different approach. In the long-term modelling, required capacity is added by region to accommodate supply and demand changes (including crude and product quality), while also allowing for options to change crude and product trading patterns between regions.

The medium- and long-term outlooks for secondary capacity are also assessed. The main emphasis is on conversion, desulphurization and octane units. The focus for the medium-term assessment (2019–2024) is on directly comparing secondary process unit capacity additions and potential yields, hence the potential for incremental supply by product at the regional level, with regional incremental demand by product. The long-term assessment also emphasizes secondary unit additions and investments needed to meet incremental demand, taking into account product quality requirements given changes in the crude slate and non-crude supply, as well as the potential for shifting trade patterns between regions. This analysis serves to provide an outlook for the global downstream and its 'strategic parameters' through 2040, discussing what factors could affect and alter the outlook.

5.1 Existing refinery capacity

5.1.1 Overview

This section provides a detailed update to base capacity assessments (distillation and secondary capacity, including condensate splitters) by refinery worldwide. It includes additions to existing refineries, new refineries that came onstream, as well as closures that occurred in 2018. Given the complexities and challenges in assessing base capacity, a 1 mb/d variation between this Outlook and the WOO 2018 is not surprising, indeed it should be viewed as encouraging. The OPEC methodology embodies a relatively conservative approach reflecting that it takes time for a major new project to fully ramp-up.

The OPEC Secretariat's approach is that, unless officially closed, refineries are included in the database of 'nameplate' capacity, though their effective capacity may be identified as being well below the nameplate level where appropriate. Overall, it should be stated that no single data source for refinery capacity can be relied upon entirely. The quality and availability of capacity reporting varies by refinery so there is always an element of arriving at a 'best estimate' for base capacity, as well for new projects and closures.

5.1.2 Refinery capacity in 2019

Primary capacity

Table 5.1 provides detail by region and process on the 100.0 mb/d of assessed base refinery capacity in 2019. Today's refineries are increasingly complex with expanding secondary

Table 5.1
Assessed available base capacity as of January 2019

mb/d

	US & Canada	Latin America	Africa	Europe	Russia & Caspian	Middle East	China	Other Asia-Pacific	World
Distillation									
Crude oil (atmospheric)	20.7	7.8	3.7	16.1	7.2	9.5	16.1	18.9	100.0
Vacuum	9.4	3.4	1.0	6.6	3.0	2.8	6.3	5.7	38.3
Upgrading									
Coking	2.8	0.8	0.1	0.7	0.5	0.4	2.1	1.1	8.6
Catalytic cracking	5.9	1.6	0.2	2.3	0.8	1.0	3.5	3.2	18.6
Hydro cracking	2.4	0.2	0.1	2.1	0.6	0.9	1.8	1.6	9.7
Visbreaking	0.1	0.3	0.2	1.6	0.6	0.6	0.2	0.5	4.1
Solvent deasphalting	0.4	0.1	0.0	0.2	0.0	0.2	0.1	0.2	1.1
Gasoline									
Reforming	4.0	0.6	0.5	2.5	0.9	1.1	1.4	2.6	13.7
Isomerization	0.8	0.1	0.1	0.6	0.3	0.4	0.2	0.2	2.8
Alkylation	1.3	0.2	0.0	0.2	0.0	0.1	0.1	0.3	2.3
Polymerization	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
MTBE/ETBE	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.3
Desulphurization									
Naphtha	4.8	0.8	0.6	3.2	1.1	1.8	1.4	3.1	16.7
Gasoline	3.0	0.5	0.1	0.7	0.2	0.4	0.9	1.1	6.8
Middle distillates	6.8	2.1	0.8	5.8	2.1	2.6	3.6	6.1	29.8
Heavy oil/Residual fuel	2.9	0.4	0.0	1.8	0.2	0.6	0.6	2.7	9.3
Sulphur (short tons/day)	43,382	7,108	3,604	19,645	6,526	12,870	13,967	30,387	137,488
Hydrogen (million scf/d)	6,674	1,204	327	4,770	1,199	3,077	4,714	5,315	27,280

Source: OPEC.

processing capacity per barrel of primary distillation capacity. This global trend is the result of a combination of the tendency to close older, simpler refineries, progressively add secondary processing at existing plants and generally build new refineries at a high-level of complexity from the outset.

The underlying drivers of this are the long-term shift toward incremental demand predominantly for light clean products, an associated gradual decline in the demand for residual fuel oil and increasingly stringent regulations on fuel quality. Together, these call for higher levels of upgrading, desulphurization, octane and related supporting capacity, including hydrogen and sulphur recovery. As a result, global vacuum distillation capacity currently stands at an average 38.3% of crude (atmospheric) distillation capacity, upgrading at 42%, gasoline octane units at 19.1% and desulphurization at 62.6%. A review of data from previous years confirms these ratios reflect a steady increase over time.

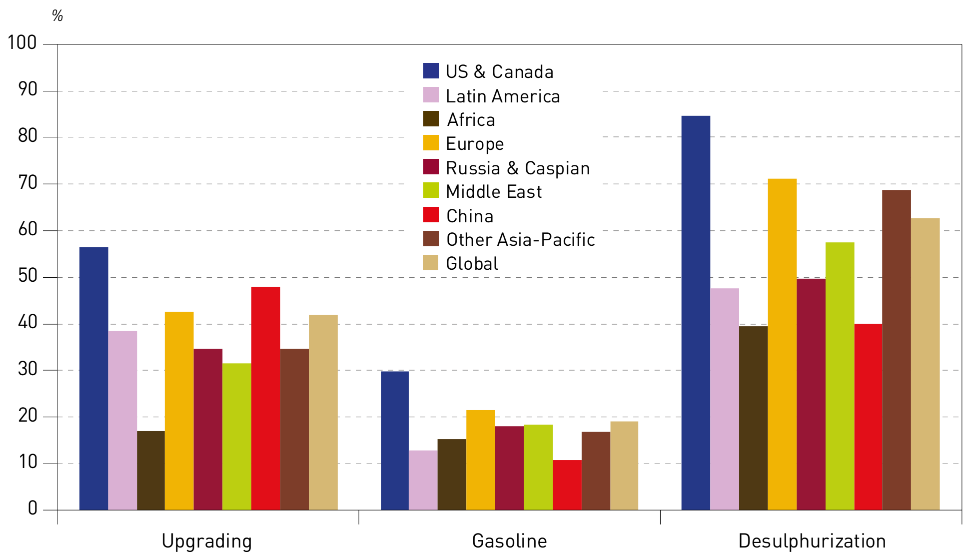
As Table 5.1 illustrates, regional capacity differences are large, but also shifting. Global refining distillation capacity was estimated at 100.0 mb/d as of 1 January 2019. Of this, the US

& Canada and Europe still comprise significant proportions, respectively at 20.7 mb/d and 16.1 mb/d of capacity, which is 20.7% and 16.1% of the global total. In Europe, a rationalization has entailed a reduction in both the total number of active refineries and total operating capacity. In contrast, in the US & Canada, total capacity has edged up in recent years, supported by increasing domestic oil supply, even though an ongoing rationalization has reduced the total number of active refineries. US capacity increased by 1 mb/d from 2000–2009 and a further 1 mb/d since 2009.

Secondary capacity

Figure 5.1 summarizes the data from Table 5.1 as percentages of crude distillation capacity. The table highlights the variations in refinery configurations from region-to-region. On the three measures of upgrading, gasoline and desulphurization relative to distillation, the US & Canada region represents the high extreme. That said, what has become evident is that several other regions now have secondary capacity at levels that are not far below those seen in the US & Canada.

Figure 5.1
Secondary capacity relative to distillation capacity, January 2019



Source: OPEC.

For upgrading, the US & Canada is at 56.5% of distillation capacity, but the other regions of the world range from 31.6% to 48%, apart from Africa at 17%. For gasoline units, the US & Canada is the outlier at 29.8% of distillation capacity because of the region's exceptionally high gasoline consumption. Other regions have 13–18%, with the exception of Europe at 21.5%, despite the recent dieselization trend in the refining sector.

Desulphurization levels vary widely, with the US & Canada at 86%, which is more than double the lowest regions of Africa and China, both at 40%. Europe and Other Asia-Pacific are each around 70% and the Middle East is at 57.5%. In Europe, as is the case in the US & Canada, the high ratio reflects the long-established implementation of ultra-low sulphur (ULS) fuel standards, while in the Other Asia-Pacific and the Middle East, the high/rising levels reflect a situation where large new refineries are invariably built for high levels of clean fuel output, generally to ULS standards. The same trend is now also underway in China.

Within the upgrading category, the distribution by type of unit varies significantly. The US & Canada, Latin America and China account for the highest levels of coking and catalytic cracking; the US & Canada, Europe and China have the highest levels of hydrocracking; and Europe, Russia & Caspian and the Middle East have the highest proportions of mild upgrading, notably visbreaking capacity.

As would be expected, the regions with the highest levels of desulphurization relative to crude capacity also have the highest levels of sulphur recovery and hydrogen capacity.

5.2 Distillation capacity

5.2.1 Overview of additions and trends

This year's medium-term outlook projects significant distillation capacity additions of 7.95 mb/d coming online between 2019 and 2024. However, the distribution and pace of the additions are clearly influenced by regional oil demand patterns. The recent trend of refinery capacity migrating to developing regions is expected to continue in the coming years. This is why the majority of the new capacity additions will be added in the Asia-Pacific and the Middle East, similar to projections in previous outlooks.

While the average annual capacity additions are seen at around 1.3 mb/d (considered a 'typical' addition rate) in the period 2019–2024, almost 70% of the additions are projected to occur in the first three years of the outlook (Figure 5.2). This is based on projected commissioning dates of several large projects in the Asia-Pacific, the Middle East, as well as in Africa. It means the average annual addition rate is estimated at around 1.8 mb/d in the period 2019–2021. This is a significantly higher expansion rate than in the 2015–2018 period. Significant oil demand increases in the years since 2015, combined with a focus on high-growth petrochemicals and adaptation to the 2020 IMO Sulphur Rule, have provided increasing optimism for new refinery projects scheduled between 2019 and 2021.

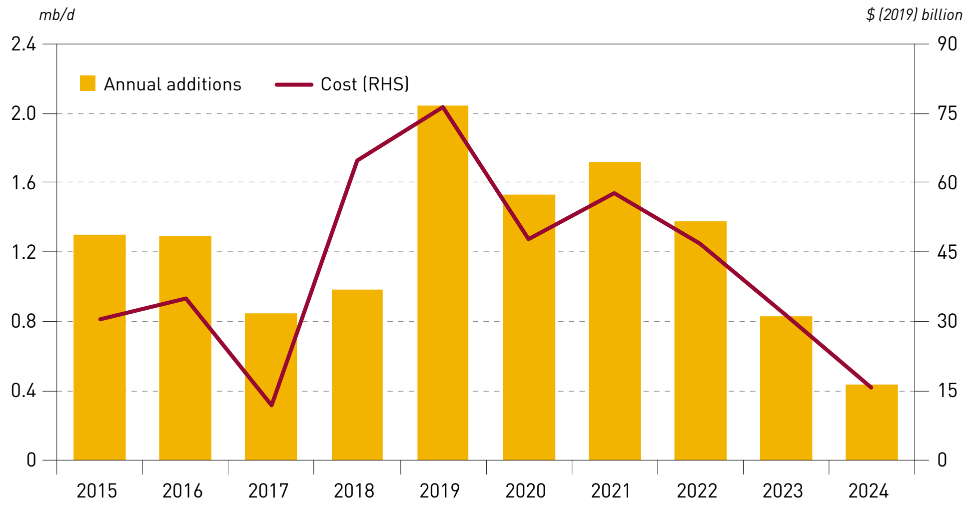
However, the rate of capacity additions is expected to level off in the years after 2021 and decline to only 0.4 mb/d in the last year of the medium-term outlook. Increasing uncertainty and the rising likelihood of heavier competition in the refining sector in the post-2020 period could be the reasons for lower additions towards the end of the medium-term.

With incremental refining capacity of almost 8 mb/d in the medium-term, this outlook is slightly higher relative to the WOO 2018 projection, which was at 7.8 mb/d. This illustrates the gradual recovery in estimates for the medium-term on a rolling basis. For instance, estimated capacity additions in the WOO 2015 for the period 2015–2020 were as low as 7.1 mb/d, reflecting the oil price drop of 2014.

Figure 5.2 shows the annual capacity additions expected to come online for 2019–2024, not accounting for assumed closures in this period. It should be noted that minor additions at existing refineries aiming at debottlenecking are not considered in the projections outlined in this section. Both major and minor additions are analyzed and discussed in further sections later in this chapter.

Table 5.2 and Figure 5.3 show the projected refinery capacity expansions by region and by year. As already described, the majority of the expansions are in the **Asia-Pacific** and the **Middle East**, driven predominantly by oil demand growth, but also efforts to increase refined product exports (mostly the Middle East). The medium-term outlook sees a total increment for the Middle East and Asia-Pacific of around 5.7 mb/d, which is more than 70% of the global additions. Significant additions (0.8 mb/d) are also expected in **Africa**, with essentially one large project in Nigeria accounting for the largest share of the increment.

Figure 5.2
Annual distillation capacity additions & total project investment



Source: OPEC.

Table 5.2
Distillation capacity additions from existing projects by region
mb/d

	2019	2020	2021	2022	2023	2024	2019–2024	%
US & Canada	0.1	0.1	0.1	0.2	0.0	0.0	0.5	*6.4*
Latin America	0.0	0.0	0.0	0.0	0.0	0.0	0.1	*1.4*
Africa	0.0	0.0	0.5	0.2	0.1	0.0	0.8	*10.3*
Europe	0.2	0.0	0.0	0.0	0.0	0.0	0.3	*3.5*
Russia & Caspian	0.2	0.2	0.1	0.0	0.0	0.0	0.5	*6.6*
Middle East	0.4	0.2	0.7	0.2	0.1	0.0	1.7	*21.8*
China	0.8	0.4	0.1	0.4	0.2	0.2	2.1	*26.8*
Other Asia-Pacific	0.2	0.6	0.3	0.3	0.3	0.2	1.8	*23.2*
World	**2.0**	**1.5**	**1.7**	**1.4**	**0.8**	**0.4**	**7.9**	*100.0*

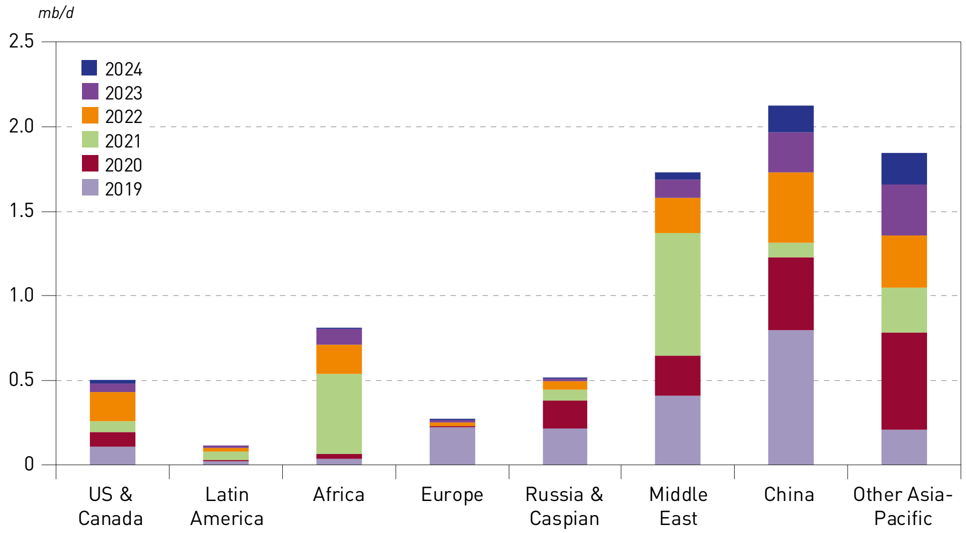
Source: OPEC.

At the same time, developed regions such as **US & Canada** and **Europe** are set to see only limited medium-term refinery capacity grassroots expansions with the focus primarily on the debottlenecking of existing refineries. The two regions are estimated to see additions of 0.8 mb/d in the medium-term. In the **Russia & Caspian** region, efforts focused on mostly refurbishing and debottlenecking existing capacity lead to an expected expansion of around 0.5 mb/d by 2024. Finally, projected medium-term expansions in **Latin America** remain limited at only 0.1 mb/d.

As emphasized in previous outlooks, a degree of caution is required when analyzing capacity additions, even for known refining projects. The tendency is for refinery projects to 'slip', due to various reasons, including delays in financing or technical difficulties. This is why the project evaluation process undertaken annually entails a 'risking' of both the probability of, and the timeframe for, completion. Overall, 7.95 mb/d of refining capacity is considered 'firm' within the 2019–2024 timeframe, which compares to the much higher volume of announced projects of around 24 mb/d.

A further caveat to this projection, one which was also raised in previous outlooks, remains that around 69% of the 7.95 mb/d of projects assessed as 'firm' through 2024 are currently under construction or nearing the construction stage. The remaining 2.5 mb/d comprises projects that are not yet near construction, but which are considered advanced enough in terms of engineering, financing, and overall support to be accorded a high probability of coming onstream by 2024. There is little time remaining to build other major projects that could start up in the medium-term. The more likely risk is for reductions in projected capacity due to delays and cancellations.

Figure 5.3
Distillation capacity additions from existing projects, 2019–2024



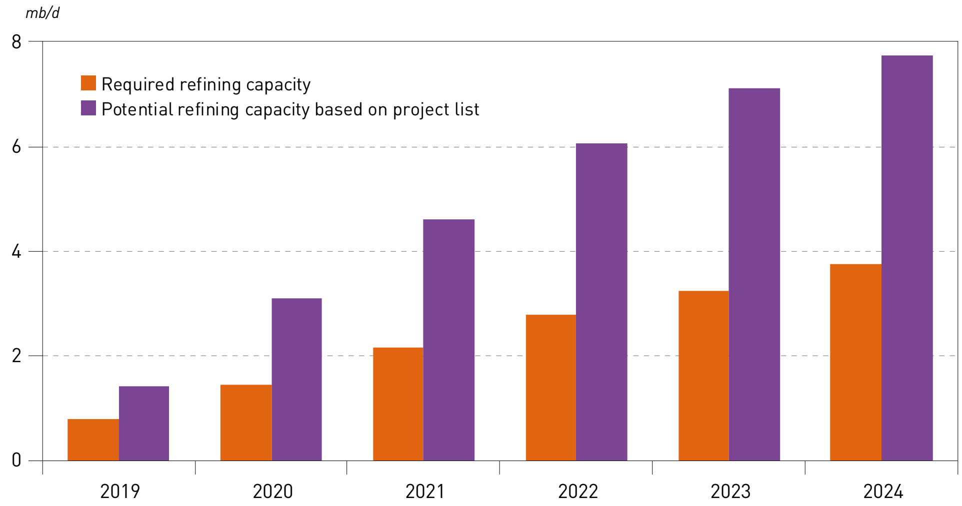
Source: OPEC.

5.2.2 Medium-term outlook for distillation capacity

As previously discussed, global medium-term distillation capacity additions were assessed at 7.95 mb/d. Some allowance has been made for limited additions to be achieved through debottlenecking, or 'capacity creep'. 'Capacity creep' most often focuses on the small expansions in the crude distillation and major upgrading units, and for the purpose of this outlook, it is assumed that additions achieved annually through capacity creep are around 0.05% of established capacity, or about 0.4 mb/d globally in respect to crude distillation capacity from 2019 through 2024. The conservative estimate of 'capacity creep' applied here is tightly linked to the very detailed list of projects that was used for capacity assessment. Consequently, the total medium-term increment to crude distillation units is projected at around 8.3 mb/d by 2024. As per the methodology applied, refinery closures are not taken into consideration at this stage but are highlighted later.

The analysis also applies a maximum assumed utilization rate at 90% for new projects in order to derive potential incremental crude runs on an annual basis. These are then compared to projections for incremental refined product demand to establish incremental refining supply *versus* demand balances, globally and by region. Figure 5.4 provides a summary assessment of the cumulative medium-term potential for additional crude runs compared to the required incremental product supply from refineries based on global product demand growth. The analysis of the

Figure 5.4
Additional cumulative refinery crude runs, potential* and required**



* *Potential: based on expected distillation capacity expansion; assuming no closures.*

** *Required: based on projected demand increases assuming no change in refined products trade pattern.*

Source: OPEC.

incremental demand takes into account (deducts) all the non-refinery fuels such as biofuels, CTLs and GTLs. This Chapter addresses balances looking solely at distillation capacity, crude runs and total demand.

On this basis, potential incremental crude runs average approximately 1.3 mb/d p.a., totalling 7.7 mb/d by 2024 (Figure 5.4). At the same time, incremental product demand is estimated at around 6.1 mb/d cumulatively over the same period. After the deduction of all non-crude stream increments, such as biofuels, CTLs, GTLs, as well as NGLs that do not go through refinery processing, the incremental required refining output is estimated at around 3.8 mb/d. Consequently, the potential incremental medium-term crude throughput is viewed as a surplus of almost 4 mb/d relative to incremental refined product demand by 2024. While the gap is still moderate in 2019, it starts widening gradually from 2020 onwards, illustrating a rising excess of distillation capacity at the global level.

It points to a period of rising international competition in product markets, as well as to the prospect of a resurgence in the need for refinery closures. At this stage, the analysis does not include the effect of projected medium-term closures, which will be discussed later in this chapter.

While the gap was estimated at levels around 2.5 mb/d in the WOO 2018, this year's estimate of nearly 4 mb/d reflects significant adjustments. The first is a downward revision of the demand increment in the medium-term, to around 6.2 mb/d, around 1 mb/d lower than in the WOO 2018. A second is higher incremental supply of non-crude streams, notably NGLs. This directly reduces the 'call on refining' and has also impacted the composition of demand itself. The latest outlook includes upwards revisions for LPG/ethane demand, covered mostly by non-refinery liquids, thereby further curbing the incremental call on refining in the medium-term. Moreover, the significant refining capacity surplus of around 1.5 mb/d already evident for 2020 is partly due to the fact that this Outlook does not see the need for additional IMO-induced refinery runs in 2020, unlike in the WOO 2018.

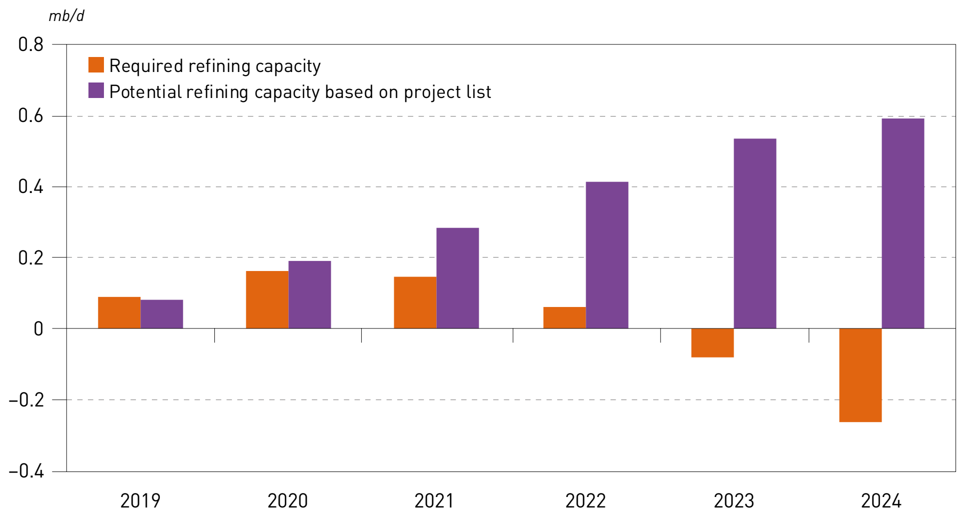
The standard caveat applies; this cumulative overhang would be lower if refinery projects slip, and higher should demand growth prove less than expected. As already mentioned, the excess supply of refining capacity will necessarily lead to increasing competition in the downstream market and, consequently, to refinery closures.

5.2.3 Medium-term regional balances

At the regional level, contrasts in the refining supply/demand balances remain stark. Figures 5.5–5.8 present a comparison of data drawn from 2019–2024 for four major world regions, namely: the US & Canada, Europe, China and the Asia-Pacific (excluding China).

Figure 5.5 shows the **US & Canada** medium-term outlook. Required refining capacity is balanced with potential refining capacity in the first two years of the outlook. However, due to the region's expected peak in oil demand, the required refining runs drop from 2021 onwards and turn negative in 2023. The negative demand trend in this region is particularly related to refinery products, such as gasoline and diesel, while at the same time, ethane and LPG demand continues increasing.

Figure 5.5
Additional cumulative crude runs in US & Canada, potential and required

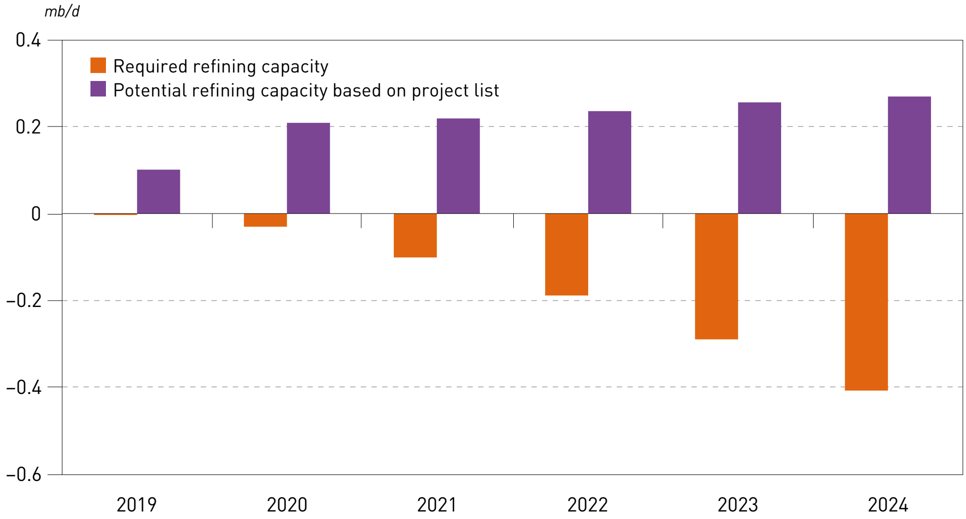


Source: OPEC.

The region's refinery production potential gradually increases due to a number of smaller distillation expansions, on top of one larger project from ExxonMobil scheduled to come online in 2022. This is why the expected potential refining capacity is estimated to increase to around 0.55 mb/d in 2024. This compares with a negative required refining capacity of –0.25 mb/d in the same year, which results in a net excess of around 0.8 mb/d in 2024. The substantial gap between the potential and required runs points to either US refineries continuing to increase product exports and/or some degree of refinery rationalization in the medium-term.

Europe paints a similar picture (Figure 5.6), with rising potential refining capacity of around 0.3 mb/d by 2024, based on one large project in Turkey and some minor capacity expansions. At the same time, as demand growth in Europe peaks, the required refining capacity already turns negative in 2020 and reaches –0.4 mb/d in 2024. This means that the gap between potential and required refining capacity will increase to around 0.7 mb/d by the end of the medium-term. In

Figure 5.6
Additional cumulative crude runs in Europe, potential and required



Source: OPEC.

combination with rising competition from other regions, the European refining market is likely to see refinery closures.

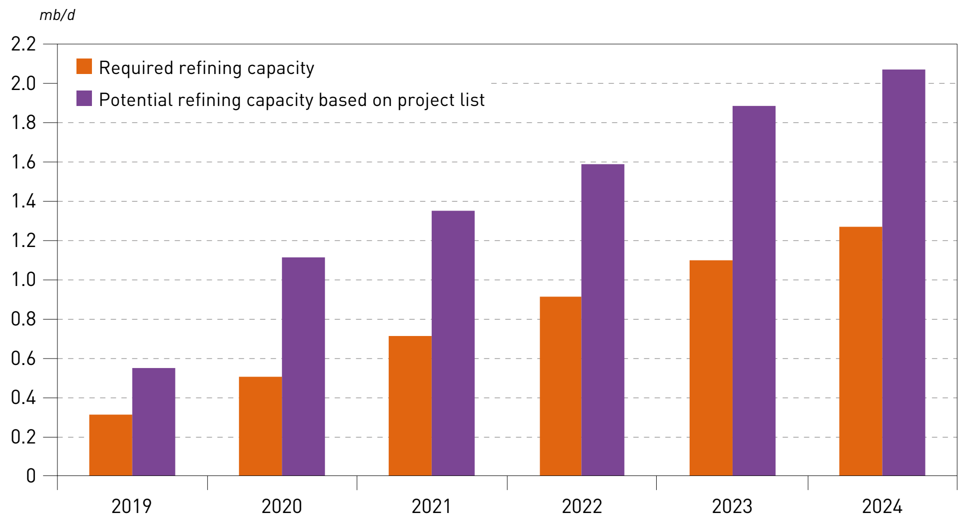
Figures 5.7 and 5.8 show the medium-term outlooks for the **Asia-Pacific** - first China, and then the Asia-Pacific excluding China - both with significant new potential refining capacity. Unlike the outlooks for the US & Canada and Europe, the Asia-Pacific region shows both significant new medium-term refining potential and rising oil demand. Nevertheless, even though this region will witness high demand growth, the outlook still shows an increasing overhang of potential refining capacity.

In **China** (Figure 5.7), due to significant medium-term refinery additions there is a steady increase in potential refining capacity, which is projected to expand to just above 2 mb/d in 2024. Set against this is a much slower rise in required medium-term refining capacity, which reaches levels around 1.3 mb/d by 2024. As a result, the gap between potential refining capacity and the capacity required to meet expected demand starts increasing from around 0.2 mb/d in 2019 to over 0.6 mb/d in 2020 and to 0.8 mb/d in 2024.

China's medium-term outlook is significantly different from a year ago for two reasons. Firstly, while the WOO 2018 saw a slowdown in China's medium-term refinery capacity additions, this outlook is more optimistic and more in line with the picture portrayed in the WOO 2017. Secondly, China's oil demand projections are more pessimistic for the medium-term outlook, in line with the assumptions outlined in Chapters 1 through 3. For example, the projected medium-term incremental demand in this outlook for refined products of around 1.3 mb/d compares to a projection of 1.6 mb/d in the WOO 2018.

In the **Asia-Pacific** (excluding China) as shown in Figure 5.8, the gap between potential refining capacity and the required volume needed to meet projected demand opens up in 2020 but then stays relatively contained at around 0.3 mb/d until the end of the medium-term. The overhang of potential refining capacity may help to reduce the region's traditionally high utilization rates,

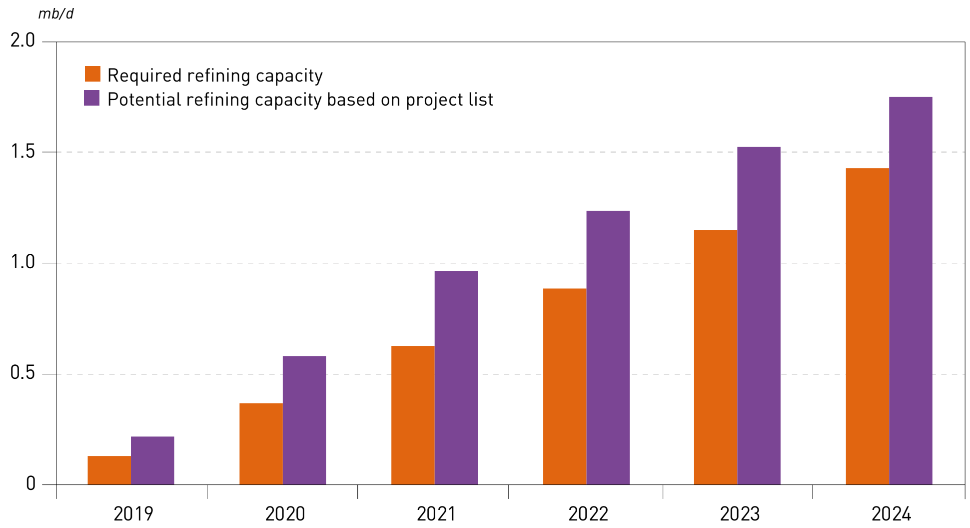
Figure 5.7
Additional cumulative crude runs in China, potential and required



Source: OPEC.

which were estimated to be above 90% in 2018. Furthermore, the excess potential crude runs in China may trigger additional product exports to the Asia-Pacific, which may contribute further to lower utilization rates in the Asia-Pacific (excluding China).

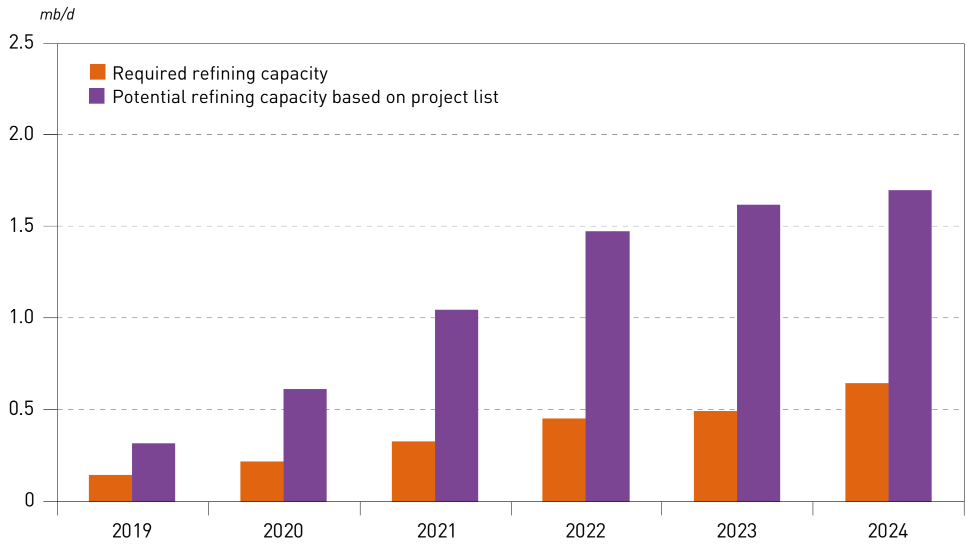
Figure 5.8
Additional cumulative crude runs in Asia-Pacific (excl. China), potential and required



Source: OPEC.

In the **Middle East** (Figure 5.9), the trend of rising refining capacity focused on export markets is expected to continue in the coming years. Although the Middle East is expected to see significant medium-term demand growth, the gap between potential refining capacity and required refining capacity volume will increase to around 1.1 mb/d in 2024. This is based on incremental potential crude runs of 1.7 mb/d set against additional required runs of 0.6 mb/d by 2024. The increasing potential to export refined products is clearly evident in the early years of the medium-term, and is in line with some countries putting additional efforts into replacing crude with product exports.

Figure 5.9
Additional cumulative crude runs in the Middle East, potential and required



Source: OPEC.

In the **Russia & Caspian** region (Figure 5.10), the increased potential refining capacity, based mostly on the expansion and refurbishment of existing refining units, is expected to reach levels close to 0.5 mb/d in 2024. This compares to a rising call on refining of around 0.2 mb/d. Consequently, the overhang of potential refining capacity is seen at around 0.3 mb/d by the end of the medium-term. This could result in lower utilization rates in the region; these were above 90% in 2018. Increasing product exports will likely become increasingly difficult due to rising competition in the global downstream market and declining oil demand in Europe, the main outlet for Russia & Caspian product exports.

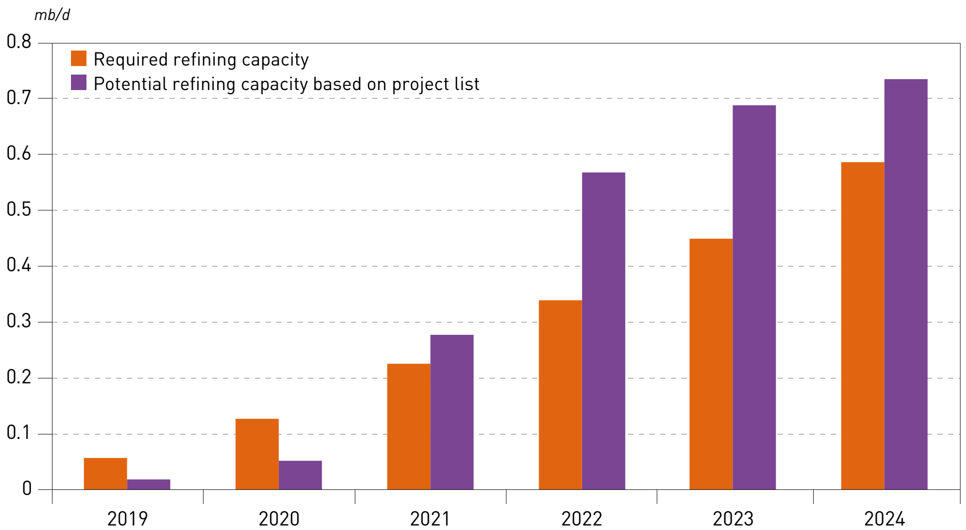
In **Africa**, as shown in Figure 5.11, the call on refining is projected to increase steadily, especially in the early years of the medium-term. By 2024, the incremental required refining runs are estimated at around 0.6 mb/d. At the same time, the potential refining capacity in the early years remains limited and below the required volume, signifying a need for additional refined product imports.

However, the situation flips in the second part of the medium-term with significant increases in the potential capacity, linked to the Dangote project in Nigeria, which changes the balance predominantly in West Africa. Consequently, the increase in total potential refining output is estimated at above 0.7 mb/d in 2024, with a slight surplus in 2024.

Figure 5.10
Additional cumulative crude runs in the Russia & Caspian region, potential and required

Source: OPEC.

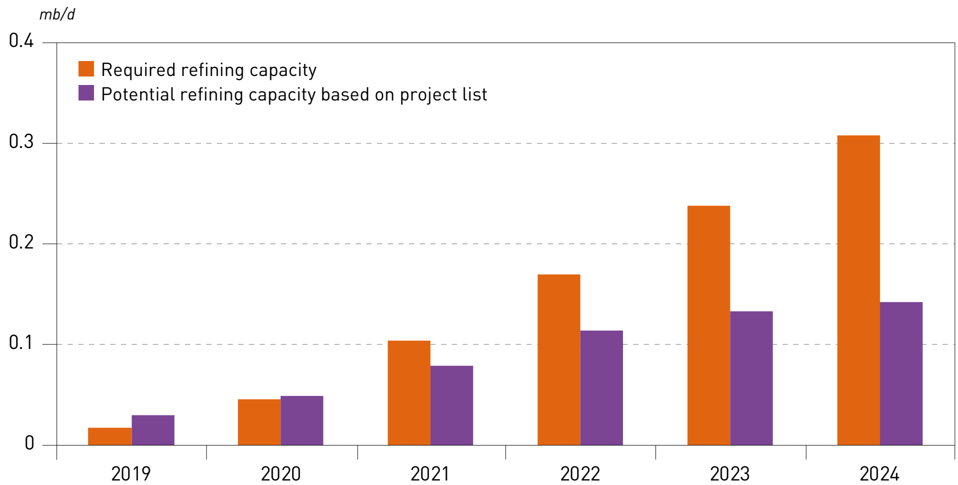
Figure 5.11
Additional cumulative crude runs in Africa, potential and required



Source: OPEC.

In **Latin America**, gradual demand growth will lead to incremental required refined product output of around 0.3 mb/d by 2024 (Figure 5.12). At the same time, the increase in refining potential based on capacity additions of only around 0.15 mb/d by 2024 lags continuously behind the call on refining throughout the medium-term. Consequently, the gap between incremental required refining output and the respective potential widens to around 0.15 mb/d by the end of the medium-term. Latin America remains the only region with a deficit in refinery capacity additions in 2024.

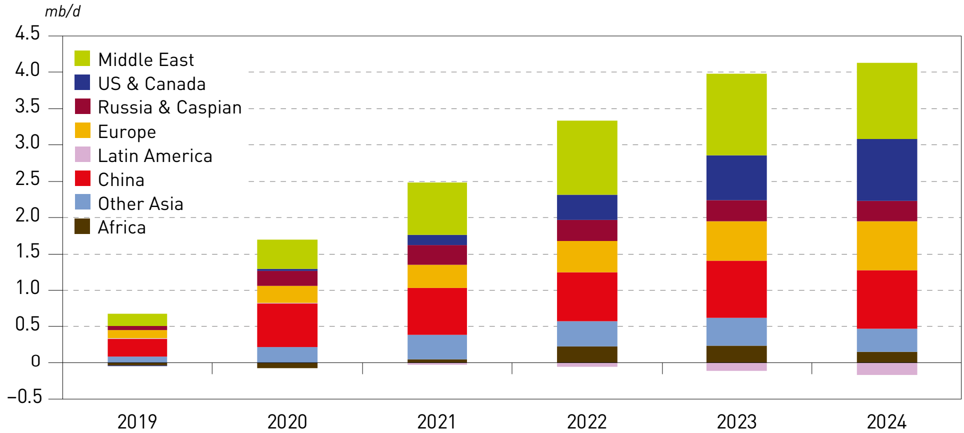
Figure 5.12
Additional cumulative crude runs in Latin America, potential and required



Source: OPEC.

Bringing all the regional outlooks together (Figure 5.13), it becomes obvious that the medium-term outlook shows a significant net surplus of incremental potential refining capacity. While the net surplus is relatively small in 2019, below 0.5 mb/d, it increases rapidly to almost 4 mb/d in

Figure 5.13
Net cumulative regional refining potential surplus/deficits *versus* requirements



Source: OPEC.

2024. The largest surplus is estimated for the Middle East (more than 1 mb/d), followed by the US & Canada, China and Europe. These regions contribute around 85% of the net surplus. Other regions show lower net cumulative excess refining potential, while only Latin America sees a net deficit of around 0.2 mb/d in 2024.

5.2.4 Long-term outlook for distillation capacity

Based on the assumptions described above, the projections for distillation capacity additions from the modelling results are summarized in Table 5.3. Figure 5.14 presents the corresponding projections by region and period. 'Assessed projects' refers to refining projects that are considered 'firm' – that is, expected to be constructed and onstream by the stated year.

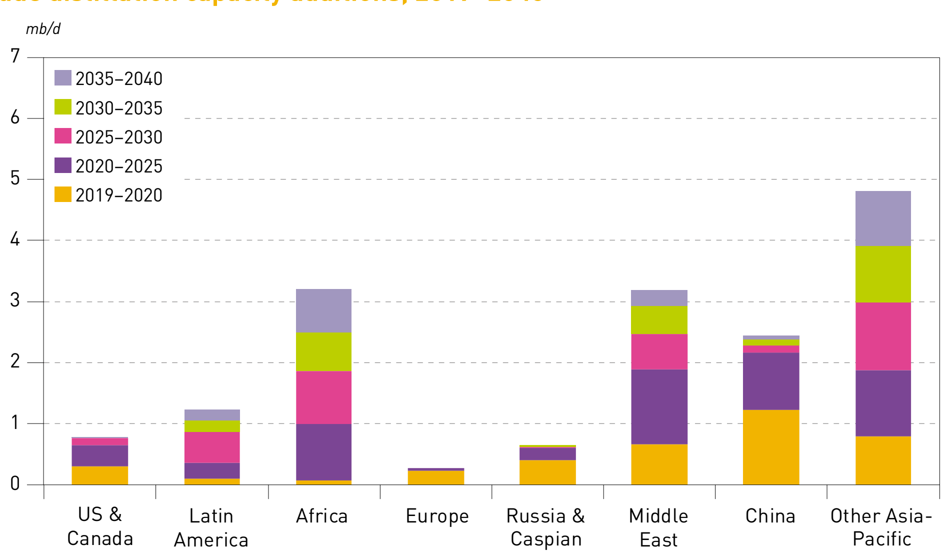
In this Outlook, this means 3.6 mb/d by the end of 2020 and 7.9 mb/d by the end of 2024. 'New units' represent further additions – that is, major new units plus debottlenecking – that are

Table 5.3
Global demand growth and refinery distillation capacity additions by period *mb/d*

	2018–2020	2020–2025	2025–2030	2030–2035	2035–2040
Global demand growth	2.4	4.6	2.8	1.6	0.6
Distillation capacity additions starting 2019					
Assessed projects*	3.6	4.4	0.0	0.0	0.0
New units	0.2	0.7	3.3	2.3	2.1
Total	3.7	5.1	3.3	2.3	2.1
Annualized	1.9	1.0	0.7	0.5	0.4

* *Firm projects exclude additions resulting from capacity creep. Total firm projects are split between 2019–2020 and 2021–2025.*
Source: OPEC.

Figure 5.14
Crude distillation capacity additions, 2019–2040



Source: OPEC.

projected to be required over and above the assessed projects. The addition of new units is developed through optimization modelling that balances the refining system for each specific time horizon.

Over and above the 3.6 mb/d of assessed projects by 2020, the model indicates a further 0.2 mb/d will be required (essentially representing assumed minor 'capacity creep'), putting total distillation capacity additions by end 2020 at 3.7 mb/d. For 2025, a further 4.4 mb/d of assessed projects comes into effect, plus 0.7 mb/d of new units for total additions *versus* 2020 of 5.1 mb/d. In the subsequent five-year periods, the modelling projections are for progressively slowing capacity additions, 3.3 mb/d in the period from 2025–2030, 2.3 mb/d for 2030–2035 and 2.1 mb/d for 2035–2040. When combined, the cumulative total additions – that is, assessed projects plus total model additions – are projected to reach 16.5 mb/d by 2040.

The pattern of a progressive slowdown in capacity additions required over time is illustrated in Table 5.3. The projections for refinery additions from 2025 onward are based on those seen as necessary in the model to balance demand growth, recognizing the growing role of NGLs, biofuels, CTLs, GTLs and petrochemical returns (backflows) as non-crude supply streams.

As Table 5.3 underlines, the pace of global liquids demand growth is projected to decline steadily over time, from 2.4 mb/d (1.2 mb/d annually) between 2018 and 2020 to an annual average of 0.5 mb/d in the period 2025–2030 and only 0.1 mb/d in the period 2035–2040. Therefore, it is expected that projected refinery capacity additions drop from an annualized 1.9 mb/d (a relative spike by historical standards) in 2018–2020 to an average 1.0 mb/d in 2020–2025, then to the 0.7 mb/d range for 2025–2030 and to 0.4 mb/d by the late 2030s. Significantly, the 7.9 mb/d of assessed 'firm' projects through to 2024 equate to almost half the total 16.5 mb/d of additions needed from 2019 through 2040. In short, refinery additions needed through 2040 are heavily front-loaded with major implications for a slowdown in projects and investment after the medium-term.

Viewed at the global level, demand growth to 2040 increases only nominally after taking out growth for non-crude supply and processing gains. It implies a 'call' for incremental refining capacity to 2040 of a mere 6.8 mb/d – yet additional capacity needs for 2018–2040 are projected at 16.5 mb/d. The reason for this large difference is twofold. Firstly, the global average refinery utilization is only 79–83% (81% average since 1990). This factor itself increases the capacity that needs to be built to meet a given amount of demand by some 25%. Secondly, rational increases in refining capacity are warranted in developing regions, the main focus of future demand growth.

Long-term declining demand in the US & Canada and Europe implies continuing closures, but also the potential for more efficient refineries to increase product exports. Product imports into these regions are also expected to drop because of declining regional demand. This has the effect of 'releasing' supplies that were exported, for example, from Middle East refineries, to meet growing demand, either locally, or in regions like the Asia-Pacific, where consumption continues to grow.

As a result, net product exports from the developed regions are projected to increase by over 4.5 mb/d by 2040, above 2019 levels. In contrast, the combined total demand increase from 2018 to 2040 for the Asia-Pacific, the Middle East, Africa and Latin America is projected at 18.6 mb/d. This necessarily means that much of the incremental demand will be met by building additional capacity within these regions. Given assumed refinery utilization of around 80%, it is therefore consistent that projected additions out to 2040 total 16.5 mb/d, and are overwhelmingly in developing regions.

In summary, declining demand in the industrialized regions will impact the total scale of refining additions required worldwide by raising industrialized-country product export potential and reducing the need for imports. What appears less likely, other than in select situations such as US Gulf Coast refineries exporting to Mexico and other countries in that region, is that this trend will fundamentally impact where refineries are built over the long-term.

That said, the slowing pace of 'necessary' long-term refinery capacity additions remains evident, meaning that whoever invests first in new capacity may be in a better competitive position compared to those who try to justify major investments in later years when demand growth is expected to be lower. The array of large additions coming onstream in the near-term, especially a surge of 6.7 mb/d projected for the 2019–2022 timeframe, is being driven by expanding demand, including for petrochemicals, but putting capacity in place sooner rather than later could also be a driving factor.

Regional additions

As illustrated in Figure 5.14, short-term additions from 2019–2020 emphasize the dominance of the Asia-Pacific region at 53% and the Middle East at 17.5%. The Russia & Caspian region is expected to contribute 10%, the US & Canada 8%, Europe 6% and Latin America and Africa around 2–3% each.

For additions in the period from 2020–2040, the combined share of the Asia-Pacific and the Middle East falls to 61% from 71% in 2019–2020. This lower, although still dominant, percentage stems mainly from 3.1 mb/d of new capacity projected in Africa after 2020, some 25% of total global additions, driven by regional demand growth. Moreover, Latin America is expected to see over 1 mb/d of capacity growth post-2020, 9% of the total. The US & Canada and the Russia & Caspian account for 4% and 2%, respectively, while additions in Europe are minimal.

In **China**, a wave of current major projects – 2.1 mb/d out of 7.9 mb/d globally to 2024 – combines with a projected slowing in the country's demand growth, leading to a situation where only modest additions to primary capacity are needed post-2025, although secondary addition requirements remain significant.

In contrast, the **Other Asia-Pacific** region, led by India, shows a sustained rate of required capacity additions, from 1.1 mb/d from 2020–2025 to 0.9 mb/d from 2035–2040, driven by continuing demand growth that totals 7.3 mb/d over the 2018–2040 period. At 4.8 mb/d, however, the total capacity additions from 2019–2040 do not keep pace with demand growth. The difference is projected to be met by increasing net product imports.

The **Middle East** is projected to add some 3.2 mb/d of total capacity from 2019–2040. This is ahead of the projected regional demand increase of 2.6 mb/d and is consistent with the region increasing its product exports over time. Critical to this outlook is an expected series of major short-term projects, 1.4 mb/d by 2021 and a total of 1.7 mb/d by 2024.

Africa is also projected to add 3.2 mb/d of distillation capacity by 2040 compared to end-2018. The relative dearth of significant projects is expected to continue in the immediate tautology-term, less than 0.12 mb/d from 2019–2020, but it is then expected to be followed by a sustained period of larger expansions, starting with the large Dangote project. Thereafter, and especially after 2025, modelling indications are that the region should be able to justify capacity increases that average 0.1–0.2 mb/d p.a. through to 2040, hence the projected total of 3.2 mb/d of additions.

Allowing for realistic, but improving, utilisation rates, these additions should enable regional refinery throughput to keep up with demand growth, which is projected at 2.7 mb/d from 2018–2040. As a result, the region's net long-term product imports are expected to stabilize. However, achieving the indicated growth in regional refinery capacity means dealing with key challenges, notably how to finance and convert project ideas into actually building and operating facilities.

Additionally, there is the challenge of how to improve utilization rates at existing refineries given that many refineries in Africa are old and relatively small.

In **Latin America**, demand is projected to increase by 1.6 mb/d over the long-term forecast period. A combination of an expected 0.3 mb/d growth in biofuels supply, improvements in refinery utilization and 1.2 mb/d of refinery capacity additions, essentially matches the demand increase. The effect is that net product imports are projected to remain relatively stable between 2019 and 2040. With only 0.1 mb/d of assessed firm projects, over 0.75 mb/d of new capacity additions are seen as required in the 2020–2030 period, with further additions needed in 2030–2040, albeit at lower levels.

In the **Russia & Caspian** region, demand is expected to increase by 0.5 mb/d between 2018 and 2040. Current firm distillation capacity projects total the same figure. Consequently, further additions beyond these projects are expected to be minor. Likewise, with capacity additions keeping up with limited product demand growth, net product exports from the region are also projected to decline marginally.

For the **US & Canada**, current projects are assessed at 0.5 mb/d. Around 0.25 mb/d of additional capacity is indicated as justified by 2024. Thereafter, however, further additions are essentially nil. This apparently simple outlook belies a multi-faceted situation. Demand in the US & Canada is seen maintaining a plateau at approximately 23.5 mb/d through 2025 but is then projected to steadily decline to less than 19 mb/d by 2040. This is a reduction of 4.5 mb/d *versus* 2018. This decline is arguably responsible for the lack of additional capacity after 2025.

US refinery runs are, however, projected to decline by only 2.2 mb/d from 2018–2040, which means they do not drop by anywhere near the reduction in domestic demand. The effect is that net product exports from the US & Canada are projected to substantially increase by 2040, made up of increases in both refined products and NGLs. The peak in US crude and condensate production between 2025 and 2030 also potentially contributes to justifying some limited further refinery expansion but also to the absence of expansion thereafter.

5.2.5 Refinery closures and utilization

Refinery closures and utilizations in the medium-term

This section reviews the recent history of refinery closures at a regional level, as well as the prospects for additional closures based on announcements and refinery capacity considered at risk of closure by virtue of a recent sale or other announcements. This leads to an updated assessment for total refinery closures from 2019–2025. The year 2025 was selected as the 'end date' for actively estimating closures since anything beyond that time horizon is considered too uncertain. As will be addressed later, the long-term modelling results indicate potential closures from 2025–2040.

Table 5.4 and Figure 5.15 summarize recent closures since 2012, and projected closures through to 2025. Total closures of 2.1 mb/d were estimated for the period 2019–2025. This includes an assumed partial restart in 2019 of the Al-Sumoud (formerly Baiji) refinery in Iraq and the 235,000 b/d Aruba refinery in 2021. Gross closures therefore equate to some 2.4 mb/d. It should be noted that a further restart at the ex-HOVENSA refinery in St. Croix was treated as a new project since the new owners, Lime Tree Bay, are reportedly spending $1 billion on revamping the facility.

In 2018, closures included the 168,000 b/d TRINTOC, Pointe-á-Pierre refinery in Trinidad. In June 2019, the 355,000 b/d Philadelphia Energy Solutions was declared permanently closed after a fire. More broadly, currently announced refinery closures are limited. However, given continuing demand declines, especially in Europe, Japan and Australasia, issues at older refineries in a

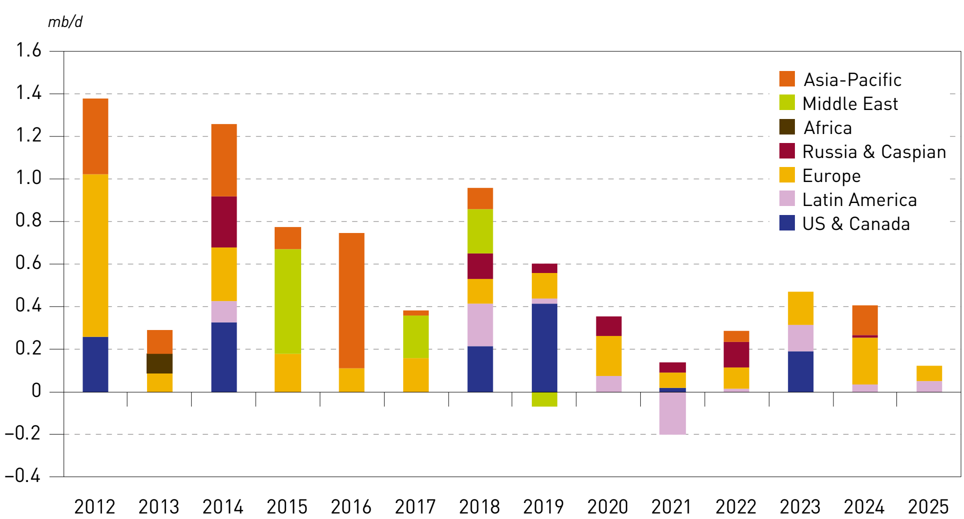
Table 5.4
Net refinery closures, recent and projected, by region

mb/d

	Total 2012–2018	2019	2020	2021	2022	2023	2024	2025	Total 2019–2025
US & Canada	0.8	0.4	–	0.0	–	0.2	–	–	0.6
Latin America	0.3	0.0	0.1	–0.2	0.0	0.1	0.0	0.1	0.1
Europe	1.7	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.9
Russia & Caspian	0.4	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.3
Africa	0.1	–	–	–	–	–	–	–	–
Middle East	0.9	–0.1	–	–	–	–	–	–	–0.1
Asia-Pacific	1.7	–	–	–	0.1	–	0.1	0.0	0.2
Total	**5.8**	**0.5**	**0.4**	**–0.1**	**0.3**	**0.5**	**0.4**	**0.1**	**2.1**

Source: OPEC.

Figure 5.15
Net refinery closures, recent and projected, by region



Source: OPEC.

number of countries, and the potential for the IMO MARPOL Annex VI Sulphur Rule to adversely impact simpler refineries that produce a large share of high-sulphur heavy fuel oil, continued closures appear likely.

The MARPOL rule could also have the effect of reactivating one or two shuttered refineries. As noted, Lime Tree Bay plans to partially restart the ex-HOVENSA refinery. In addition, HES International is reported to be potentially partially restarting a refinery it owns in Wilhelmshaven, Germany, that has been closed since 2011. Whether such projects go ahead is open to question, as is whether they would remain in operation for long given they were shuttered because they were deemed unprofitable.

At 2.1 mb/d, the projected level of medium-term closures represents an increase over the level in the WOO 2018, while still a far lower rate of closures than the 5.8 mb/d that occurred from 2012–2018. Though, the projected level of closures for the medium-term is an estimate and actual closures could be higher or lower.

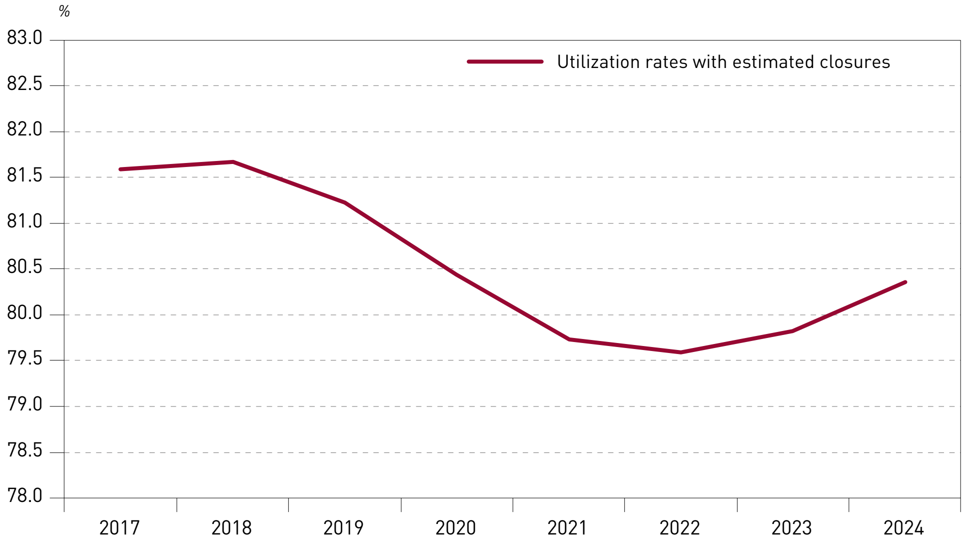
The fact that the projections for closures were not extended beyond 2025 does not mean that the era of refinery closures is over. As will be addressed later, a continuing long-term need for closures is expected, especially post-2025, as demand declines in industrialized regions and as smaller, less efficient, often ageing refineries in developed and developing regions struggle to compete with the larger, highly sophisticated, efficient refineries that are increasingly coming onstream, especially in the Middle East and Asia.

Based on the assumed closures described, the gap of nearly 4 mb/d between potential incremental and required refinery runs in the medium-term analysis would look somewhat lower. Applying a possible utilization rate of 75% for all closed units, as older refineries tend to run at lower utilization rates, the gap in 2024 would drop by around 1.5 mb/d, bringing the excess refining potential compared to requirements down to around 2.5 mb/d.

Refinery utilization in the medium-term

Figure 5.16 illustrates the pathway for global refinery utilization trends in the medium-term. In 2018, the average utilization rate was estimated at around 81.7%. In the coming years, however, this utilization rate is expected to gradually decline in line with the expected growing surplus of refining capacity. The refinery utilization rate is expected to fall below 80% in the years 2021/22, as a consequence of significant additions in the first years of the outlook.

Figure 5.16
Historical and projected global refinery utilization, 2017–2024

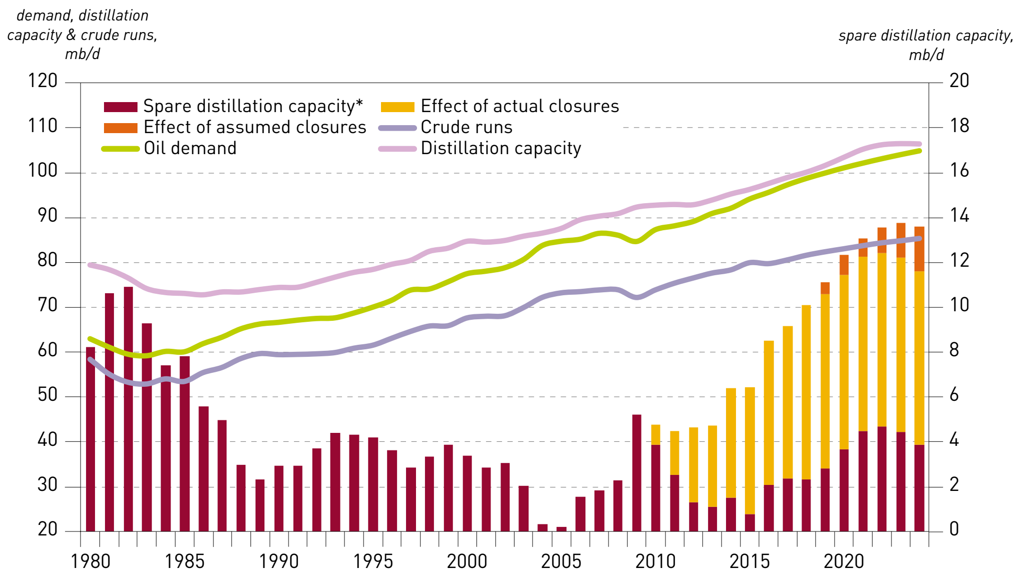


Source: OPEC.

However rising demand and lower refinery additions are expected to lead to a rising utilization rate of just below 80.5% in 2024 (Figure 5.16). However, if no closures are assumed, the average utilization rate drops below 79% in 2022, which would be the lowest level since 2009 when the world was suffering from the effects of a major recession. Adding in 2.0 mb/d of closures by 2024 would raise the average utilisation rate over 2021–2024 to close to 80%. However, this is still below recent levels, implying more than 2 mb/d of closures may be needed.

Figure 5.17 provides a perspective covering distillation capacity, oil demand and crude runs and estimated effective spare refining capacity since 1980. Based on this history, the highest utilization rate across the period was 84% in 2004/2005 – consistent with the tightness that then existed (more details available in the WOO 2018, pages 228–229). As large surpluses of capacity have gradually been whittled down since the 1980s, the levels of total liquid demand and nameplate refinery capacity have almost converged in recent years, such that installed capacity sits minimally above global liquids demand.

Figure 5.17
Global oil demand, refining capacity and crude runs, 1980–2024



* Effective 'spare' capacity estimated based on assumed 84% utilization rate, accounting for already-closed capacity.
Source: OPEC.

However, as stated, refineries tend to run well below their nameplate capacity and, hence, crude runs in 2020 are projected at around 83 mb/d, increasing to around 85.5 mb/d in 2024. The gap between runs and demand is expected to be met by a combination of non-crude supply and processing gains.

The right-hand axis on Figure 5.17 illustrates the effect of refinery closures since 2010. Around 7.5 mb/d of closures have occurred between 2010 and 2018. To this, an estimated 2 mb/d of additional closures by 2024 has been added for an aggregate total of 9.5 mb/d. The chart illustrates the dramatic effect closures have had on containing surplus refining capacity. If none of the closures since 2010 had occurred, current spare capacity (assuming 84% effective availability) would be around 11 mb/d, a level not seen since the large excesses of the early 1980s. Instead, the actual current level is in the 2–2.5 mb/d range. However, with growing additions, and considering the assumed medium-term closures, spare capacity is expected to increase to around 4 mb/d in 2024. This is relatively high compared to recent history, excluding the recession years of 2009 and 2010.

This historical perspective thus reinforces the conclusion that the years covered by the medium-term projections are likely to be another period when closures could be substantial. Significant regional differences are lost in the global trend but it is clear that substantial recent closures have been effective in reducing overall global average spare capacity to a limited level that has been supportive of reasonable refining margins. Likewise, this points to the importance of further closures in order to avoid a return to high excess capacity that has the potential to force abrupt closures by lowering refining margins to unsustainable levels.

Refinery closures in the long-term

Modelling results provide a means to 'back-calculate' the implied closures required within a region to reach a user-input level of utilization. This parameter is currently set at 80%, representing the lowest utilization level considered viable. Thus, any region with a utilization level below 80% in the model results will indicate some level of implied closures. This feature is especially useful for assessing the potential need for additional closures by region over the long-term.

The results provide a cross-check on whether the assumed level of closures by 2025 is appropriate, or whether there is a need to indicate more or fewer. The global average utilization by 2025 is projected at 80.6% (Table 5.5.). This level of global utilization appears plausible, yet it is toward the lower end of the range that has existed post-2005, again, with the exception of the recession years 2009 and 2010. The implication is that the assumed 2.1 mb/d of net closures embedded in the 2025 modelling may represent the low end of what is needed (consistent with the analyses above).

Regions flagged by the model for potential additional closures are Japan and Australasia where falling utilization indicates that further closures by around 2025 may be called for and in Latin America and Africa, where low utilization rates logically imply that closures are needed.

Beyond 2025, the outlook for long-term regional refinery utilization demonstrates a need for continuing refinery closures, beyond those built in to the modelling, especially for industrialized regions where demand is projected to further decline.

In summary, the modelling indicates that additional closure requirements across the world's regions are close to 5 mb/d over the long-term to 2040. Adding the 2.1 mb/d number built into the modelling base outlook for 2019–2025 indicates that total closures somewhere in the range of 7 mb/d are needed from 2019–2040. This level is higher than was projected a year ago, driven by lower long-term demand and more non-crude supply that reduces the long-term call on refining. Crude throughput in 2040 is projected at 1.5 mb/d lower in this Outlook and utilization in 2040 is 0.4% lower at 77.4% *versus* 77.8% a year ago.

The projected closures out to 2040 equate to an annual average rate of 0.3 mb/d for 2019–2040. Thus, the projection is for a continuation of the same 0.3 mb/d level included for 2019–2025. While continued closures in the industrialized regions can be expected to be a major requirement, it is also clear that significant closures are required in other regions if efficient levels of refinery operations are to be reached and maintained.

Crude runs and refinery utilization in the long-term

The projected global and regional long-term refinery crude throughput and related utilization rates are presented in Table 5.5. At the global level, throughput rises from 81.7 mb/d in 2018 to 83.2 mb/d in 2020 and then to 88.5 mb/d in 2040.

Table 5.5
Crude unit throughput and utilization

	Total crude unit throughput mb/d					
	2018	2020	2025	2030	2035	2040
US & Canada	18.5	18.4	18.4	18.1	17.3	16.3
Latin America	4.5	4.9	5.4	6.2	6.5	7.0
Africa	2.3	2.4	3.0	3.5	4.1	4.8
Europe	12.6	12.6	12.3	11.8	11.4	10.7
Russia & Caspian	6.9	6.6	6.6	6.4	6.2	6.1
Middle East	7.5	8.1	8.9	9.4	10.1	10.3
China	12.1	12.7	13.7	14.0	14.1	14.3
Other Asia-Pacific	17.2	17.4	17.7	18.0	18.4	18.9
World	**81.7**	**83.2**	**86.0**	**87.3**	**88.1**	**88.5**
	Crude unit utilization *% of calendar day capacity*					
	2018	2020	2025	2030	2035	2040
US & Canada	89.9	88.8	88.7	86.7	83.1	78.2
Latin America	55.8	61.1	67.5	71.9	73.8	78.4
Africa	54.8	65.0	64.7	62.5	65.8	68.9
Europe	75.1	78.9	79.7	76.4	73.7	69.3
Russia & Caspian	96.7	88.6	87.4	85.3	82.5	81.2
Middle East	81.1	77.5	77.9	78.4	80.6	81.2
China	81.5	73.6	75.7	77.2	77.4	78.3
Other Asia-Pacific	90.6	88.3	85.1	82.1	80.7	79.9
World	**81.7**	**80.4**	**80.6**	**79.4**	**78.4**	**77.4**

Source: OPEC.

The annual increase in crude runs of slightly above 0.7 mb/d for 2018–2020 slows to under 0.3 mb/d by the period 2026–2030 and to under 0.1 mb/d from 2036–2040. As already emphasized, the rate of annual increase in refinery crude runs is projected to steadily decline due to the combined effect of a gradual slowing in the annual demand growth rate and steady increases in non-crude supply. This is evident in the projection that the period to 2030 accounts for the bulk of the demand growth, at 9.7 mb/d or 81.5%, of the total growth of 11.9 mb/d from 2018–2040. Demand growth for the period from 2031–2040 is a mere 2.2 mb/d. This, plus the continuing rise in non-crude supply, leads to the outlook for minimal annual growth in global crude runs by the mid-to-late-2030s.

Put another way, crude runs rise by 5.6 mb/d in the period 2018–2030, but by only 1.2 mb/d from 2031–2040. This changing growth profile reinforces how much lower future refinery additions will need to be in the longer-term compared to where they are currently.

The corresponding outlook for global refinery utilization is for a gradual decline, from 81.7% in 2018 to 77.4% in 2040. Because of a lower global demand outlook for 2020 (Chapter 3), global crude runs are projected to rise by only 1.5 mb/d between 2018 and 2020. Adding this to the significant refinery additions of 3.8 mb/d 2019–2020 results in a drop in global refinery utilization to 80.4% in 2020. This level is then expected to be maintained through 2025, followed by a steady decline of around 0.2% p.a. to 2040. Again, it should be noted that this outlook does not embody any refinery closures beyond 2025. Adding up to 5 mb/d of long-term closures that are required according to the modelling would raise 2040 global utilization to a healthier 80.9%.

Projected long-term refinery utilization rates are in part a function of long-term capacity additions over and above assessed projects. It is important to bear in mind that the capacity additions generated in the modelling correspond to additions that are only considered necessary to balance demand.

Table 5.5 highlights the variation in outlooks between major regions. Crude throughput in the **US & Canada** is projected to remain close to 18.5 mb/d in the medium-term to 2025. This is courtesy of regional demand maintaining a plateau of around 23.5 mb/d and of the region benefitting from domestic crude supply growth. Thereafter, declining domestic demand results in a long gradual decline in crude throughput. From 18.4 mb/d in 2025, throughput is expected to drop to 18.1 mb/d in 2030 and then the downward trend is seen accelerating, with throughput at 16.3 mb/d by 2040.

Starting from record levels of almost 90% in 2018, US & Canada utilization remains close to 89% through 2025, then is seen dropping steadily to reach 78.2% by 2040. This clearly indicates the potential for closures in the region in the longer-term , over and above the 0.6 mb/d included for 2019–2025. By 2040, the potential for additional closures is something in the order of 0.5 mb/d, some or most of which could occur much earlier. As noted elsewhere in this Outlook (Chapter 6), the advantages for US refiners will enable them to at least partially compensate for domestic demand reductions with increased product exports. This will allow them to maintain higher refinery throughputs than would otherwise be the case.

In **Europe**, crude runs are expected to steadily drop in line with progressively declining regional demand from around 12.6 mb/d from 2018–2020, to 12.3 mb/d in 2025 and 10.7 mb/d by 2040. Combined with the US & Canada, the effect is a total reduction in North Atlantic basin crude runs of over 4 mb/d from 2020–2040, split roughly evenly between the two major regions.

Demand in **Japan** and **Australasia** is projected to drop by one third, from 5.0 mb/d in 2018 to 3.35 mb/d in 2040. This leads to the potential for additional closures that equates to as much as 0.7 mb/d across the period to 2040. In the tables and figures in this Outlook, the region and its demand is masked by its inclusion within the Other Asia-Pacific region. The Other Asia-Pacific region comprises three sub-regions: Japan and Australasia, the Pacific High Growth sub-region – which contains countries such as South Korea, Thailand, Indonesia and Vietnam - and the Rest of Asia sub-region, which is dominated by India.

In the **Pacific High Growth** sub-region, demand is expected to grow by 1.9 mb/d from 2018–2040, while in the Rest of Asia sub-region, demand is estimated to rise by 7.0 mb/d across the same period, driven by the strong growth potential in India. These significant differences between the sub-regions of Other Asia-Pacific, as well as their impacts on refinery throughput and capacity additions, are captured in the modelling. Even with the differences in growth rates, refinery utilization in both Pacific High Growth and the Rest of Asia is projected to remain above 80%, pointing to a low likelihood of closures in these regions.

In **China**, crude runs are projected to rise from 12.1 mb/d in 2018 to 14.3 mb/d in 2040, however, most of that increase – 70% or 1.6 mb/d – will come in the period to 2025 and only a further 0.6 mb/d from 2025–2040. The outlook is for demand to grow by 2.0 mb/d from 2018–2025 and a further 2.3 mb/d from 2025–2040. The slowing in refinery runs and production over the longer-term relative to the region's demand growth is tied to a projected swing from China being a net product exporter to a significant net product importer by 2040.

The surge of 2.1 mb/d in refinery projects by 2024 leads to utilization in China dropping back moderately by 2025 *versus* 2018, but gradually recovering thereafter. Aside from 2018, the utilization projected for each horizon is below 80%. This situation relates in part to the existence of significant capacity in so-called 'teapot' refineries that generally exhibit low utilization. The implication is that China could, or should, experience appreciable refinery closures, potentially 0.5 mb/d or more, to improve utilization rates. A great deal depends, though, on government policies regarding the nation's refineries.

In the **Russia & Caspian** region, demand is expected to increase modestly, from 4.3 mb/d in 2018 to 4.8 mb/d by 2040. Conversely, refinery crude runs are projected to gradually decline throughout the period to 2040, by a total of around 0.8 mb/d. The reason for the decline in runs, despite the demand increase, is a projected drop in product exports over the period. This occurs in part because of the demand decline in Europe, which is the primary market for Russian products.

Noting the near absence of any assumed closures through 2025, Russia & Caspian utilization is projected to slowly decline but remain above a level likely to call for any appreciable closures.

In the remaining regions, significant demand increases are expected, in turn, to lead to substantial gains in refinery throughput from 2018–2040; Latin America and Africa each by 2.5 mb/d and the Middle East by 2.8 mb/d.

In the **Middle East**, 1.7 mb/d of additional refining projects are projected to drop medium term utilization to 77.5% in 2020, before they gradually recover to over 80% by the mid-2030s. One implication is that the region could see additional closures – possibly around 0.25 mb/d – at some point in the mid-to-late 2020s.

Latin America and **Africa** face a different set of challenges. An array of issues has led to very low utilization across many refineries in these regions. The question has become whether these will 'soldier on' or be closed and replaced with new capacity. In this regard, a recovery to around an 80% utilization rate would imply anything up to 2 mb/d of closures by the mid-to-late 2020s across the two regions. Overall, utilization is projected to gradually rise in both regions over time as the combination of closures and new capacity additions bring more efficient operations.

5.3 Secondary capacity

5.3.1 Medium-term capacity additions

Substantial amounts of new secondary units are accompanying new distillation capacity in newly built refineries and in major expansions. In addition, secondary capacity additions are occurring in order to upgrade existing refineries, often with limited or no added distillation capacity.

The goal of achieving a high degree of conversion, desulphurization and other quality improvements, ties into the aim of producing predominantly light, clean products that meet stringent product specifications. This goal is derived from the fact that the vast majority of incremental product demand is for clean products – predominantly naphtha, gasoline, jet fuel and diesel – and that standards, especially for transport fuels, continue to be tightened.

Table 5.2 shows that the 7.9 mb/d of new distillation capacity from assessed projects through to 2024 is expected to be accompanied by an additional 4.2 mb/d of conversion units, 5.9 mb/d of desulphurization capacity and 1.9 mb/d of octane units (Table 5.6).

As of early 2019, the total conversion capacity in place – coking, fluid catalytic cracking (FCC), hydrocracking and visbreaking – equating to 40.8% of global crude distillation capacity, desulphurization to 62.6% and octane units to 19.1%. With respect to current firm projects, a

Table 5.6
Secondary capacity additions from existing projects, 2019–2024 *mb/d*

	By year					
	2019	2020	2021	2022	2023	2024
Conversion	1.2	0.8	0.7	0.8	0.4	0.2
Desulphurization*	1.4	1.2	1.4	0.9	0.7	0.3
Octane units	0.5	0.3	0.4	0.3	0.2	0.1

	By region		
	Conversion	Desulphurization*	Octane units
US & Canada	0.0	0.2	0.1
Latin America	0.1	0.1	0.0
Africa	0.6	0.5	0.3
Europe	0.3	0.2	0.0
Russia & Caspian	0.5	0.5	0.1
Middle East	0.7	1.9	0.5
China	1.2	1.2	0.5
Other Asia	0.7	1.3	0.3
World	**4.2**	**5.9**	**1.9**

* *Desulphurization capacity in this table includes naphtha desulphurization.*
Source: OPEC.

surge in conversion additions in 2019 will boost their level to nearly 53% of distillation capacity additions over the period to 2024, which is well above the ratio for existing capacity. Likewise, desulphurization unit projects, at 74% of new distillation, and octane units at 24%, also comprise additions appreciably above the level for current existing capacity. This is matched by the rates of projected additions for hydrogen and sulphur recovery plants that are also well above (over 2.5 times) their historical ratios relative to crude capacity.

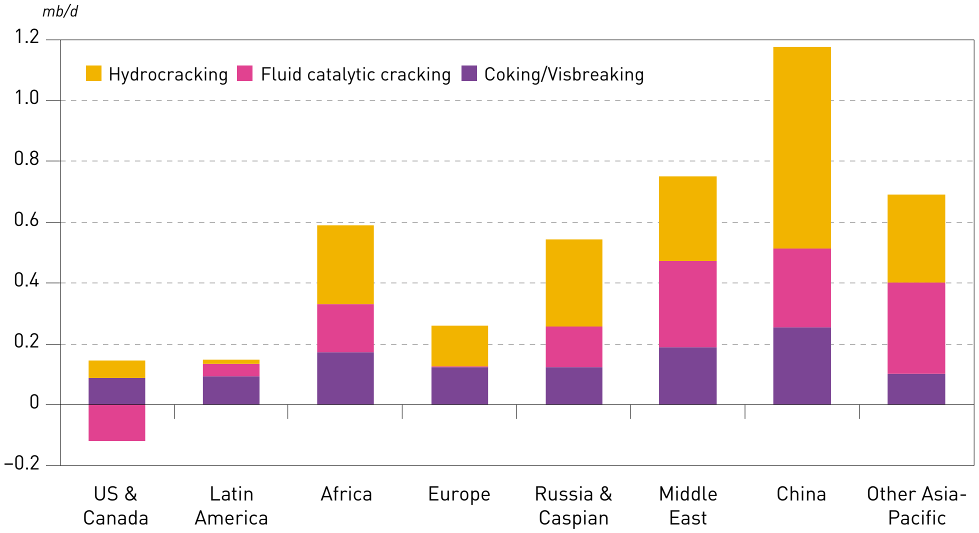
One possible explanation for the relative surge in short-term upgrading and desulphurization additions could be that, after a distinct lack of any visible response to the IMO Sulphur Rule in 2017 and 2018, the new IMO regulations set for January 2020 are (finally) seeing refiners respond with extra secondary additions. More broadly, the high ratios of secondary unit additions reflect that incremental demand is predominantly for light, clean products.

Conversion units

Figure 5.18 highlights the geographic distribution of conversion capacity additions by major unit category. The 4.2 mb/d in new global conversion units for the period 2019–2024 include substantial additions for each of the three main unit categories: 47% for hydrocracking at 2.0 mb/d, 28% for coking/visbreaking (essentially all coking) at 1.15 mb/d and 25% for FCC)residue fluid catalytic cracking (RFCC) capacity at just over 1 mb/d.

While the levels of medium-term additions for coking and FCC have remained stable, hydrocracking additions are up appreciably *versus* the 1.4 mb/d projected a year ago for 2018–2023. Expected distillates demand growth would appear to be the key driver. The expectation for total distillates

Figure 5.18
Conversion projects by region, 2019–2040



Source: OPEC.

– gasoil/diesel plus jet/kerosene – demand growth for 2018–2024 is down from 2.9 m/d in the WOO 2018, but is remains substantial at 2.55 mb/d in this Outlook. The 2020 MARPOL Annex VI Sulphur Rule is a key factor.

Additions in each of the three conversion unit categories are expected in all regions except Europe and the US & Canada. A short-term surge pushed US & Canada gasoline demand to a record level of 10.4 mb/d in 2018 from 9.9 mb/d in 2014. Announced FCC unit closures in US refineries are occurring despite high gasoline demand because the growth in light tight oil production has boosted the supply of naphtha for use as a gasoline blendstock via catalytic reforming and isomerization. In Europe, the substantial regional gasoline surplus provides little incentive to add to the gasoline supply. In both regions, the emphasis continues to remain on raising distillate yields.

As a result of its paucity of firm projects, Latin America is the one other region where only minor conversion additions are projected over the medium-term (0.15 mb/d). In all other regions, conversion additions are projected in the 0.5–0.75 mb/d range, with the exception of China at 1.2 mb/d.

Africa, Russia & Caspian, Middle East, China and Other Asia-Pacific all display a mix of coking, FCC and hydrocracking additions, with the latter leading the way. In the Middle East, conversion additions (0.75 mb/d) are geared towards both meeting growing regional demand and supplying clean products for export. In Africa (0.6 mb/d), China (1.2 mb/d) and Other Asia-Pacific (0.7 mb/d), the conversion additions are geared more towards satisfying domestic demand. In the Russia & Caspian region (0.5 mb/d) the additions continue to derive from recent changes in tax policy designed to encourage refiners to upgrade away from heavy fuel oil production. Geographically, the additions are widespread, but are heavily focused on developing regions where there is significant demand growth.

Desulphurization units

Medium-term desulphurization unit additions are expected to equate to 74% of new distillation capacity. Of this projected additional capacity, close to 1.5 mb/d is for naphtha processing, 0.7 mb/d for gasoline, 2.5 mb/d for distillates and 1.2 mb/d for heavy streams (vacuum gasoil and residuum).

The naphtha desulphurization additions stem mainly from the 1.3 mb/d of new global catalytic reforming capacity. The gasoline additions relate primarily to the processing of FCC naphtha to ULS standards. The distillate additions – 42% of the total – reflect the current drive, in developing regions especially, to implement low and ULS standards for diesel, and potentially also preparations for the impact on marine diesel demand from the 2020 IMO Sulphur Rule. The vacuum gasoil/resid additions reflect mainly a mixture of FCC and RFCC pre-treatment, and resid desulphurization in the Middle East and the Asia-Pacific, in part for IMO 2020, plus minor lube oils processing.

As noted, the relative 'front-loading' of desulphurization additions in the years 2019 through 2021 may relate in part to refiners reacting to the MARPOL Annex VI Sulphur Rule now set for 2020. However, the primary reason for the significant desulphurization additions would still appear to be the number of low sulphur and ULS gasoline and diesel programmes that are now moving ahead.

The fact that OECD countries have largely completed the implementation of ULS standards for gasoline, diesel and heating oil means that the continuing shift of non-OECD countries towards Euro 3/4/5/6 standards is the main force driving global hydrotreating capacity expansion.

This effect is evident in the desulphurization projects. Projected additions in the US & Canada and Europe total only 0.2 mb/d each over the medium-term period. In contrast, additions in the Middle East total 1.9 mb/d and 2.5 mb/d in Asia as an array of new refinery projects and upgrades come online with a major drive toward high refinery complexity and the ability to produce fuels generally to Euro 5 standards. Additions in the Russia & Caspian region are forecast at 0.5 mb/d. They are driven, as with conversion additions, by the effects of the new tax regime, as well as regulations to meet ULS gasoline and diesel standards. New desulphurization capacity in Africa is projected at 0.5 mb/d, indicating further progress on the continent towards tighter 'AFRI' fuel standards, while Latin America lags at 0.1 mb/d.

The concentration of additions in mainly non-OECD countries reflects trends towards cleaner domestic products, but also the efforts of export-oriented refineries to provide products that better comply with advanced standards, generally Euro 5 or 6.

Octane units

Octane unit additions are estimated at 24% of incremental distillation in the medium-term. As noted, this is above the 19% level for base global refinery capacity as of early 2019 and reflects the fact that octane levels are being raised and/or total gasoline output is being increased essentially across all developing regions.

In line with this, the Middle East and Asia continue to dominate additions, (at 0.5 and 0.8 mb/d respectively), with 0.3 mb/d in Africa. The outlook for Latin America is for only minimal medium-term additions of less than 0.05 mb/d. In Europe and the Russia & Caspian, additions are at or below 0.1 mb/d in each case, reflecting minimal gasoline demand growth. In the US & Canada, additions of somewhat over 0.1 mb/d result from the shift toward a lighter crude slate and the resulting need to process incremental naphtha supplies to raise their octane level.

The 1.9 mb/d of octane unit additions is comprised mainly of catalytic reforming at 1.3 mb/d, or 67% of the total. The remainder is split between isomerization (0.3 mb/d), alkylation (0.2 mb/d) and methyl tertiary butyl ether (MTBE) units (0.1 mb/d). In Europe, MTBE consumption levels are flat. In the US, the use of MTBE was effectively banned in 2006, though some 70,000 b/d of MTBE and related oxygenates is still exported from merchant plants on the US Gulf Coast. In terms of MTBE projects, these are predominantly in the Middle East and Asia, notably China, where there continues to be interest in expanding MTBE use to meet rising gasoline pool octane requirements.

5.3.2 Medium-term implications for refined products supply and demand balances

In assessing the effects of capacity additions on regional product balances, it needs to be recognized that refiners have some flexibility to optimize their product slate depending on market circumstances and seasonality. This can be done by changing feedstock composition and by adjusting process unit operating modes. Taking this into account, Table 5.7 presents an estimation of the cumulative potential incremental output of refined products resulting from existing projects by major product category.

Table 5.7
Global cumulative potential for incremental product output*, 2019–2024 *mb/d*

	2019	2020	2021	2022	2023	2024	Share of additional output %
Gasoline/naphtha	0.6	1.1	1.4	1.8	2.0	2.1	27
Middle distillates	1.1	1.8	2.5	3.1	3.4	3.6	47
Fuel oil	–0.2	–0.3	–0.1	–0.1	–0.1	–0.1	–1
Other products	0.6	0.9	1.3	1.7	1.9	2.1	27
Total	**2.0**	**3.5**	**5.2**	**6.5**	**7.3**	**7.7**	**100**

* *Based on assumed 90% utilization rates for the new units.*
Source: OPEC.

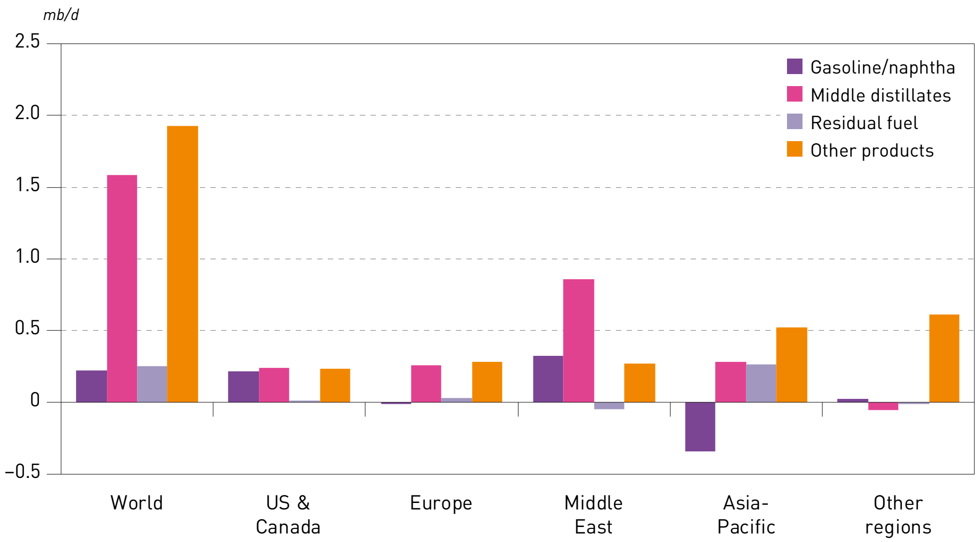
As already highlighted, the incremental medium term potential from refining is projected at around 7.7 mb/d. This is under the assumption that new refinery units are run at maximum 90% utilization rates. Furthermore, the estimates do not include refinery closures.

The resulting projections continue the pattern evident in recent Outlooks in terms of the proportions of incremental supply by major product category. Light, clean products predominate, led by distillates and there is no incremental supply of residual fuel oil. In turn, this reflects broadly similar proportions of new secondary processing, especially upgrading, relative to new distillation capacity. Almost half (47%) of the increase by 2024 is for middle distillates (3.6 mb/d) and another 2.1 mb/d (27%) for light products, specifically naphtha and gasoline. Assuming that new secondary units are run at 90%, the ability to produce fuel oil declines initially in the period, but by 2024 it is only 0.1 mb/d lower relative to 2018. The ability to produce 'other products' is projected to rise by 2.1 mb/d, or 27% of the total incremental product output.

Figure 5.19 compares the potential additional regional output by major product group from assessed projects (Table 5.7) to projected incremental regional demand for the period 2018–2024. In assessing net incremental requirements by product, Figure 5.19 takes into account product supply coming from non-refinery streams, notably additional biofuels, CTLs, GTLs and NGLs.

As already mentioned, the overall medium-term outlook is for incremental refining potential of 7.7 mb/d *versus* incremental requirements of 3.75 mb/d, leading to a cumulative surplus of nearly

Figure 5.19
Expected surplus or deficit* of incremental product output from existing refining projects, 2019–2024



* *Declining product demand in some regions contributes to the surplus.*
Source: OPEC.

4 mb/d by 2024. The trend towards a growing excess of refinery output potential compared to refined product requirements was previously described from the perspective of overall distillation capacity. This analysis shows the breakdown as net surpluses/deficits by major product group, both globally and regionally, based on the same underlying figures.

While gasoline/naphtha and residual fuel are broadly balanced at the global level, middle distillates and other products show significant surpluses. Gasoline/naphtha shows a surplus of 0.2 mb/d at the global level. However, at the regional level, two regions stand out – the Middle East will have a surplus of around 0.3 mb/d of gasoline and naphtha, while the Asia-Pacific shows a deficit of 0.35 mb/d in the period to 2024. Regarding fuel oil, only the Asia-Pacific shows a significant surplus of nearly 0.3 mb/d, while other regions are balanced in the medium-term. This is because fuel oil demand growth is negative over this timeframe, slightly more negative than the incremental supply potential.

The two product groups that show the largest surpluses are middle distillates and 'other products', which reach levels of around 1.5 mb/d and 2 mb/d, respectively by 2024. While middle distillates show the highest demand increment of all product groups at the global level, the recent investment focus on middle distillate capacity in refinery additions results in significant medium-term additions. Moreover, the recent downward revisions to middle distillate demand have also contributed to an increasing capacity surplus. Furthermore, non-refinery streams, notably biofuels and GTLs and CTLs, increase considerably over the medium-term, reducing the call on refining.

It should be noted that the distribution of the global surplus is not even at the regional level. Some regions such as Latin America and Africa will have a combined deficit of around 0.3 mb/d by 2024. This is more than offset by significant surpluses from the Middle East (0.8 mb/d), the US & Canada and Europe (0.25 mb/d each). This is where trade will come into play to offset the regional imbalances.

Finally, the expected surplus of over 2 mb/d in 'other products' is based on the projected surge in NGLs supply growth and that this will be well in excess of demand growth mainly for LPG and ethane in the medium-term. The surplus is distributed over several regions, including the US & Canada, the Middle East, the Asia-Pacific, as well as other regions. This is the sector where competition between oil-based and gas-based streams is obvious. According to estimates, the surplus in 'other products' would be significantly lower at around 0.7 mb/d in 2024 if the NGLs growth were not to materialize.

One implication of this analysis is that, globally, it indicates refiners will have to operate their newly added capacity at utilization rates below 90% to avoid creating excess product supply. Adding together the surpluses for gasoline/naphtha, middle distillates and residual fuel, plus part of that for 'other products', points to a needed 'turn down' of at least 2 mb/d of refined product output. Associated with this, the model results indicate that refiners will need to rebalance yields by changing refining operations to reduce the potentially high surplus of middle distillate output. Since the majority of the overhang in 'other products' relates to surging NGLs supply, the issue there may be that the market will need to adapt by leaving more ethane in natural gas streams (effectively reducing supply) and/or by finding additional outlets for LPG.

The overall picture points towards increasing medium-term competition in the markets for middle distillates, as well as 'other products', including LPG and ethane. The emergence of Middle East middle distillate production capacity is likely to become the major challenge for competing refineries in other regions. Furthermore, increasing trade in gasoline/naphtha supply can be expected over the medium-term, potentially with rising exports from the Middle East to the Asia-Pacific.

5.3.3 Long-term secondary capacity additions

Refining capacity is generally denoted by 'primary' distillation capacity. However, it is the 'secondary' capacity, which includes conversion and product quality improvement units, that is crucial for processing crude fractions into finished products – and which deliver most of a refinery's 'value-added'. Hence, the importance of 'secondary' processes is a key gauge in the refining sector's capability to meet final product demand.

Today, essentially all major projects for new refineries and large expansions comprise complex facilities with high levels of upgrading, desulphurization and related secondary processing. In addition, many new refineries are being designed to be able to process heavy, low quality crudes and those which have a high Total Acid Number (TAN), as well as better quality grades, and/or to produce petrochemical feedstocks, such as propylene and aromatics.

In the US and in Asian countries, such as India, FCC unit yields are often geared to maximizing propylene output and catalytic reformer yields are geared to producing aromatics. More broadly, the number of large integrated refining plus petrochemicals 'mega-projects' continues to rise, especially in the Middle East and Asia. Smaller projects at existing refineries are generally directed towards the same upgrading goals of reducing residual fuel output and achieving quality improvements for clean products.

Together, these factors are leading to greater proportions of secondary capacity per barrel of distillation. One exception to this trend is the high volume of new condensate splitter capacity recently, or currently being built, primarily in the US and the Middle East. Condensate splitter capacity tends to bring with it only limited secondary processing, often centred on catalytic reforming, isomerization and hydrotreating of lighter fractions.

Projections for future required secondary processing through 2040 are presented in Table 5.8. Similar to those for crude distillation units, projections for secondary process units take into account the 2.1 mb/d of refinery net closures assumed for the period 2019–2025. These not only

Table 5.8
Global capacity requirements by process, 2019–2040

mb/d

	Existing projects to 2024*	Additional requirements 2024–2030	2030–2040	Total additions to 2040
Crude distillation	**7.9**	**4.2**	**4.4**	**16.5**
Conversion	**4.2**	**1.9**	**2.7**	**8.8**
Coking/Visbreaking	1.1	0.2	0.5	1.9
Catalytic cracking	1.06	1.3	1.3	3.6
Hydrocracking	2.0	0.5	0.9	3.4
Desulphurization**	**4.5**	**10.1**	**3.5**	**18.0**
Gasoline	0.7	0.8	0.7	2.1
Distillate	2.5	8.7	1.3	12.6
VGO/Resid.	1.2	0.6	1.5	3.3
Octane units***	**1.9**	**1.7**	**1.6**	**5.2**
Catalytic reforming	1.3	1.0	1.0	3.3
Alkylation	0.2	0.3	0.3	0.8
Isomerization	0.3	0.1	0.1	0.4
MTBE	0.1	0.3	0.2	0.7

* *Existing projects exclude additions resulting from 'capacity creep'.*
** *Naphtha desulphurization not included.*
*** *New units only (excludes any revamping).*
Source: OPEC.

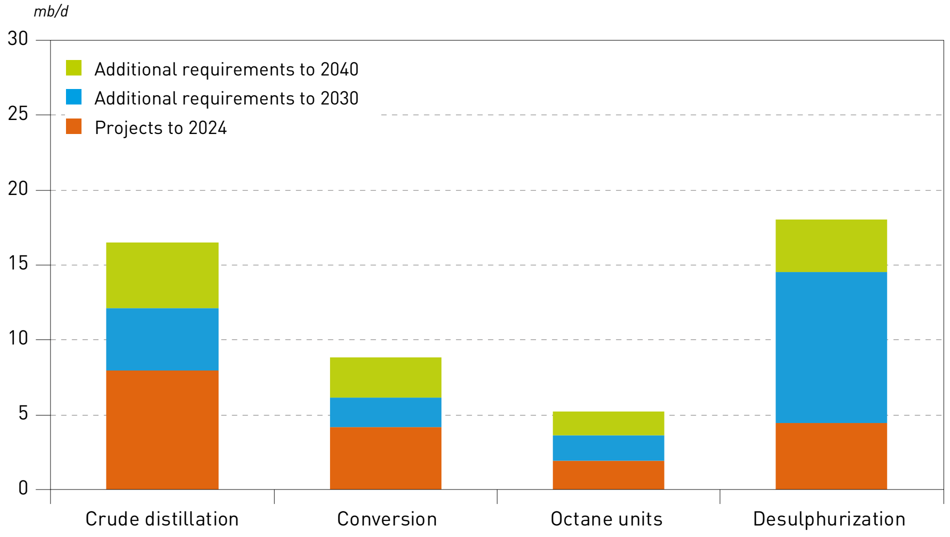
remove distillation, but also, in many cases, the associated secondary unit capacity. As a result, projected total additions are somewhat higher than they would have been had no closures been assumed. At the global level, projections indicate the need to add some 8.8 mb/d of conversion units, 18.0 mb/d of desulphurization capacity and 5.2 mb/d of octane units in the period to 2040.

As shown in Table 5.6, existing projects to 2024 have conversion additions at 53% of new distillation capacity. Table 5.8 and Figure 5.20 illustrate that this level is projected to be broadly maintained through 2040. Desulphurization unit additions are projected to continue throughout the period to 2040, but with the largest additions expected in the period 2024–2030. This is based on the projection that by 2030, most regions will have largely completed the shift to ULS fuels and that additional desulphurization capacity post-2030 will be restricted only to regions with additional demand growth for clean products.

Octane units will see additions both pre- and post-2030. This is based on the long-term projection that the octane levels in gasoline will progressively increase around the world, approaching the levels currently seen in more industrialized countries. Moreover, levels in industrialized countries themselves are expected to keep rising in order to improve engine efficiency.

It is important to bear in mind that the projections needed for conversion and desulphurization additions are sensitive to the extent to which the 2020 IMO Sulphur Rule is met by the use of onboard scrubbers, which would allow the continued use of HSFO, *versus* 0.5% sulphur fuels. As discussed in Chapter 3, the outlook is that scrubbers will become widely used with a rising share of HSFO in the marine fuel mix. However, there remain uncertainties concerning scrubbers,

Figure 5.20
Conversion capacity requirements by process type, 2019–2040



Source: OPEC.

especially the more common 'open-loop' form. Thus, any turn away from expected scrubber use would increase the call on the refining industry to add VGO/resid desulphurization and/or upgrading plus distillate desulphurization capacity relative to what is included in this outlook.

Conversion units

Expectations for additions of 1.1 mb/d of coking/visbreaking capacity to 2024 – predominantly coking – leads to a period of relatively limited additions of 0.2 mb/d from 2024–2030 then 0.5 mb/d from 2030–2040. The slowdown in additions between 2024–2030 arguably points to a degree of overbuilding in the projects to 2024, especially given the effects of declines in Latin America heavy crude production and projected further increases in light tight oil supply. Additions are projected to continue post-2030 because incremental demand is overwhelmingly for light clean products, while, in parallel, the longer-term incremental crude supply gradually reverts toward medium and high sulphur crude grades. This trend is moderated, however, by a gradual, albeit small, recovery in residual fuel demand over time.

Future coking additions and utilization will, of course, be sensitive to heavy crude developments in countries such as Canada, Venezuela, Brazil, Colombia and Mexico, as well as the Middle East.

Catalytic cracking (FCC) additions are driven primarily by gasoline demand. Globally, this is projected to rise from 25.9 mb/d in 2018 and peak at 28.4 mb/d in 2030, before falling to 28.1 mb/d by 2040. However, this trend masks the fact that demand in Latin America, Africa, the Middle East and the Asia-Pacific continues to grow. In these regions, the rate of growth slows, but gasoline demand is projected to rise by 2.9 mb/d from 2018–2030 and another 1.9 mb/d from 2030–2040. This continued growth in developing regions helps sustain the need for new FCC and other gasoline units, despite the parallel demand declines in the industrialized regions. On top of 1.1 mb/d of projects, FCC additions of 1.3 mb/d are seen as needed for the six years from 2024–2030 and the ten years from 2030–2040. Again, the pace of additions slows, but new capacity continues to be required.

Hydrocracking additions start with a substantial 2.0 mb/d of projects from 2019–2024. This surge arguably moderates the need for further near-term additions, hence only 0.5 mb/d of additions are projected for 2024–2030. Together, however, these amount to around 0.2 mb/d p.a. of average additions for 2019–2030, which then declines to around 0.1 mb/d p.a. from 2030–2040. This slowing pace for additions is consistent with the projection for a deceleration in distillates demand growth over the longer-term . Jet/kerosene plus diesel/gasoil demand growth of 3.7 mb/d from 2018–2030 drops to under 0.5 mb/d from 2030–2040.

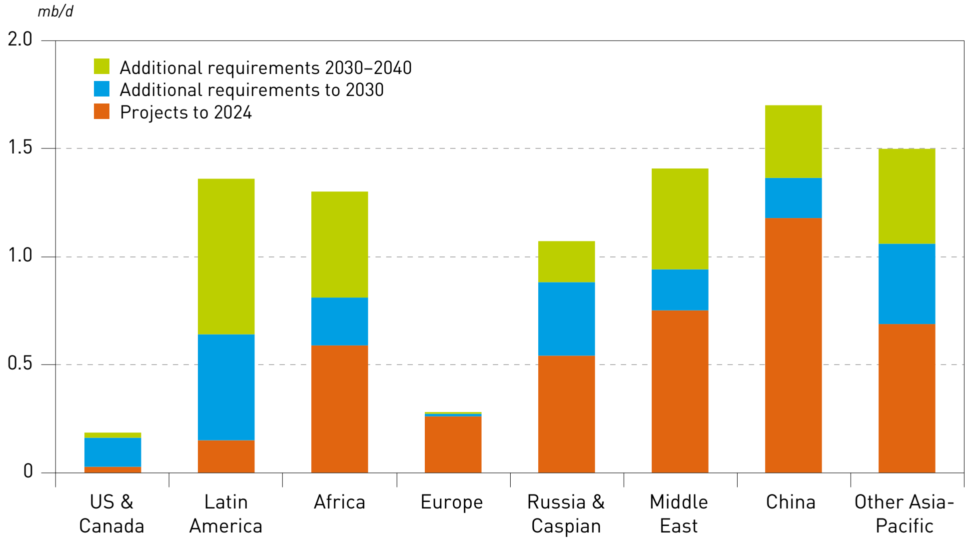
The varying outlooks across specific conversion units are also reflected in the utilization rates indicated by the Outlook's modelling. Hydrocracking unit utilization is projected to be consistently high – in the low 80% range – through the period to 2040. This is supported by continuing, albeit slowing distillates demand growth. FCC unit utilization is projected to drop from not far below 80% in the short-term to the 76–77% range post-2030. This trend in global average utilization is a reflection of the hub that capacity additions and relatively high utilization in developing regions will be offset by gasoline demand declines in the US & Canada and other industrialized countries. One clear implication is a need for FCC unit closures, potentially as part of full refinery closures, in these regions.

In the short-term, the IMO Sulphur Rule is expected to drive refiners to sustain or raise coker throughput to dispose of excess high-sulphur heavy residual streams. Thereafter, utilization is expected to steadily fall as additional coker capacity comes onstream in parallel with a take-up of onboard scrubbers, as assumed in this Outlook. As previously stated, these lead to a partial return back to high sulphur marine fuel, from 0.5% distillate and heavy grades.

As a result, utilization at coking units is projected to drop sharply, from around 80% currently to around 70% by 2025, and then to recover moderately to the 72–73% range through 2040. As with FCC additions, these projections imply a need for future selected coker closures, something that has historically been rare.

The regional distribution of total future conversion capacity additions is presented in Figure 5.21. Consistent with the general refinery addition trends, requirements are expected to be led by the

Figure 5.21
Conversion capacity requirements by region, 2019–2040



Source: OPEC.

Asia-Pacific, at around 36%, or 3.2 mb/d, of total future conversion additions to 2040, and the Middle East, with 16%, or 1.4 mb/d.

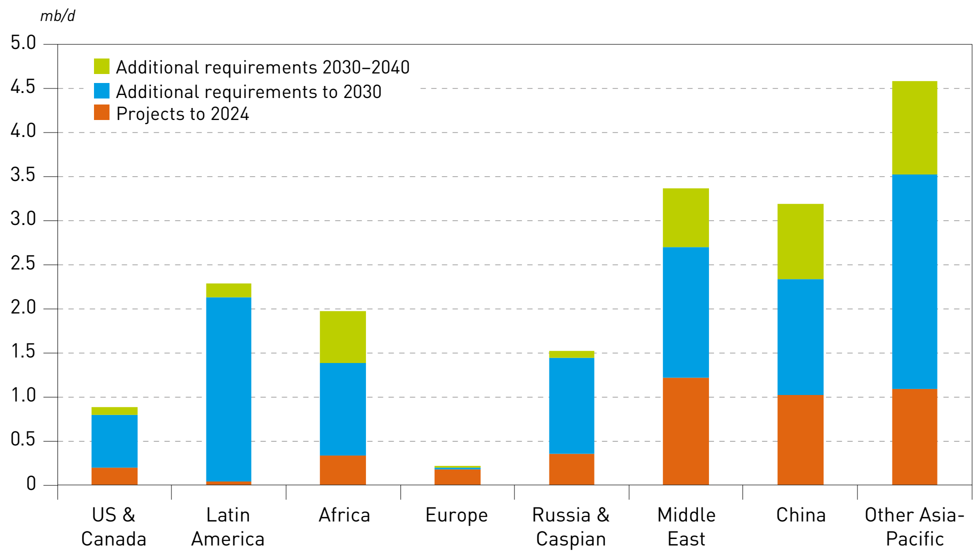
Significant additions are also projected for Latin America and Africa, at around 1.4 mb/d and 1.3 mb/d, respectively. These are driven by sustained regional product demand growth with the bulk of additions in the longer-term . Additions in the Russia & Caspian region to 2040 are estimated at 1.1 mb/d, occurring mainly in the period to 2030. Overall, it is the non-OECD region that will sustain conversion capacity growth over the period to 2040. Only 5% of conversion capacity growth to 2040 is expected in the US & Canada and Europe.

Desulphurization units

In addition to conversion, desulphurization capacity is another important component of secondary units. Driven by the progressive move towards near universal ULS gasoline and diesel standards in the long-term, plus expected reductions in sulphur content for jet fuel, heating oils, as well as marine fuels, desulphurization additions represent the largest capacity increases among all process units over the forecast period.

With OECD regions already largely at ULS standards for gasoline and diesel, the focus is shifting to non-OECD regions as they progressively move towards low and ULS standards for domestic fuels and as they build export capacity to produce fuels at advanced ULS standards. Over and above the 4.5 mb/d of desulphurization capacity (excluding naphtha desulphurization) that is included in assessed projects to 2024 (Table 5.6), a further 10.1 mb/d is projected to be needed by 2030, and an additional 3.5 mb/d between 2030 and 2040 (Figure 5.22). This leads to additions totalling 18.0 mb/d by 2040, which is more than the 17.8 mb/d of total crude distillation capacity additions by 2040. The stated gasoline desulphurization additions exclude those for naphtha desulphurization, which is mainly associated with a front-end step in catalytic reforming. Naphtha desulphurization capacity additions are included in Table 5.8.

Figure 5.22
Desulphurization capacity requirements by region*, 2019–2040



* *Projects and additions exclude naphtha desulphurization.*

Source: OPEC.

Two features stand out. Firstly, while major new refinery projects are designed with significant built in desulphurization capacity, the high-level of total desulphurization additions relative to distillation points to substantial desulphurization additions occurring at existing refineries, especially in developing regions, as they adapt to meet progressively tighter fuel sulphur standards.

Secondly, a considerable slowing in the pace of desulphurization capacity additions is apparent in the decade from 2030–2040, compared to the period 2024–2030. This follows the projection that most regions will see gasoline/distillate fuel volumes reach ULS standards by 2030. Furthermore, while global demand for the gasoline/jet-kerosene/diesel-gasoil product group is expected to grow by 6.3 mb/d from 2018–2030, additional net global growth post-2030 is seen as minimal. However, this is again made up of demand losses in industrialized regions, which is offset by gains in developing regions that call for capacity increases.

In terms of the regional breakdown (Figure 5.22), total additional global desulphurization capacity of 18.0 mb/d by 2040 is projected to be led by the Asia-Pacific at 7.8 mb/d, of which China comprises 3.2 mb/d. The Middle East follows with 3.4 mb/d and then Latin America with 2.3 mb/d and Africa at 2.0 mb/d. Again, the drivers are demand growth, the expansion of the refining base and stricter quality specifications for domestic fuels.

Significant additions are also projected for the Russia & Caspian region (1.5 mb/d), which is in line with the region's tightening domestic quality standards and the intent to produce diesel to ULS standards for both domestic use and export to Europe.

The expected 0.9 mb/d requirements for the US & Canada comprise 0.2 mb/d from current projects, plus minor long-term additions, in part to deal with high sulphur crude from oil sands. The lowest desulphurization capacity additions are projected for Europe, with less than 0.2 mb/d over the forecast period, where transport fuels are already at ULS standards, and both demand and refinery throughput are projected to continue to decline.

Octane units

For octane units, future requirements are projected at 5.2 mb/d throughout the forecast period. The majority of these units are expected to be required in the form of catalytic reforming at 3.3 mb/d, with alkylation at 0.8 mb/d, isomerization at 0.4 mb/d and MTBE units at 0.7 mb/d. Reforming and isomerization raise the produced naphtha's octane content and thus enable additional naphtha – including that from condensates – to be blended into gasoline. MTBE and associated ethers are used (outside the US) either to meet oxygen content requirements in gasoline and/or to boost octane levels.

In line with other secondary processes, most of these additions are projected for the Asia-Pacific and the Middle East, the two regions with the largest gasoline demand increases and expanding petrochemical industries. Together, these account for 64% of the total expected octane unit additions to 2040. Latin America and Africa are also projected to have significant octane unit additions as their gasoline standards rise, each accounting for roughly 10% of the total additions.

With gasoline demand projected to be flat through 2025 and then gradually decline, the US & Canada is expected to see 0.4 mb/d, or 8%, of total additions, most of which will be in place by 2025–2030, as a result of the need to process naphtha from light tight oil into gasoline. Additions in Europe and the Russia & Caspian are projected to be minor, at 2% and 4%, respectively.

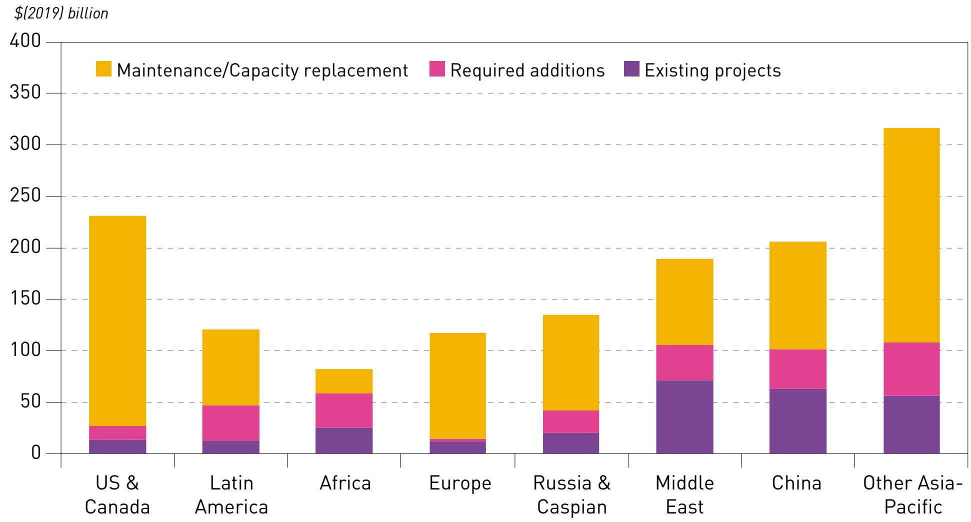
Of the projected MTBE capacity additions totalling 0.7 mb/d to 2040, the majority, nearly 65%, are in the Middle East and the Asia-Pacific, with the balance spread across all regions, except for the US & Canada where MTBE is not used.

5.4 Investment requirements

Downstream sector investment requirements are highlighted in three separate categories. The first category relates to identified projects, which are expected to be commissioned in the medium-term (2019–2024). The second category is related to long-term investments in further new capacity beyond known projects. The third category focuses on the continuous maintenance of the global refining system and covers necessary capital replacements throughout the projection period.

For the first category (Figure 5.23), the total medium-term investment requirement is estimated at around $275 billion, similar to investment levels estimated in the WOO 2018 for the period 2018–2023. The regional distribution of this amount is uneven and follows the regional developments and capacity additions. The largest share of investments is projected to occur in the Asia-Pacific and the Middle East, the regions with the largest medium-term capacity additions. The major driver for these expansions is increasing demand.

Figure 5.23
Refinery investment, 2019–2040



Source: OPEC.

Combined investment for the two regions is seen at $190 billion, which is almost 70% of the global investment requirement. This is relatively stable compared to the WOO 2018. Asia-Pacific investment requirements alone are estimated at around $120 billion in the medium-term, of which $63 billion is located in China, while the remainder is distributed across the rest of the Asia-Pacific region, notably projects in India, Vietnam, Malaysia, Indonesia and Pakistan.

Medium-term additions in the Middle East are expected to result in investment of around $72 billion, with new projects across the region, including in Saudi Arabia, Kuwait, IR Iran, Iraq, Oman and the UAE. The rise of investment in the downstream sector is not only supported by the region's increasing demand but also by the efforts to increase refined product exports to other regions.

All other regions show lower investment levels, totalling around $85 billion by 2024. In Africa, investment is estimated at around $25 billion, driven mostly by one large project in Nigeria. Investment in the Russia & Caspian region is seen at around $20 billion, due not only to the expansion of distillation capacity but also because of further upgrades to secondary capacity at existing refineries.

In the US & Canada, around $14 billion is expected to be invested in the medium-term with one major new project. The increase in light-sweet supply has also reduced the need for upgrading capacity, which limits the amount of required investments in this region.

In Latin America, the investment volume is seen at around $13 billion, based on minor refining system expansions and no major new projects. Repeated delays and the cancellation of refinery projects have lowered the capacity outlook for this region in recent years, which is reflected in its investment volume.

The lowest investment volume is projected for Europe at $12 billion, mostly driven by the new refinery project in Turkey.

Looking at the expected long-term capacity additions (Figure 5.23), after the medium-term period ends in 2024, there are significant assessed investments needed for the period 2025–2040 to maintain sufficient refining capacity to balance demand at the global and regional levels. According to the estimates, investments of around $230 billion will be required in the period until 2040.

Looking at the various regions, the majority of investments will be located in the Asia-Pacific (excluding OECD Asia-Pacific) driven by demand growth in the region's developing countries. Investment volumes in China and Other Asia-Pacific are assessed between $40 and $50 billion, which is lower compared to medium-term levels. At the same time, investments in the Middle East are projected at around $30 billion, which is less than half of the medium-term investments. This underscores the expected overall slowdown in capacity additions after the medium-term period.

Latin America and Africa are projected to have investment levels of close to $35 billion each, based on significant additions and rising oil demand after the medium-term period. African domestic feedstock is mostly sweet, which keeps investment in secondary units, such as desulphurization, lower relative to other comparable regions such as Latin America.

In the Russia & Caspian region, investments (mostly in secondary units) are estimated at below $22 billion, which is understandable given the focus on export markets, such as Europe, that have stricter product specifications.

The US & Canada is projected to see some further limited investments beyond the medium-term, estimated at around $14 billion, mostly stemming from secondary unit investments.

Finally, Europe's refinery investments beyond the medium-term are assessed at merely $2 billion, reflecting only some minor projects at existing refineries. Due to declining oil demand, this region is likely to see a high level of medium-term project closures, which is anticipated to continue in the long-term.

Altogether, capital investments in the global refining system in the medium- and long-term are seen at around $505 billion.

Finally, maintenance requirements and the 'capital replacement' of installed refining capacity over the forecast period will need associated investments of around $890 billion. The assessment of this investment category is based on the assumption that the annual capital needed for capacity maintenance and replacement is around 2% of the cost of the installed base. Based on this approach, the largest share of medium-term maintenance costs will occur in developed countries, as these countries have the highest levels of base capacity. In the long-term, however, the share of maintenance and replacement costs will increase in favour of non-OECD countries.

In summary, the total of the three downstream investment categories is estimated at $1.4 trillion in the period 2019–2040. Of this, $275 billion is expected to be invested in known medium-term projects and $230 billion is anticipated to be invested into long-term additions beyond known projects. The investment requirement for maintenance and replacement is estimated at around $890 billion for the whole period from 2019–2040.

5.5 Refining industry implications

There is a wide disparity between the 7.9 mb/d of medium-term projects assessed as firm – and even the total 16.5 mb/d of additions assessed as needed to 2040 – when compared with the 'inventory' of announced refinery distillation additions that exceeds 24 mb/d. Essentially, all of the listed 24 mb/d of projects have stated completion dates of no later than 2024, against which the current outlook is for 9 mb/d of total needed additions by 2025. It is widely recognized that refinery projects tend to 'slip', pushing start-up dates farther into the future. Moreover, many announced projects simply do not make it to construction and start-up.

Even so, the high level of declared projects points to a disconnect between the additional capacity that is rationally needed in the next five-to-ten years and what refining companies perceive as warranted. Either many of the projects currently listed will need to be modified, deferred or cancelled, or the tendency to over-build, as is evident in the medium-term, will remain.

The projected rate of required additions slows post-2025, to the global level of 0.4 mb/d to 0.5 mb/d annually. Today's new refineries, or major expansions, generally have 0.3 mb/d to 0.4 mb/d or more as initial capacity. The implication is that it will become increasingly difficult to justify building a large grass-roots refinery. Rather, as has been evident for some time in most industrialized and some industrialising countries, expansions will come from debottlenecking and the upgrading of existing facilities. These projects will likely be partially offset by the retirement of older, less efficient process units and/or entire refineries.

Finally, the modelling that generated the projections for refinery additions was undertaken assuming that a slow recovery in the tanker market and, especially the 2020 IMO Sulphur Rule would raise tanker freight rates, most notably in the short- to medium-term. Higher freight rates can impact trade patterns, and higher dollar per tonne differentials between crude and product movements tend to support curbing transport activity and raising refinery investments in demand-growth centres. Thus, higher freight rates tend to support increased refinery investment and vice versa. The outlook for freight rates therefore needs to be monitored, in part, because of its potential to impact refinery additions and investments.

Over the longer-term , a high uptake of scrubbers on vessels would moderate the cost of inter-regional marine movements *versus* a low-scrubber-take-up scenario. How freight rates play out will thus affect the ability of refineries in regions and countries such as Europe, the US and even Japan, to compete for expanding markets in developing regions. In turn, this could either reduce or raise the level of capacity additions needed in developing regions *versus* the current projections. Lower freight rates would also help to keep more refineries in industrialized regions open.

Oil movements

Key takeaways

- Global crude oil and condensate exports are expected to fall from almost 38 mb/d in 2018 to 37.5 mb/d in 2025 due to higher local crude use in some crude-producing regions.
- While crude exports to the Asia-Pacific are seen remaining stable in the period to 2025, exports to all other destinations are likely to decline. At the same time, the local use of crude in the Middle East is estimated to rise by almost 1.5 mb/d.
- After 2025, global crude and condensate trade is expected to reach levels close to 42 mb/d, based on higher flows out of the Middle East. At the same time, export volumes from most other regions are anticipated to decline after 2025.
- Middle East crude exports are forecast to increase from around 16 mb/d in 2025 to slightly above 23 mb/d in 2040, predominantly driven by rising flows to the Asia-Pacific and Europe.
- Oil flows from Latin America are expected to remain between 4.2 mb/d and 4.6 mb/d through to 2040, balanced between rising supply and higher local use as refinery capacity increases. The US & Canada and the Asia-Pacific are the major markets for Latin American crude.
- Oil exports from the Russia & Caspian region are projected to increase slightly from 6.6 mb/d in 2018 to 6.8 mb/d 2040, with a rising focus on the Asia-Pacific based on pipeline expansions such as the Eastern Siberia-Pacific Ocean pipeline (ESPO). Europe is nonetheless expected to remain the main outlet for crude from the Russia & Caspian region.
- After an initial increase to almost 6 mb/d in 2020, African crude exports are set to decline. This is mostly due to higher local use as refinery capacity increases. Crude flows from Africa are seen below 5 mb/d in 2040, with Europe and the Asia-Pacific the main destinations for African barrels.
- In line with rising supply, crude exports from the US & Canada are anticipated to increase strongly to 2025, reaching levels just below 5 mb/d, up from 1.8 mb/d in 2018. Exports, which are generally light-sweet US crude, are seen going to all major importing regions.
- The US & Canada will remain a crude importer throughout the period, although volumes decline significantly. Imports were around 4.3 mb/d in 2018, but these are expected to decline to 2.1 mb/d in 2040, mostly heavy grades from Latin America.
- European crude imports are expected to decline gradually from around 9.6 mb/d in 2018 to 8.6 mb/d in 2040. Europe's import mix is dominated by the Russia & Caspian region, although the US & Canada is anticipated to see rising medium-term volumes and the Middle East is likely to send more barrels towards the end of the projection period.
- On a net import basis, the Asia-Pacific is expected to see rising refined product imports between 2020 and 2040, which will be balanced by rising net product exports from the Middle East and the US & Canada. Product net imports in other regions are forecast to remain stable throughout the period.

Trade movements of crude oil, intermediate and refined products are crucial elements of the global oil market and are responsible for the integration of different regions into the overall global system. This Chapter describes projected crude and product flows based on the assumptions presented throughout this Outlook, including assumptions related to logistics.

6.1 Logistics developments

The development of logistics infrastructure is crucial for maintaining oil exporting capability and the availability of products to markets. Crude oil and product movements tend to vary with the type of infrastructure developed. For crude oil, this is mainly pipelines that can move important volumes and provide economies of scale and, to a lesser extent, rail systems. Developing infrastructure from pipeline, coastal terminals and berthing capacity for moving crude and oil products, including liquid hydrocarbons, is key to accessing new international markets and providing export flexibility.

Certain regions require continuous attention because of their potential to alter inter-regional crude trade. This applies especially to China, the Middle East, the Russia & Caspian and US & Canada regions.

6.1.1 US & Canada

In recent years, the growth of US tight oil and Canadian oil sands production has led to a massive build-out and re-orientation of the region's crude oil logistics system. In the US, this has primarily been to take large new production volumes to the coasts – instead of bringing imported crudes inland. Pipeline capacity in western Canada, cross-border from western Canada into the US and east to Ontario and Montreal has also been expanded. In parallel, substantial crude-by-rail capacity has been developed, especially from the Bakken and other US producing regions to the coasts, as well as to carry western Canadian production to eastern Canada and US destinations.

These production increases are ongoing. Canadian production has risen from 3.1 mb/d in 2012 to 4.2 mb/d in 2018 and is projected to hit 4.6 md/d by 2024 and then witness continued steady growth thereafter. US crude oil and condensate production rose from 6.5 mb/d in 2012 to 11.0 mb/d in 2018 and it is expected to rise to 13.5 mb/d by 2020 before peaking at 15.5 mb/d in 2024.

These substantial increases have run headlong into logistics constraints, resulting in widening discounts for regional crudes *versus* markers, notably Western Canadian Select (WCS) *versus* WTI and WTI *versus* Brent. For takeaway capacity out of western Canada, the issue has been generally one of delays and disputes in implementing a few well-defined pipeline projects; for the US, it has been more a matter of trying to keep up with rapid tight oil supply growth.

The cross-border pipeline system out of western Canada into the US is currently operating at its limit. Cross-border pipelines have a total capacity today of close to 4.2 mb/d, plus there is a nominal 0.85 mb/d of crude-by-rail loading capacity in western Canada. Regional refineries in western Canada consume around 0.5 mb/d of crude oil, but effective pipeline limits and the limited use of crude-by-rail, due to long-drawn-out contract negotiations, led to a situation in late-2018 where the outright WCS price had plummeted to heavy discounts to regional benchmarks such as WTI.

To alleviate this situation, the Alberta government imposed mandatory production limits, which are still in place. The limits have been partially relaxed, but Alberta has announced that they may remain in place into 2020. The temporary limits have led to a number of announcements by Western Canadian Select Basin (WCSB) producers that they will delay oil sands expansion projects. Data from the US Energy Information Administration (EIA) indicates that imports of Canadian crude oil into the US essentially stalled at 3.7 mb/d in 2018, but resumed a slow increase over the first half of 2019.

Alberta's mandated cutbacks have led to a marked short-term improvement in supply economics for western Canadian oil producers, but this does not mean they are 'out of the woods'. The reason is that Western Canada continues to be beset by delays to long-planned pipeline projects and faces issues in terms of restoring and maintaining capacity on existing pipelines. While rail can be used as an export option, in reality it is pipeline capacity that is the key to enabling further production growth in the WCSB.

After receiving a second Presidential permit, the long-running Keystone XL project appears close to finally proceeding, although there are still lawsuits pending. However, start-up is unlikely before 2021. Keystone XL would transport 830 tb/d of mainly heavy Canadian crude to the US Gulf Coast, supplying additional barrels to regional refiners that would offset lower heavy crude imports from Latin America. The line would also open up the possibility for WCSB crude oil exports via the Gulf Coast.

The second critical project for the WCSB is the expansion of the Trans Mountain pipeline from 300 tb/d to 890 tb/d. Crucially, this project would enable Canada to open up export markets other than the US, since the project would lead to most or all of the additional crude volumes being shipped by tanker from the pipeline's Westridge terminal near Vancouver. After undertaking what some deemed an extreme move of purchasing the pipeline project from Kinder Morgan in 2018, the Canadian government has recently announced that it will authorize the expansion, having received an additional review from the Canadian National Energy Board and having undertaken additional consultation with First Nations and other groups. Numerous permits are still outstanding, but the expansion could be up and running by late-2022.

At a combined 1.4 mb/d, Keystone XL and the Trans Mountain expansion should deliver more than enough incremental capacity to support Canadian production growth. However, there is still around three years before both projects are operational and there is always the possibility of further issues and delays.

In the immediate short-term, three pipeline companies have made announcements for small expansions to cross-border pipelines that would total approximately 200 tb/d of additional capacity in steps from early 2020 through early 2021. Together with some further crude-by-rail, these may be sufficient to keep up with supply increases from the WCSB for a year or two. Crude-by-rail exports from Canada to the US averaged 230 tb/d in 2018, have risen over 2019 to date, and could reach 400 tb/d by the end of the year. Rail volumes may be limited, though, by high costs, even though significant crude-by-rail loading capacity exists in Western Canada. It should be noted that the most likely destination for the additional pipeline and rail volumes would be the US Gulf Coast.

The main project expected to fill the short-term gap in cross-border capacity is the so-called Enbridge Line 3 Replacement. This project is slated to restore the line's original capacity by replacing the ageing existing pipeline. In doing so, it would add an effective 370 tb/d to cross-border capacity. As of a year ago, the project was moving ahead and start-up was expected for late-2019. However, environmental assessments have recently been ruled as inadequate, which means that start-up is now likely to be 2021.

On top of this, Enbridge is now in a dispute with the newly elected Michigan administration over how and when to replace an underwater section of Line 5, a 540 tb/d of capacity line carrying crude oil and NGLs from western Canada to the US Midwest and to Ontario. The state has sued to close the line over fear of leaks. In addition, Enbridge is being forced to consider replacing and relocating part of the line as a result of a lawsuit initiated by a Native American tribe in Wisconsin.

The net effect is that the export situation for western Canada is unlikely to improve significantly for at least the next two years – and could even deteriorate before it improves courtesy of Keystone

XL and the Trans Mountain expansion. Infrastructure limits are thus constraining (incremental) WCSB supply from reaching markets during a period of supply declines for other heavy crudes.

As already indicated, US crude oil and condensate production is projected to increase by a further 4.5 mb/d *versus* 2018 before plateauing at around 15.5 mb/d in 2024. It will then witness a gradual decline. Based on the quality of tight oil and the complex US refinery set-up, most of that incremental domestic production is likely to be exported.

With respect to the **US & Canada**, refinery throughput for 2025 is slightly above 2018 actual levels of 18.2 mb/d. US & Canada demand is projected to grow slightly to 2024/2025, supporting current run levels. With regard to crude oil imports, today these are predominantly medium to heavy, and generally sour grades, whereas incremental US production is predominantly light to very light, in the 40–55° API range. Average US refinery crude slates are in the 32–34° range and heavier on the West Coast. Therefore, the current crude oil import quality is well matched to US refineries and likely to be maintained, whereas the large share of the incremental US light tight oil production is not a good fit and so is likely to continue to be exported.

In 2018, US crude oil exports (including Canada) averaged 2.0 mb/d. This is *versus* 1.15 mb/d in 2017. It should also be noted that for January through July 2019, exports averaged over 2.8 mb/d. Adding expected production increases implies that the US could need to export between 4-6 mb/d of crude and condensates by the mid-2020s.

This begs the question: will the infrastructure be in place? Given the current pace of developments, the answer would appear to be yes, although the current logistics capacity is racing to catch up and the situation should be viewed as complex.

Firstly, there needs to be enough pipeline capacity to take incremental production to the coast, predominantly the Gulf Coast. Secondly, there needs to be adequate storage and terminal capacity to export the crude volumes, preferably in larger tankers than the historically utilized AFRAMAX size. Thirdly, substantial amounts of gas and gas liquids are being co-produced with tight oil and infrastructure for these volumes needs to be sufficient so as not to constrain crude supply and delivery. Finally, US NGLs and refined product exports are also expanding and thus infrastructure for this also needs to be developed alongside that for crude oil exports.

Pipeline takeaway capacity, especially from the Permian, is constrained, as is gas handling and transmission. Gas flaring is at a high level in the Permian, and prices paid for natural gas delivered to processing hubs in the region, notably the Waha gas hub, even dipped below $0/million British Thermal Unit (MMBtu) earlier in 2019. Pipelines are being built to transport natural gas to the Gulf Coast and there is an array of LNG projects at various stages of development, from announcement to completion. This is also true for NGLs handling, with additional pipeline capacity of almost 1.4 mb/d expected to come online by 2021. Combined, developments in these two areas should help ensure that gas and NGLs production does not constrain crude oil production moving forward.

In 2018, the Permian's crude oil pipeline takeaway capacity averaged 2.5 mb/d, plus 0.5 mb/d of crude-by-rail takeaway. Three new pipelines that will start up between the third quarter of 2019 and the first quarter of 2020 will add a total of nearly 2.2 mb/d of additional capacity. These additions should alleviate the current bottlenecks, with one potential result being a narrowing of the Brent-WTI differentials from their recent levels of $5–10/b. Assuming further listed projects all go ahead, these will lead to a total of potentially 7.6 mb/d of Permian-to-Gulf Coast capacity by end-2021 and 7.9 mb/d by end-2022, indicating flows out of the Permian should not be constrained by crude oil logistics.

Pipeline projects are also extending to several ports along the Gulf Coast, including the western Texas port of Corpus Christi. Current crude and condensate pipeline capacity into Corpus Christi is around 2 mb/d and this could increase to more than 5 mb/d by 2022, if all current slated projects go ahead. The region has significant local refining capacity and today is exporting around 0.7–0.8 mb/d. The Port of Corpus Christi has embarked on a plan, through dredging and other actions, to raise export capacity to 3 mb/d.

Overall pipeline capacity to the Gulf Coast could reach more than 9 mb/d or more by 2022. This is in excess of the potential US supply growth and is an indication that some pipeline projects may not be built. Nonetheless, the prospect is that there will be adequate capacity to get crude to the US Gulf Coast, including from the Cushing hub.

In addition, new pipelines are being built to take crude oil along the Gulf Coast, including to Louisiana where the Louisiana Offshore Oil Port (LOOP) is increasingly exporting, as well as importing crude oils. Very large crude carrier (VLCC) loadings for export there are rising rapidly. The reversal of the Capline pipeline to run north to south, planned for second half of 2020, initially around 300 tb/d, will further add to the amount of Bakken, Niobrara and Canadian crude supply that is able to reach Louisiana and LOOP. In addition, the reversed system will incorporate a link to Cushing.

Complementing the incoming pipeline capacity, a number of onshore and offshore crude loading terminals are at various stages of planning and development. These will not only add substantial export capacity, they will also lead to a shift from traditional smaller (AFRAMAX) tankers towards bigger ships. Partial loading of SUEZMAX and VLCCs, plus reverse-lightering, is already occurring today. Many of the expansions are planning to allow full VLCC loading. To date, some eight VLCC terminals have been proposed, but likely only two to three will materialize.

Thus, the overall outlook is for rising export capacity out of the Gulf Coast, from Corpus Christi in the west to St. James and LOOP in the east. Current crude and condensate export capacity of around 5 mb/d should increase significantly – despite some growing pains. Consistent with the trend to lighter production, and the resulting need to segregate, transport and export light crude oils and condensates, a new 44.1–49.9 °API West Texas Light grade has now been recognized.

6.1.2 Russia & Caspian

The pipeline systems out of the Russia & Caspian region (notably Russia, Azerbaijan and Kazakhstan) has a significant influence on crude oil flows and expansions will likely further amplify this influence. Currently, a large share of oil exports is transported via pipeline systems, such as the Druzhba pipeline system to Eastern Europe and the Eastern Siberia-Pacific Ocean (ESPO) pipeline to China and the Pacific Ocean. Russia is continuously developing its pipeline network and increasingly expanding it to rising demand centres, such as Asia, especially China.

In terms of expansions, the most significant change relates to the ESPO pipeline moving crude to China and the Pacific Coast. Current pipeline capacity is around 1.2 mb/d and an expansion to 1.6 mb/d is on its way. The expansion is expected to be finalized in 2020 with a 1 mb/d capacity between Skovordino and the Pacific Coast and the remainder flowing to China. This Outlook assumes continued expansions of the ESPO pipeline system to China and the Pacific Coast after 2020, with overall capacity increasing to 2 mb/d in 2030 and 2.4 mb/d in 2040.

In the west, the Druzhba pipeline could be expanded from Slovakia to Austria (Schwechat refinery) in the long-term, although this potential development is uncertain. This would lower the transportation costs of Russian crude to Austria.

Furthermore, the expansion of the Caspian Pipeline Consortium (CPC) pipeline, including construction of new pumping stations and storage facilities, was finalized in 2018. Consequently, export capacity was raised from around 0.55 mb/d to 1.3 mb/d. This has helped to accommodate rising Kazakhstan crude production through the Black Sea. In addition, further expansions are possible with the CPC consortium planning a minor expansion up to 1.45 mb/d in the medium-term, which would allow for further exports of Kazakh crude through the CPC pipeline.

In terms of Kazakhstan's eastern pipeline towards China that carries Kazakh and Russian crude, the current capacity of around 0.44 mb/d could be further expanded using additives to improve the flow of liquids and reduce drag. This would enable higher Kazakh exports to China, in line with expected rising long-term production.

6.2 Crude oil and product movements

The integrated global downstream sector relies on the ability to move crude oil, refined products and different intermediate streams between regions economically. It is built on the capacity to move large amounts of oil liquids (crude or products) between almost any two regions of the world, whether over short or long distances via a variety of transport modes. These inter-regional movements enable physical supply, as well as trade and competition, as they respond to price signals and limit open market price differentials (for the same or similar streams) between regions. The ability to move crude oil and products also helps to avoid short-term shortages of fuels. For example, the market's ability to respond to price signals and swiftly deploy tankers or other logistics can help offset shortages caused by weather-related issues.

Various factors affect the direction and volume of petroleum trade movements. These include demand levels; the production and quality of crude and non-crude streams; product quality specifications; refining sector configurations; trade barriers or policy-driven incentives; the capacity of existing transport infrastructure, such as ports, tankers, pipelines and railways, and its economics; ownership interests; term contracts; price levels and differentials; freight rates; and, at times, geopolitics. There is an interplay among these features that determines the volumes traded between regions at any given time, creating a sector that functions with a mix of activities ranging from stable, long-term movements to rapidly changing, market-driven 'arbitrage' trading.

The refining sector is a key element in this regard. In general, the economics of oil movements and refining results in a preference for locating refining capacity in consuming regions due to the lower transport costs for crude oil compared to oil products, but also for strategic reasons. This leads to the majority of trade – especially over long distances – involving crude oil. However, when costs or other hurdles exist to building the required refining capacity, or where there are substantial regional supply/demand imbalances, the result can be significant trade in products.

For producing and consuming countries alike, there is an emphasis on securing refined products through local refining rather than imports, regardless of the economic factors. This is particularly true for oil consuming countries. For producing countries, there is the additional consideration of seeking to increase domestic refining capacity in order to not only cover domestic demand, but also to benefit from the export of value-added products instead of just crude oil. As an extension of this strategy, in their efforts to secure future outlets for their crude production, some producing countries may choose to participate jointly in refining projects in consuming countries, especially where long-term contracts for feedstock supply can be arranged.

The relationships between the various factors mentioned can result at times in oil movements that are far from being the most economic or efficient in terms of minimizing overall global costs. In contrast, movements generated in the models used for this Outlook are all based on an optimization procedure that seeks to minimize global costs across the entire refining/transport supply system, in accordance with existing and additional refining capacity, logistical options and costs.

Generally, few constraints are applied to crude oil and products movements in the modelling approach, especially in the longer-term where it is impossible to predict what the ownership interests and policies of individual companies and countries might be. The differences between short-term market realities, such as the constraints resulting from ownership interests and term contracts, and a modelling approach that looks at the longer-term , with few restrictions on movements and one that operates by minimizing global costs, mean it is necessary to recognize that model-projected oil movements do not fully reflect short-term factors. Therefore, they may predict trade patterns that are not direct extensions of those that apply today. Historical volatility in tanker freight rates and the difficulties in predicting where they may be in two, five or ten years add to the uncertainties in projecting future oil movements.

Nevertheless, the model-based results presented in this Chapter provide a useful indication of future trends in crude oil movements, which necessarily function to resolve regional supply and demand imbalances for both crude and products. These projections are, of course, dependent on the assumptions used in this Outlook, which, if altered, could materially impact projected movements.

Key elements in this are the volumes and qualities of both crudes produced and the products consumed by region, and how these change over time. Another element is the location and capability of refining capacity. Over the longer-term , the relative economics of building new refinery capacity in different regions, and the ability of existing refineries to export and compete against imports all affect the trade patterns of crude and products. There is an interplay, too, between freight and refining costs. Broadly, higher freight rates tend to curb inter-regional trade and encourage more refining investment, while lower freight rates tend to enable greater trade and competition between regions, and serve to provide more opportunities to those regions with spare refining capacity to export products.

As set out in Annex C, the world is represented as 23 regions. For reporting purposes, these regions are aggregated into seven regions: US & Canada, Latin America, Africa, Europe, Russia & Caspian, Middle East and Asia-Pacific. This necessarily eliminates from the reported trade activity those movements that are 'inter-regional' at the 23-region level, but which become 'intra-regional' at the more aggregated seven-region level. This is why the final reported level of trade activity is somewhat lower at the seven-region level *versus* the 23-region level.

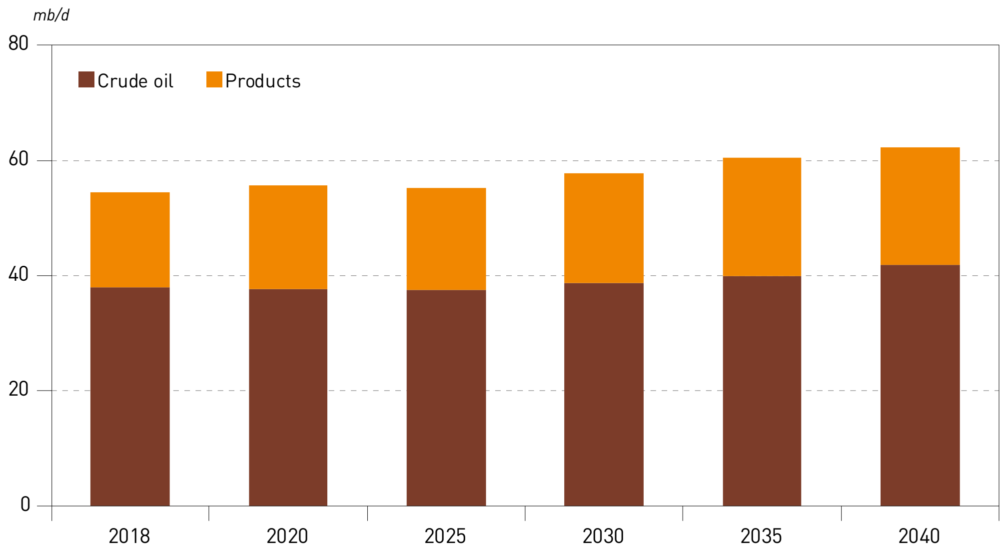
Figure 6.1 provides an overview of projected global oil trade between 2018 and 2040 as reported on a seven-region basis. Crude trade volume is projected to decline slightly between 2018 and 2025 from nearly 38 mb/d to 37.5 mb/d. Despite this relatively minimal decline, there are several significant shifts in medium-term regional crude exports.

Exports from the US & Canada are expected to increase considerably in this period. As explained in section 6.1.1, this is based on supply increases in the region, combined with essentially flat regional refining runs and the need for US refiners to continue import heavy grades. At the same time, crude exports out of the Middle East are projected to decline in line with lower demand for OPEC crude, as well as rising local crude use in this region.

In the long-term (post-2025), overall crude trade picks up and reaches a level of around 42 mb/d due to higher oil flows to the Asia-Pacific. The major contributor to the increase in oil trade is the Middle East. At the same time, other regions, such as Latin America and Africa, are expected to witness a decline in crude exports after 2025, despite rising crude output. This can be explained by higher domestic demand and rising domestic refining capacity. Exports from the US & Canada are also set to decline after a 2025 peak, in line with declining US production.

At the same time, product flows are estimated to increase from around 16.5 mb/d in 2018 to 18 mb/d in 2020 driven in part by rising oil demand in several regions where expected refining capacity does not match demand trends, such as Africa and Latin America. In addition, the implementation of the IMO regulations in 2020 is expected to result in additional trading activities, contributing

Figure 6.1
Inter-regional crude oil and products exports, 2018–2040



Source: OPEC.

to a temporary jump in product trade. Products like compliant LSFO or marine gasoil (MGO) are likely to see additional trade as supply is expected to become geographically more concentrated than for HSFO, while several regions may have to import compliant fuel. Furthermore, HSFO is also expected to see additional trade flows to find a home for surplus barrels after the switch in early-2020.

By 2025, overall product trade is anticipated to have declined slightly as the IMO-related effects are expected to have smoothed out. Crude exporting regions such as Africa and Latin America are anticipated to have added more refining capacity, reducing the need for product imports. Post-2025, product trade is projected to increase gradually to just below 20.5 mb/d in 2040, driven by rising demand in non-OECD countries, mainly in the Asia-Pacific.

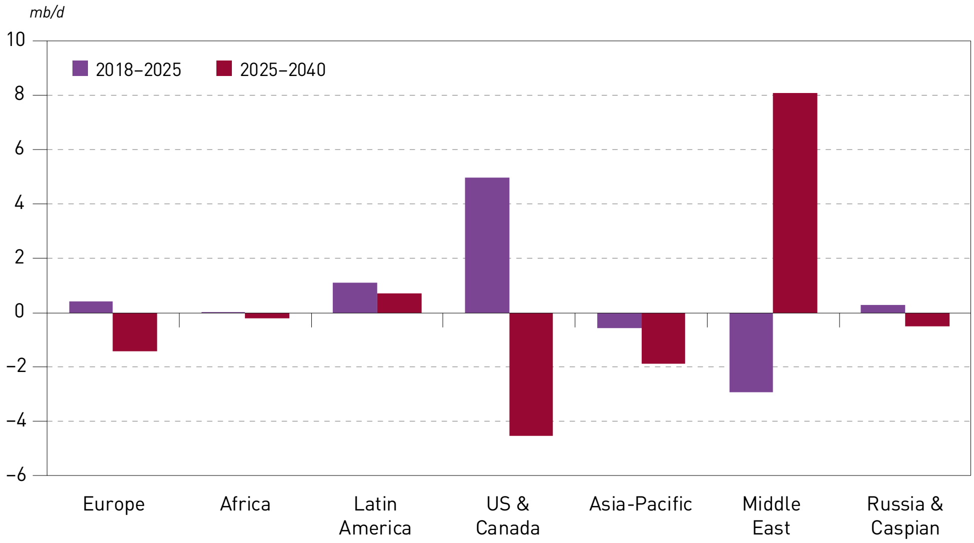
6.3 Crude oil movements

All projections for crude oil trade flows between major model regions are based on the projections for regional oil demand and supply patterns (Chapters 3 and 4), the outlook for regional refining capacity developments (Chapter 5), the installed refinery base capacity and the complexity of the regional refining system. In addition, assumptions on logistics and infrastructure development, for example, major interregional pipeline developments, play an important role in the movements of crude oil in the medium- and long-term.

Crude oil supply and quality

Looking at oil supply (Chapter 4), the most significant change is the increase in medium-term US production with a peak sometime around 2025 (Figure 6.2). US & Canada supply is projected to see production increase by almost 5 mb/d between 2018 and 2025. This increase will be mostly offset by declines in Middle Eastern supply of nearly 3 mb/d over the same time period as demand for OPEC crude declines. Other regions show rather smaller changes, including small increases in Europe, Latin America and the Russia & Caspian. The Asia-Pacific is expected to see a decline of around 0.5 mb/d by 2025, due to lower production.

Figure 6.2
Change in crude oil* supply between 2018 and 2040



* *Includes condensate crudes and synthetic crudes.*
Source: OPEC.

However, these trends change significantly between 2025 and 2040. Following the expected peak in US supply in 2025, US & Canada supply is projected to decline by more 4 mb/d between 2025 and 2040. Asia-Pacific, Europe and the Russia & Caspian regions are also likely to see oil production declines of around 1.9 mb/d, 1.4 mb/d, and 0.5 mb/d, respectively. The major reason is the increasing production share from ageing oil fields, with new additions not able to offset declines. These declines, as well as the demand increase, are expected to be offset by the Middle East, where supply is anticipated to rise by more than 8 mb/d in between 2025 and 2040.

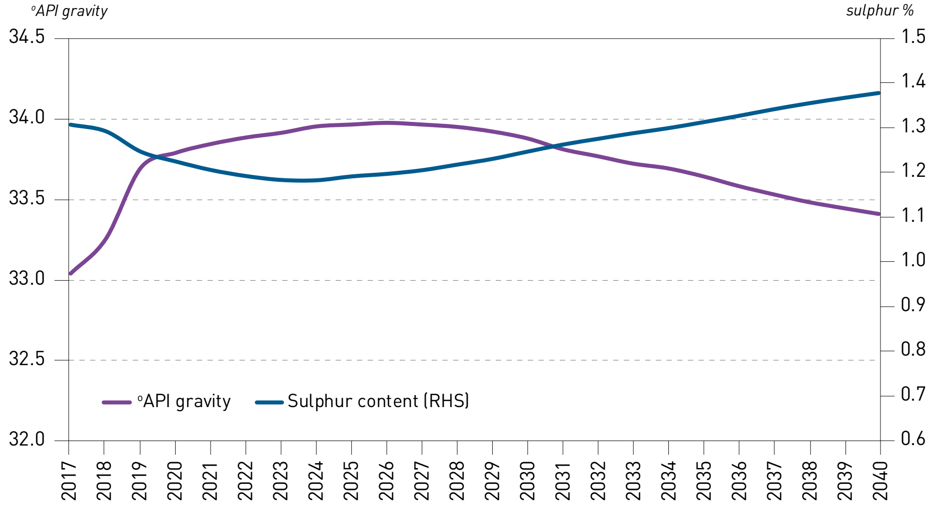
This supply change will have various impacts, including a shift in trade flows (discussed later) and, in connection with this, a change in global crude quality. The majority of the US & Canada additions are light-sweet barrels having an API gravity above 45°. These barrels are rich in light distillates, with low middle distillate yields. At the same time, Middle East crudes are generally medium- and heavy-sour, with a relatively high share of middle distillates and heavy residue, which makes them suitable for complex refining systems, such as in the US.

The change in quality is reflected in the average global API gravity and sulphur content. The average API gravity was close to 33° in 2017 and this increased to around 33.3° in 2018 (Figure 6.3). Based on the rise in US light-sweet supply, as well as light supply from elsewhere, such as Kazakhstan, coupled with a decline in medium and heavy Middle East and heavy Latin American supply, the average API gravity is expected to increase to around 34° by 2025.

However, as the US and other regions will see production decline in the longer-term , leading to an anticipated increase in Middle East output, then average API gravity is expected to fall back towards 33.4° in 2040. At the same time, the average global sulphur content is projected to decline from around 1.3% to below 1.2% around 2025, followed by a significant increase to almost 1.4% in the long-term.

The expected supply changes over the medium-term raise justifiable questions on the ability and willingness of refiners in both the US and worldwide to consume light-sweet US crudes, due to

Figure 6.3
Global crude oil* quality



* *Includes condensate crudes and synthetic crudes.*

Source: OPEC.

several reasons. The first is technical concerns, in terms of the flexibility of refiners to change the crude slate, limitations of crude distillation units, as well as the utilization of secondary units. Furthermore, the potential change in crude slate would necessarily lead to shifts in the product yield, which could limit the attractiveness of light-sweet crudes. And finally, it is also a question of the economics (crude spreads).

It is assumed that refiners have some, albeit limited, flexibility to increase the intake of light-sweet barrels without major changes to refinery set-ups. An increase of around 2–3° of API gravity relative to the original refinery design is normally considered feasible, which means that light-sweet crude could be blended with heavier barrels.

Several regions have already shown that a change in refinery intake is possible. For instance, the average API intake of refiners in the US has risen significantly in recent years, driven by a higher intake of light-sweet grades. According to US EIA data, the average API gravity of refinery intake in PADD 3 refineries in 2018 was around 32.6°, up from just below 30° in 2013. Furthermore, while the average API gravity of the South Korean refining system was below 36° in 2014, it rose to almost 38° in 2017, based on a rising intake of Middle East condensates.

In both cases, rising API gravity was in line with increasing demand for light distillates. In South Korea, the expanding consumption of petrochemical feedstock, combined with respective refinery expansions, has favoured a lightening of crude intake. In the US, strong gasoline demand helped refiners decide to increase runs of light-sweet barrels. Finally, relatively wide discounts made light-sweet crudes attractive for US refiners. At the end of the day, the decision by US refiners to take domestic crudes was supported by wide refining margins.

Nevertheless, US refiners are not likely to swap all of their medium- and heavy-sour intake with light-sweet crudes due to a mismatch with desired yields and economics. Consequently, a significant portion of these grades will be exported, with exports expected to reach almost 5 mb/d in 2025. Based on refining flexibility, as well as the product mix in key growth markets, the strong indication from integrated modelling is that the final destination of these barrels will be in other regions.

For instance, India, which has seen minimal imports of US crude and currently consumes only a small portion of light-sweet grades, could potentially import more light-sweet crude in the future. Assuming an upside flexibility of around 2° API to the average API gravity of refinery intake, it is assumed that India could take up to 0.5 mb/d of US crude in the medium-term, without major changes to refineries. This is additionally supported by India's strong LPG demand and increasing petrochemical demand, with several refiners expanding into the petrochemical sector. Similarly, China is increasing its focus on petrochemicals, leading to increased potential to raise its purchase of US light-sweet barrels, although the ongoing trade dispute between the US and China has had adverse short-term impacts.

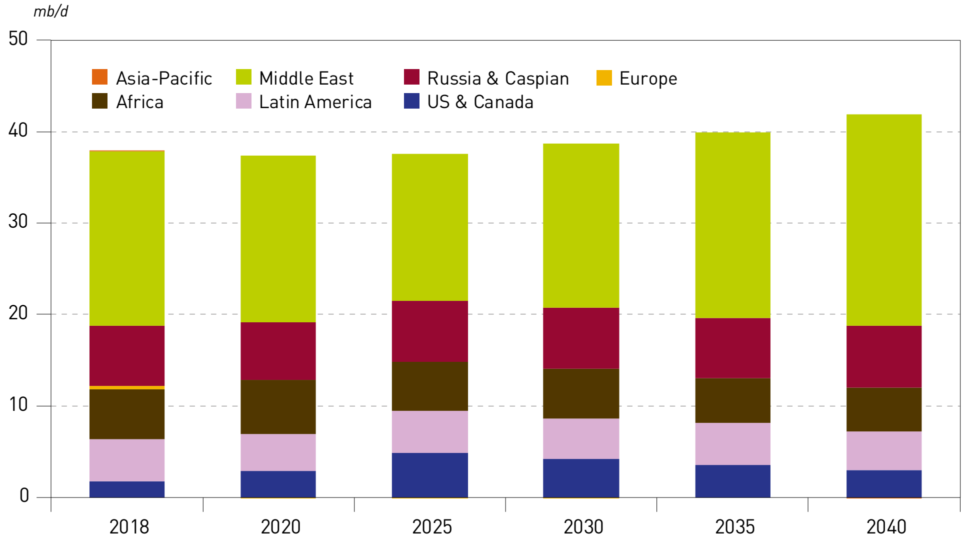
Finally, incremental exports from the US can also replace some of the losses in light-sweet supply, notably in the Asia-Pacific and the North Sea.

This Outlook assumes that the global refining system has sufficient flexibility to accommodate a significant increase in US light-sweet exports, which will require additional blending with existing supply. Furthermore, additional imports of intermediate streams, such as vacuum gas oil (VGO) to keep secondary units running, is possible. However, the question of economics (crude spreads and refinery margins) will remain the key factor in any decision to purchase US crude, especially in destinations such as India or China.

Crude oil movements

As shown in Figure 6.4, crude oil trade is expected to increase by around 4 mb/d between 2018 and 2040. In the medium-term, overall crude trade is forecast to decline from almost 38 mb/d in 2018 to 37.5 mb/d in 2025. The major reason for this development is the increasing local use of crude oil in several producing regions, such as in the Middle East and to some degree the US & Canada. This leads to a partial shift towards, and increases in, product export trade at the expense of crude trade. That said, in terms of regional exports, the biggest shift is the significant increase in crude

Figure 6.4
Global crude oil exports by origin*, 2018–2040



* *Only trade between major regions is considered.*

Source: OPEC.

exports from the US & Canada. These are expected to climb to a level just under 5 mb/d in 2025, up by around 3 mb/d from 2018.

Meanwhile, crude exports from other regions – Latin America, Africa and Russia & Caspian – are forecast to be stable between 2018 and 2025. In Africa, exports are estimated at around 5.4 mb/d in 2018 and are projected to peak at close to 6 mb/d in 2020. However, due to the expected start-up of the new Dangote refinery in Nigeria, crude exports from Africa are expected to decline to 5.4 mb/d by 2025.

After the medium-term, however, the outlook changes fundamentally, with exports expected to rise by 4.5 mb/d between 2025 and 2040, as global demand and refinery capacity in demand regions continue to expand. As a result, global exports are estimated at around 42 mb/d in 2040.

Looking at the regional distribution, export flows from the US & Canada are projected to drop to around 3 mb/d by 2040 from a peak in 2025. Furthermore, exports from Latin America and Africa are expected to decline gradually by 2040 to around 4.2 mb/d and 4.8 mb/d, respectively, due to rising local use. Exports from the Russia & Caspian region are seen mostly stable throughout the period, rising only marginally to just below 7 mb/d in 2040. All of the export losses, as well as oil demand increases, in importing regions (mostly Asia) are expected to be covered by rising exports from the Middle East. Total Middle East exports are set to increase by around 7 mb/d between 2025 and 2040, to reach levels around 23 mb/d.

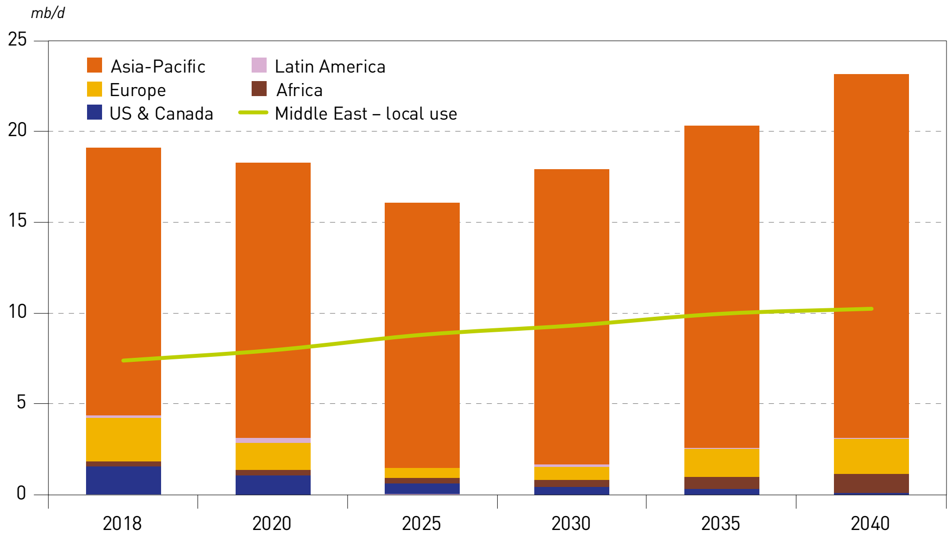
In Figures 6.5–6.9, the regional outlooks for crude exports, including condensates and synthetic crudes, are shown, focusing on traditional exporting regions, such as the Middle East, Russia & Caspian, Latin America and Africa, as well as for the US & Canada, which is becoming an important exporting region. In Figures 6.10–6.12, the major importing regions are shown: the US & Canada, Europe and the Asia-Pacific. Finally, Figure 6.13 shows regional long-term net crude oil imports for the seven regions.

The Middle East is forecast to remain the largest crude exporting region in terms of volume. Its relationship with the largest crude importing region, the Asia-Pacific, is set to grow further. As already described, crude oil exports from the Middle East are forecast to decline from 19 mb/d in 2018 to 16 mb/d by 2025. While crude exports to the Asia-Pacific are expected to remain stable between 2018 and 2025, exports to all other destinations are expected to decline. Flows to the US & Canada are estimated at around 0.6 mb/d in 2025, down by 1 mb/d from 2018, which is due to increasing domestic supply in this region, specifically US tight oil, but also heavy oil from Canada. Furthermore, crude movements to Europe are expected to decline even more, dropping by over 1.5 mb/d to around 0.6 mb/d in 2025. European domestic supply, which is expected to rise over the same time period, as well as competition from US supply, are the reasons for lower Middle East imports.

In the long-term, total Middle East crude exports are projected to increase to slightly above 23 mb/d in 2040, predominantly driven by rising flows to the Asia-Pacific and a recovery in exports to Europe. Middle East exports to the Asia-Pacific are expected to be around 20 mb/d in 2040, up by roughly 5.5 mb/d from 2025. The share of Middle East exports going to the Asia-Pacific is expected to grow to 85% in 2040, up from 77% in 2018.

As noted, Middle East crude exports to Europe are expected to recover from 2025 onwards as European domestic supply wanes and US crude exports decline. Middle East flows to Europe are estimated at around 2 mb/d in 2040, up by 1.4 mb/d from 2025. Middle Eastern exports to the US & Canada are likely to diminish by 2040 as the region is expected to increase production of heavy, sulphur-rich grades, mostly in Canada, and as domestic refinery runs decline. Finally, Middle East exports to Africa are expected to increase gradually in the long-term, rising to around 1 mb/d in 2040, from below 0.5 mb/d in 2025.

Figure 6.5
Crude oil exports from the Middle East by major destinations, 2018–2040

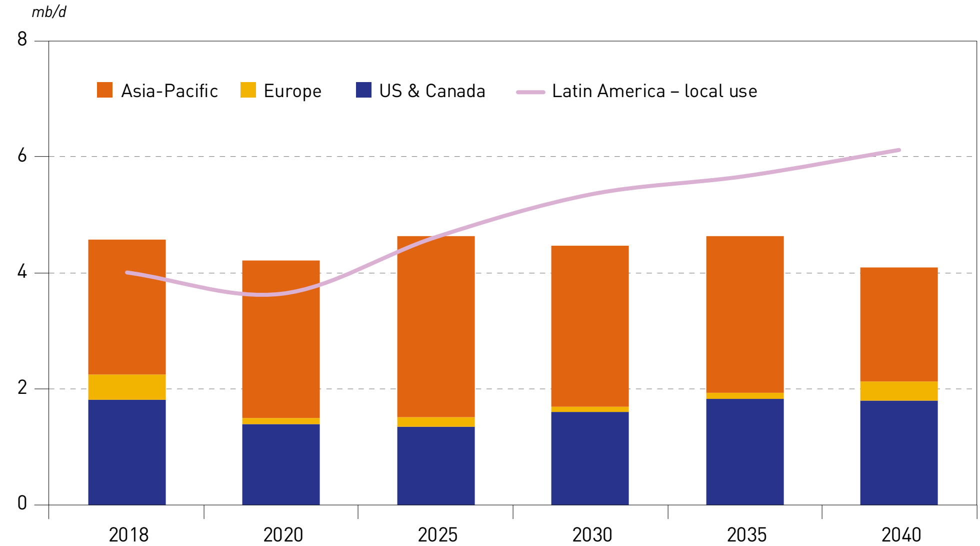


Source: OPEC.

The local use of crude oil in the Middle East is estimated at around 10 mb/d in 2040, which is an increase of 2.6 mb/d from 2018. This reflects rising local demand, but also rising product exports throughout the period.

Oil flows from Latin America are expected to remain in a range between 4.2 mb/d and 4.6 mb/d throughout the projection period, as shown in Figure 6.6. Both crude oil supply and local crude use

Figure 6.6
Crude oil exports from Latin America by major destinations, 2018–2040



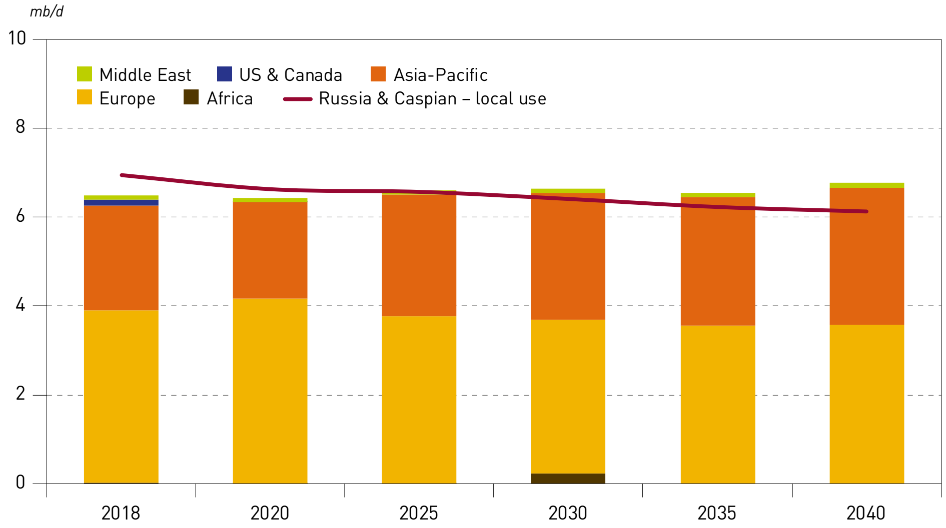
Source: OPEC.

are forecast to increase between 2018 and 2040. The local use of crude in this region is estimated at above 6 mb/d in 2040, up from around 4 mb/d in 2018. It is based on refinery additions mostly post-2025. As a result, crude oil exports from this region are expected to drop from 4.6 mb/d in 2018 to 4.2 mb/d in 2040. Latin American exports target two major markets, the US & Canada and the Asia-Pacific, where heavy-sour crude from Latin American is strongly demanded.

Flows of Latin American crude to the US & Canada are expected to decline in the medium-term, from around 1.8 mb/d in 2018 to 1.4 mb/d in 2020 and 1.3 mb/d in 2025. This is due to domestic supply increases in the US & Canada. However, with rising longer-term supply in Latin America, crude exports to US & Canada are expected to increase towards 1.8 mb/d in 2040. At the same time, flows to the Asia-Pacific are seen increasing to around 3.1 mb/d by 2025, up from 2.3 mb/d in 2018. However, exports to this region will likely decline gradually post-2025, reaching 2 mb/d in 2040, as some volumes are redirected to the US & Canada. Transportation costs to the US & Canada are significantly lower than to the Asia-Pacific, which influences flows of Latin American crude to these two regions. Latin American exports to Europe remain rather insignificant and are estimated at levels between 0.1 and 0.3 mb/d between 2020 and 2040.

Oil exports from the Russia & Caspian region are projected to increase slightly from 6.6 mb/d in 2018 to 6.8 mb/d 2040. Outflows to the main outlet for crude from the Russia & Caspian region, Europe, are expected to see a gradual decline from almost 4 mb/d in the early years of the outlook to close to 3.6 mb/d in 2040. This is mainly due to declining European crude demand, as well as the increasing focus of Russia on the Asia-Pacific. Crude exports to the Asia-Pacific region are expected to increase from around 2.3 mb/d in 2018 to 2.7 mb/d in 2025, reflecting capacity expansions on the ESPO pipeline.

Figure 6.7
Crude oil exports from Russia & Caspian by major destinations, 2018–2040

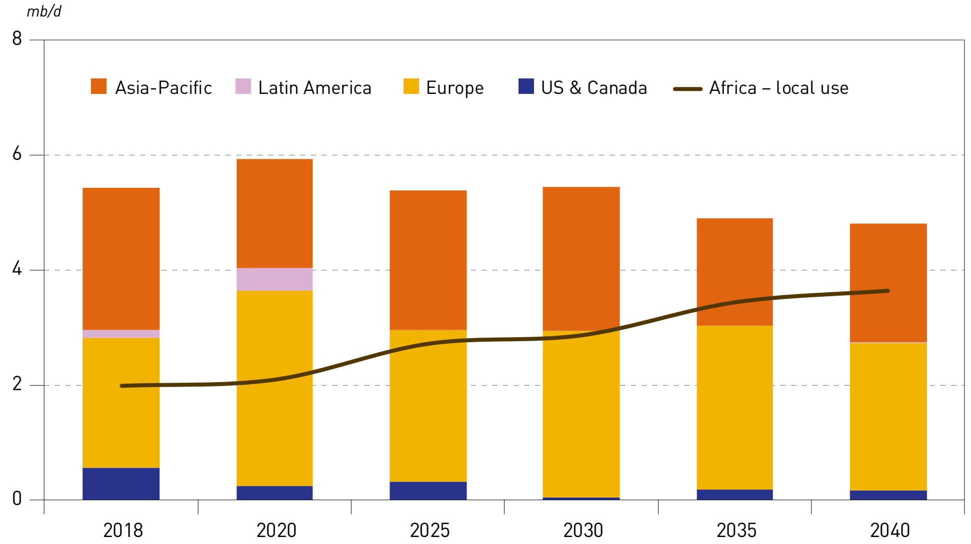


Source: OPEC.

In the period between 2025 and 2040, flows to the Asia-Pacific are set to increase further by 0.4 mb/d to above 3.1 mb/d. This is in line with the continued expansion of pipeline infrastructure to the east. Crude flows to other regions, such as Africa and the Middle East, are expected to remain minimal throughout the forecast period. In line with flat domestic demand, declining product demand in target export markets, such as Europe, and increasing competition from the US and the Middle East, Russian product exports to Europe are forecast to decline in the long-term. Consequently, local crude use in the Russia & Caspian region is expected to drop from just below 7 mb/d in 2018 to 6.1 mb/d in 2040.

As shown in Figure 6.8, the rise in Africa's crude exports to world markets from around 5.4 mb/d 2018 to almost 6 mb/d by 2020 will be short-lived. The advent of the IMO Sulphur Rule in 2020 is expected to lead to a short-term premium for sweet and especially sweet-heavy African crudes. Crude exports from Africa in the years after start declining due to the region's increasing refining capacity and expanding domestic African oil demand. The local use of African crude is estimated to increase from around 2 mb/d in 2018 to 3.6 mb/d in 2040. Consequently, total African exports are seen at just below 5 mb/d in 2040, down from almost 6 mb/d in 2020.

Figure 6.8
Crude oil exports from Africa by major destinations, 2018–2040



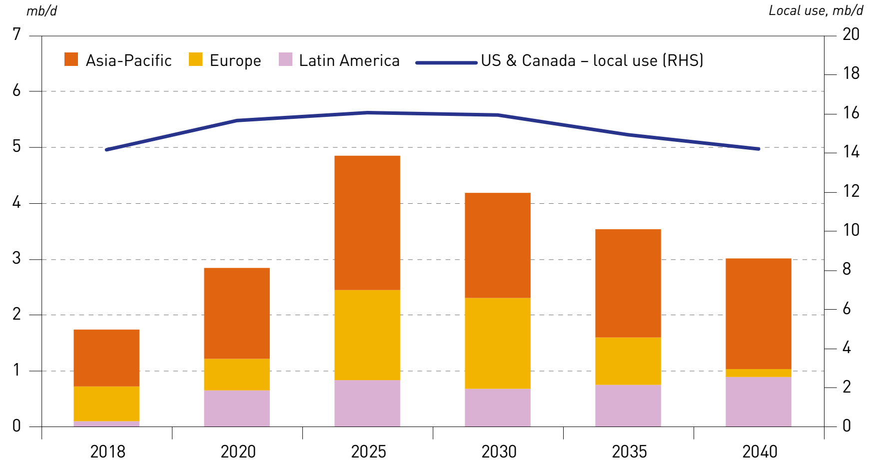
Source: OPEC.

Europe and the Asia-Pacific remain the main outlets for African crude in the long-term. Crude exports to Europe are forecast to rise in 2020 to almost 3.5 mb/d, but then gradually decline towards 2.6 mb/d in 2040. This is predominantly due to declining demand in Europe, as well as rising competition from other countries and regions, such as the US and the Middle East, from 2025 onwards.

African exports to the Asia-Pacific are seen hovering between 1.9 mb/d and 2.5 mb/d throughout the period. At the same time, African exports to the US & Canada are expected to drop to around 0.2 mb/d in the medium-term and to remain at lower levels due to competition from US light-sweet grades.

Crude exports from the US & Canada were estimated at an average level around 1.8 mb/d in 2018. In line with rising supply, crude exports from this region are anticipated to increase strongly by 2025, reaching levels just below 5 mb/d. However, crude exports are thereafter expected to drop to an estimated 3 mb/d in 2040. In terms of local crude use, consumption in the US & Canada is set to increase by almost 2 mb/d by 2025, reaching 16.1 mb/d, which is in line with declining crude imports in this period as discussed. However, local crude use is projected to drop to 14.2 mb/d in 2040, in line with rising domestic production in the short-to-medium-term followed by declining supply. As US & Canada refinery runs will change little in the short- to medium-term, the effect is that crude imports are expected to drop.

Figure 6.9
Crude oil exports from the US & Canada by major destinations, 2018–2040



Source: OPEC.

US & Canada crude exports flow to three regions: Latin America, Europe and the Asia-Pacific. Crude exports to Latin America are estimated at around 0.7 mb/d in 2020, followed by modest increases towards 0.9 mb/d by 2040. These flows consist mostly of light-sweet oil, targeting simpler refiners in Latin America. At the same time, the US & Canada continues to import high sulphur crude oil from Latin America. Crude exports to Europe are expected to peak between 2025 and 2030 at around 1.6 mb/d, up from 0.6 mb/d in 2018. Exports to Europe will decline in the longer-term due to falling domestic oil production after 2025 and a drop in European demand and refinery intake. US & Canada exports to Europe are forecast to be around 0.2 mb/d in 2040.

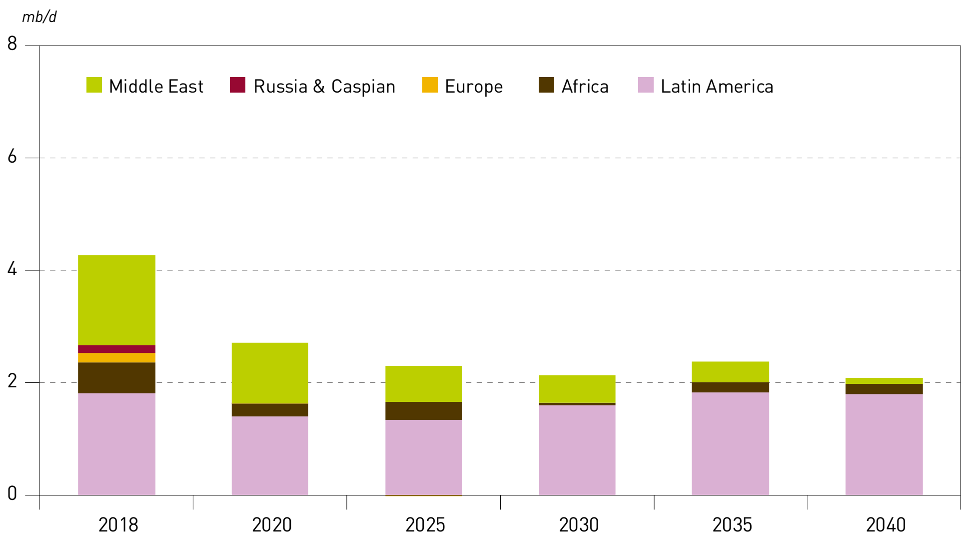
Exports from the US & Canada to the Asia-Pacific were estimated at around 1 mb/d in 2018 and are expected to rise to almost 2.5 mb/d in 2025. This increase is based not only on competition with other exporting regions, such as the Middle East, but also the replacement of domestic Asia-Pacific production, which is set to fall by around 0.6 mb/d between 2018 and 2025. Crude oil flows to the Asia-Pacific remain strong at around 2 mb/d by the end of the forecast period, reflecting rising demand in this region. These projections also assume a normalization of trade between the US and its trading partners in the region.

The US & Canada sub-region is set to remain a crude importer throughout the period, although volumes decline significantly. Imports to the region were seen at around 4.3 mb/d in 2018, mostly from Latin America, the Middle East and Africa. Imports are expected to decline to 2.7 mb/d in 2020 and drop further to 2.1 mb/d in 2040 as a consequence of rising domestic supply in the medium-term and lower refinery runs in the long-term. Although crude imports from Latin America are expected to decline to 1.3 mb/d by 2025, in the long-term they are expected to return to 2018 levels around 1.8 mb/d by 2040. Crude flows from Latin America are based on the flows of heavy-sour grades that are strongly in demand at complex US refineries.

Crude imports from the Middle East are likely to decline gradually from around 1.6 mb/d in 2018 to almost zero in 2040. The reduction in the short- to medium-term results in large part from the projected supply growth for heavy WCSB crude and also deep offshore Gulf of Mexico medium-sour grades. In the longer-term , WCSB heavy production is projected to continue to grow while US & Canada refinery runs fall, further reducing the role for Middle East imports. Imports from Africa are impacted by rising US light-sweet production in the short- to medium-term, followed by declining refinery crude runs in the longer-term .

It is important to note that the increase in crude exports from the US & Canada is followed by a significant reduction in crude imports (Figure 6.10). The increase in crude exports between 2018 and 2025, estimated at 3.1 mb/d, is forecast combine with a reduction of crude imports of around 2 mb/d over the same period. While the US & Canada as a region was still a net crude importer in 2018 at a level of around 2.5 mb/d, it will become a net exporter (if including intra-regional trade between the US and Canada) in 2020, even if only marginally so. Net crude exports are then projected to rise to around 2.6 mb/d in 2025 – not including intraregional trade between Canada and the US. Consequently, the change in net exports between 2018 and 2025 is calculated at a substantial 5.1 mb/d, in line with the roughly 5 mb/d crude supply increase in this region projected in the Outlook.

Figure 6.10
Crude oil imports to the US & Canada by origin, 2018–2040

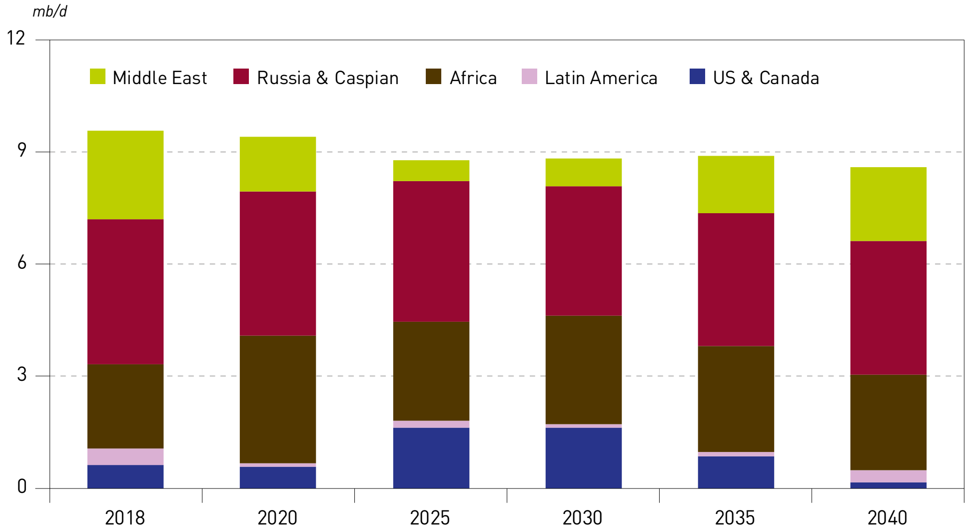


Source: OPEC.

As shown in Figure 6.11, Europe's crude imports are expected to decline gradually from around 9.6 mb/d in 2018 to 8.6 mb/d in 2040. Domestic crude oil supply is expected to increase by around 0.5 mb/d between 2018 and 2025, which is part of the reason for an expected decline in crude imports from 9.6 mb/d to 8.8 mb/d over this period. After 2025, crude oil production in Europe is forecast to decline by almost 1.5 mb/d by 2040. When this is combined with a strong decline in domestic demand and refining, it ultimately leads to only a modest decline in overall crude imports to a level around 8.6 mb/d.

In terms of the regional distribution of European imports, the Russia & Caspian region remains the most dominant long-term source, although crude oil imports are expected to drop from 3.9 mb/d in 2018 to 3.6 mb/d in 2040. European imports from the US & Canada are expected

Figure 6.11
Crude oil imports to Europe by origin, 2018–2040



Source: OPEC.

to increase strongly in the period to 2025, reaching a level of 1.6 mb/d, before witnessing a decline to just 0.2 mb/d by 2040. Again, this is the result of the projected rise then fall in US production.

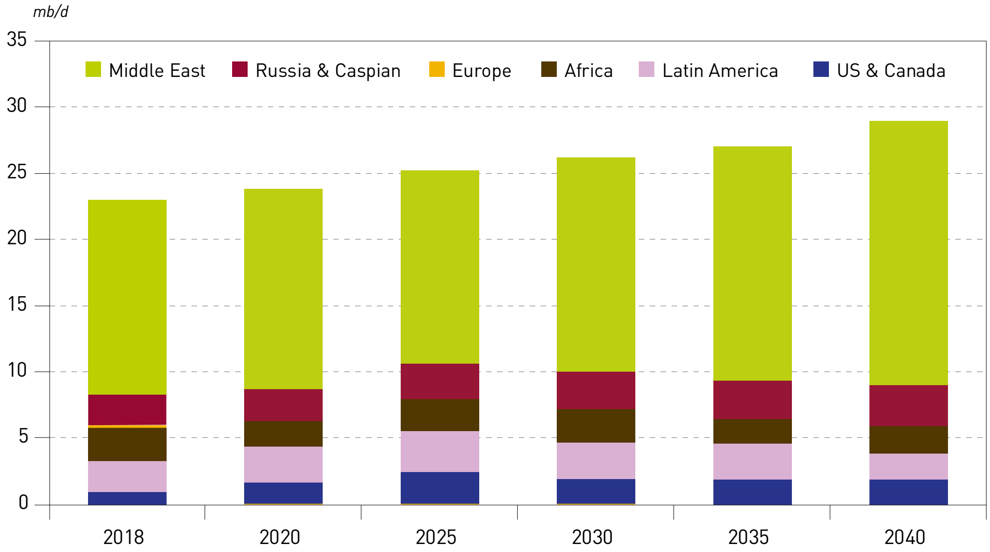
Crude imports from the Middle East exhibit the opposite pattern to US & Canada flows. As the 'balancing' source of supply, they are forecast to drop from 2.4 mb/d in 2018 to just 0.6 mb/d in 2025. However, flows from the Middle East are expected to recover towards 2 mb/d by the end of the forecast period. Finally, crude imports from Africa are estimated to peak in 2020 at almost 3.5 mb/d and then gradually decline to 2.6 mb/d in 2040. This is in line with lower European demand, but also a lower availability of African export volumes.

The Asia-Pacific will see continuous crude oil import growth throughout the period (Figure 6.12). Imports are expected to increase from around 23 mb/d to just above 29 mb/d in 2040. The Middle East remains the main crude supplier to the region throughout the forecast period. However, other suppliers are expected to increase their shares in the period to 2025, notably the US & Canada, Latin America and the Russia & Caspian.

These increases are the reason why Middle East volumes are relatively stable in the period to 2025, hovering between 14.5 mb/d and 15.2 mb/d. US & Canada flows are forecast to reach 2.4 mb/d in 2025, up from 1 mb/d in 2018. US & Canada exports to the Asia-Pacific are mostly light-sweet barrels, which are expected to find a place in the region's refining mix, considering the increasing focus of Asian refiners on petrochemicals.

Latin America is expected to expand flows to the Asia-Pacific in the medium-term, reaching 3.1 mb/d in 2025, up by 0.8 mb/d from 2018. Russia & Caspian exports are also set to gradually increase, partly based on the expansion of the ESPO pipeline. Crude flows from the Russia & Caspian are projected at 2.7 mb/d in 2025, increasing by 0.4 mb/d relative to 2018. Despite a temporary dip in 2020, African flows to the Asia-Pacific are seen as relatively stable between 2018 and 2025 at around 2.4 mb/d. Consequently, the share of Middle East volumes in the Asia-Pacific's total import mix is projected to decline from around 64% in 2018 to 58% in 2025.

Figure 6.12
Crude oil imports to the Asia-Pacific by origin, 2018–2040



Source: OPEC.

After 2025, imports from the US & Canada, Latin America and Africa are forecast to decline due to lower US supply and higher local use in Africa and Latin America. Consequently, imports of US & Canada crude are projected to fall to slightly below 2 mb/d in 2040, down by 0.4 mb/d from 2025. Imports from Latin America are projected at around 2 mb/d in 2040, a drop of 1.1 mb/d relative to 2025. This relates in part to the reduced level of total Latin American crude oil exports out to 2040. Crude imports from Africa are projected to drop around 0.3 mb/d from 2025, to a level of 2.1 mb/d in 2040. Again, the lower availability of crude exports is a factor.

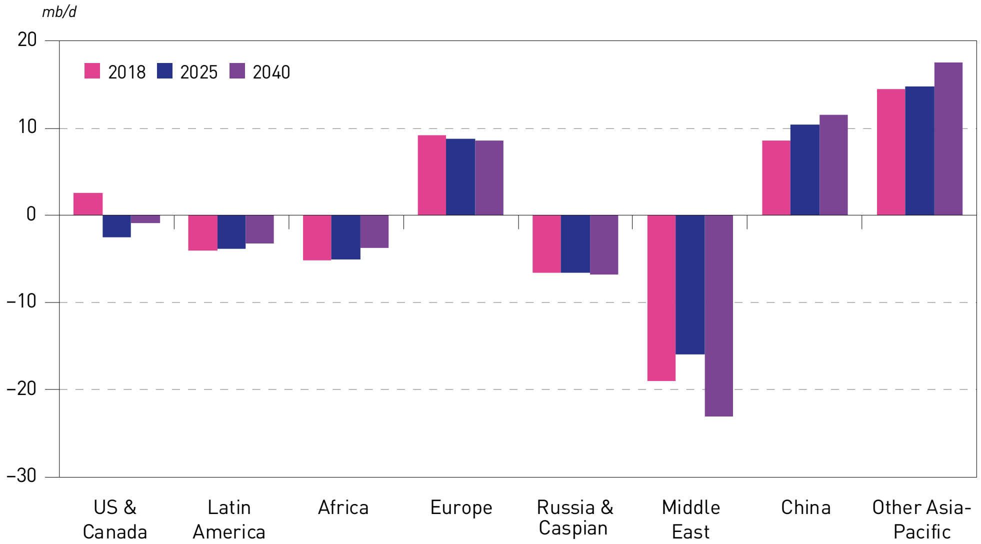
The Russia & Caspian region is set to further expand exports to the Asia-Pacific, reaching 3.1 mb/d in 2040, up by 0.4 mb/d compared to 2025. Finally the region that is expected to fill the majority of the longer-term gap is the Middle East, with exports to the Asia-Pacific rising to 20 mb/d in 2040, up by more than 4.5 mb/d relative to 2025. The share of Middle East exports in the Asia-Pacific mix is expected to grow to almost 69% in 2040, a strong increase from 59% in 2025.

Figure 6.13 presents net crude imports (imports minus exports) for all regions for the years 2018, 2025 and 2040. It summarizes the inter-regional flows already highlighted and puts regional net imports into perspective. Due to rising supply, net imports to the US & Canada, which were around 2.5 mb/d in 2018, flip to negative as early as 2020. The region is estimated to have net exports of 2.5 mb/d in 2025 when US tight oil supply is expected to peak. By the end of the forecast period, the US & Canada is anticipated to still be a net exporter, albeit at a lower level of around 1 mb/d in 2040.

Net exports from Latin America and Africa are projected to decline gradually over the outlook period, dropping by 0.9 mb/d and 1.4 mb/d, respectively. This is mostly due to the higher local use of crude to meet domestic oil demand. Crude net exports from the Russia & Caspian region are forecast to increase only slightly between 2018 and 2040.

On the import side, net flows to Europe are forecast to drop somewhat – approximately 0.6 mb/d over the outlook period – due to the region's declining demand. However, declining supply in

Figure 6.13
Regional net crude oil imports, 2018, 2025 and 2040



Source: OPEC.

Europe will somewhat offset this drop in demand, which is the reason for the rather modest declines in net imports. China and Other Asia-Pacific are expected to see continuous increases in net crude imports throughout the projection period, rising by 3 mb/d and 3.1 mb/d from 2018 levels, respectively.

Highlighting its balancing role, between 2018 and 2025, a combination of increases in non-OPEC production, led by the US, and large regional refining projects, will lead to a reduction in medium-term crude oil exports out of the Middle East. Longer-term , the reduced ability of other regions to export crude, combined with sustained demand growth in the Asia-Pacific, will see Middle East crude oil exports recover and grow.

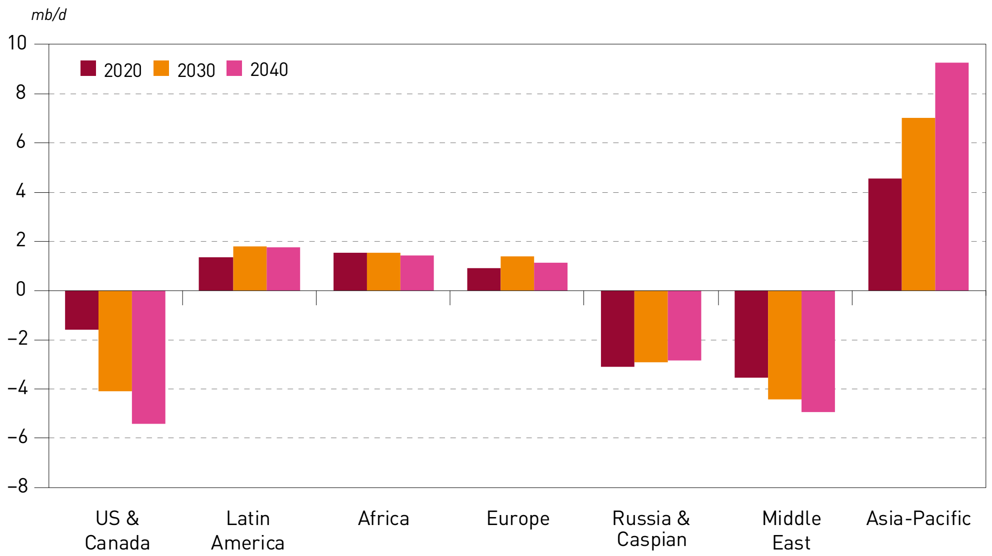
6.4 Product movements

In comparison to crude movements, refined product movements between the seven major regions are significantly lower, as refined products are mostly produced and consumed within the regions. Transportation costs for clean products are normally higher relative to crude, which is another reason for lower inter-regional product movements.

Overall, product trade is expected to increase from around 16.5 mb/d in 2018 to almost 20.5 mb/d in 2040. Based on demand growth and insufficient refinery additions in some regions, such as Latin America and Africa, product flows are estimated to increase to around 18 mb/d in 2020. The new IMO Sulphur rule is expected to result in additional product trade in 2020, with more flows of intermediate products, gas oil and fuel oil.

As IMO effects dissipate, and because of the expected expansion of refining systems in demand growth regions, overall product trade is projected to drop slightly in 2025. From 2025 onwards, the modelling results suggest a progressive expansion in product trade to levels around 20.5 mb/d in 2040. This is in line with rising oil demand in major consuming regions, notably the Asia-Pacfic, and rising product net exports from the Middle East and the US & Canada (Figure 6.14).

Figure 6.14
Regional net product imports, 2020, 2030 and 2040



Source: OPEC.

Projected product net imports to the Asia-Pacific are set to rise from around 4.5 mb/d in 2020 to 9.5 mb/d in 2040. Increasing refining capacity in the Asia-Pacific is not viewed as sufficient to satisfy all of the expected additional demand, which calls for further imports from the Middle East and the US & Canada, which will see rising exports due to the availability of crude feedstock. High-quality clean products, such as LPG and naphtha, as well as middle distillates, represent the majority of the increase.

Latin America and Africa are expected to remain net product importers throughout the period, with refining capacity additions in these regions not sufficient to reduce import flows. Latin American net product imports are set to increase from around 1.4 mb/d in 2020 to 1.8 mb/d in 2040, as demand is seen picking up faster than projected refinery throughputs. New refining capacity in Latin America is also likely to face competition from the complex refining system in the US, which will target Latin America due to its close proximity.

In Africa, net product imports are expected to remain stable at around 1.5 mb/d between 2020 and 2040. This means that refinery additions are forecast to cover Africa's demand increment, with the region remaining a net importer.

Meanwhile, refiners in Europe will likely continue to compete with imports from the US & Canada, but also from the Middle East and the Russia & Caspian, which all have the advantage of an availability of crude feedstock. This leads to an increase in net imports to Europe, from just below 1 mb/d in 2020 to almost 1.5 mb/d in 2030. Nevertheless, falling European oil demand in the long-term will lead to lower net product imports of around 1 mb/d by 2040.

On the net product export side, the Middle East and the US & Canada are seen increasing their export volumes significantly, while Russia & Caspian is expected to see next exports decline somewhat. The focus of some Middle East oil producers on product exports is anticipated to lead to additional long-term net product exports, from around 3.5 mb/d in 2020 to around 5 mb/d in 2040. The Middle East has a clear advantage in terms of its proximity to the major consuming regions of the Asia-Pacific, Europe and Africa, as well as ample crude supply in the region. The majority of additional net exports will likely be destined for markets in the Asia-Pacific.

The US & Canada region also sees a significant increase in net product exports over the medium- and long-term. This is driven by three factors: ample crude oil and also NGLs supply, declining domestic demand and highly complex and competitive refining systems. Product net exports from the US & Canada are anticipated to increase from around 1.5 mb/d in 2020 to 5.4 mb/d in 2040. Finally, product net exports from the Russia & Caspian are anticipated to decline from around 3.1 mb/d between 2020 to 2.8 mb/d in 2040. This can be explained by Europe's declining demand, as Europe is the main products market for the Russia & Caspian region.

Energy and technology

Key takeaways

- ICEs will continue to play an important role in the transportation sector, with substantial development potential for improved fuel efficiency.
- Battery technology is expected to continuously evolve, while e-motors are likely to become less dependent on rare earth metals.
- Recycling will be vital in helping EVs become less resource and energy-intensive.
- Flight gas turbines are expected to remain the main engines for commercial airplanes.
- Electrification is gaining traction in the aviation sector, in terms of adding to operational security and aiding peak power development.
- Innovative and information technology (IT)-based road transportation services are expected to expand out to short-distance air transportation; air taxis may be the first commercial example.
- The combination of LNG use and technological advances for marine engines and the vessels themselves, will not be sufficient to reduce the marine transportation's GHG emissions by half by 2050. It is clear that further measures are required.
- Combined cycle gas turbines (CCGT) have by far the lowest, and coal-fired power plants the highest, specific CO_2 emissions of fossil fuel technologies used in power generation.
- Future renewable power generation is expected to come mainly from wind and solar, although the associated capacity factor needs to be considered for a correct interpretation of capacity build-up.
- Tight oil will continue to play an important supply role, especially in the medium-term, due to recent, as well as expected future technological advances.
- The petrochemical sector requires more flexible operations; innovative and IT-based concepts, such as 'Industry 4.0', are ready to support this shift.
- Data collection, data processing and AI are making impressive advances and are increasingly shaping the energy business.

Technology and science are the foundations of modern societies and have provided numerous benefits to humanity, bringing innovation, not only in terms of gadgets and machines, but also adding to knowledge. The most recent and still ongoing scientific and technological revolution has been fuelled by ever-rising calculation speeds and changed the way information is processed in modern AI systems. For the first time in history, computing power and related technology has made it possible to apply basic and compellingly simple physical laws to complex systems – a task which was impossible even a decade ago. This has already become an integral part of the oil and energy business.

Related to these developments, the WOO 2019 considers current and potential future trends in technological advancement. For example, energy intensity will likely be reduced by efficiency improvements and the energy base may be broadened by the increasing use of other energy sources. The use of advanced technology will be key to meeting rising energy demand, especially for electric power, as countries and populations see increased economic and social development.

The ever-increasing focus on climate change will also play an important role in technology development. Tightening efficiency standards and an increasing global awareness of the impact of climate change has the potential to accelerate technological research development beyond the evolutionary path of mature technologies. Nevertheless, it is evident that any future energy transition will require the further use of all energy sources; it is not about choosing one energy source over another. There is a need to continually look to develop, evolve and adopt cleaner energy technologies that make it possible to meet expected future energy demand in a sustainable and ever more efficient manner.

Transportation is one of the most visible energy consuming sectors; essential to the daily life of billions of people. The advent of electric mobility is not only an evolutionary development in the sector; it has helped speed up advancements in battery technology and increased the calls for ICEs to become more efficient.

In fact, recent advancements in modern ICE-based vehicles are already proving beneficial, with vehicles consuming substantially less fuel than their predecessors just a decade ago. These developments are expected to allow so-called conventional vehicles to remain a major component of the vehicle fleet in the long-term, especially the commercial vehicle fleet. Nonetheless, it is clear that the sector will see a far broader variety of powertrain technologies than it has witnessed in the past.

The second largest sector in terms of oil consumption, petrochemicals, is expected to face fewer long-term threats to oil demand than the transportation sector. Nevertheless, this sector will also be subject to the trend of renewable energy sources potentially replacing, or at least complementing, oil and gas. Concepts such as COTC will also rely on advanced technology, not least through the integration of modern concepts such as 'Industry 4.0'.

In general, it is evident that IT is playing an increasingly important role in the oil industry. Although embracing new types of technology is nothing new for the industry, the speed at which IT is changing the industry and the corresponding advantages are astounding. For example, optimizing tight oil production, steeply increasing the efficiency of petrochemical operations, and the development of new products based on oil and its derivatives would be very difficult without the aid of modern IT and AI systems.

7.1 Road transportation

Transportation, particularly road transportation, remains the single most important consumer of oil products. In 2018, around 56.8 mb/d were consumed globally in the transportation sector, equivalent to 58% of overall oil demand.

In recent years, road transportation has become a particular focus of public attention, due to the volume of fuel it consumes and the corresponding GHG emissions, as well as because of rapid technology advances and the appearance of EVs.

At the beginning of the automobile era there were several electric models; however, ICEs quickly took over for the same reasons that they remain dominant today: range and cost. Following the development of commercially-viable lithium-ion batteries, EVs are now gaining traction. While there are undoubtedly other exciting new vehicle concepts, it is sometimes overlooked that all vehicles still require a powertrain for propulsion, which consumes energy, be that a fuel or electric power. Frequently, the source used in power generation – often a fossil fuel – is overlooked when the environmental footprint of EVs is being discussed. With the increasing use of renewable power, real zero emission mobility is now a real possibility, not only at a local level, but globally too.

In parallel, innovative internet-based fleet management systems – car and ride sharing, or advanced hire car services – are also contributing significantly to new mobility concepts. At the moment, however, these are basically limited to urban areas. Nevertheless, IT advancements may completely reshape personal transportation, shifting it from an active driving task for one occupant towards a mainly service-oriented activity where all occupants are moved around autonomously.

Human behaviour is an important factor when forecasting future energy and oil demand, especially for passenger transportation. Large SUVs are a good example – although the average road condition in OECD countries makes such vehicles unnecessary, many customers prefer them and are prepared to pay more for them than sedans. It underscores the fact that fuel consumption is not always the most important argument. This type of preference may also counteract some of the conversion efficiency improvements for modern combustion engines.

7.1.1 Technology advances for ICEs

An important characteristic of ICEs is their scalability. Standard reciprocating piston ICEs range from tiny motors that produce less than 100 watts (W) up to the largest ship engines that can produce 80 MW, equivalent to a scaling up of over six magnitudes. Gas turbines, a different class of ICEs because they use continuous combustion, can have a maximum power development of above 300 MW. Another substantial advantage is that ICEs – especially reciprocating piston engines – can burn a broad range of fuels, in addition to gasoline and diesel. For example, they can run on LPG, CNG, LNG, hydrogen, alcohols and biodiesel. Their robustness and their tolerance for fluctuating fuel qualities is expected to see them remain a preferred choice in many regions.

Only two different combustion principles are used for a broad range of fuels: spark-ignited or self-ignited, with the latter usually referred to as 'diesel combustion'. This flexibility allows alternative fuels, including zero-emission hydrogen, to quickly play an important role by leveraging the long-established technology of ICEs. EVs, on the other hand, require a parallel upgrade of vehicle technology and charging infrastructure.

Efficiency improvements

The fuel cost for vehicles, whether passenger or commercial, has always been an important consideration for owners. It has also pushed vehicle manufacturers to continually make their products more fuel efficient.

The initial focus of improvements is evidently the vehicle's engine, given that fuel consumption is directly linked to its efficiency. This is typically measured in grams of fuel per kilowatt hour (kWh) of the developed mechanical shaft power. In recent decades, engineers have improved typical ICE efficiency for passenger vehicles from less than 20% to around close to 40% today for optimized gasoline engines. For diesel engines, efficiency has risen from round 30% to above 40%.

This corresponds to a specific fuel consumption of around 230 g/kWh in the case of gasoline and 215 g/kWh for diesel. Moreover, heavy duty diesel engines for commercial vehicles can reach as high as 45% efficiency, meaning they consume only approximately 190 g/kWh of power generated.

Large CCGTs that combine a gas turbine and a steam bottoming cycle for waste heat recovery can reach more than 62% efficiency. This is only around 10% below the physical limit for such combustion engines of around 75%. Attempts have been made, and are still being made, to downsize this concept so that it may be applied to mobile applications by means of thermocouples or small vapour-based systems with small expanders.

It is important to keep in mind that these values refer to typical testbed conditions with stable (non-fluctuating) loads and revolutions per minute (rpm) under standard environmental conditions, related to temperature, air pressure and humidity. Generally, in the course of load and rpm transitions – such as acceleration or braking – efficiency can drop significantly.

It should also be noted that vehicle fuel efficiency measurements incorporate the efficiency of the vehicles themselves. For example, reducing a vehicle's weight will obviously reduce the amount of energy required to move it a certain distance. Additionally, on-board add-ins that are not necessary for vehicle propulsion, but still consume energy (A/C), lighting, rear shield de-icing, etc.) can significantly contribute to lowering vehicle efficiency. Modern light-emitting diode (LED) headlights consume only a fraction of the power used for older headlight bulbs – power that must be generated by the vehicle's engine. Power recuperation from braking plays an important role, especially when there are frequent velocity changes.

Raising engine efficiency close to the physical limit would require a substantial re-engineering of combustion engines. However, there is no reason why intermittent piston ICEs cannot reach a fuel efficiency of 60% (kW of shaft power *versus* kW of fuel burn ratio). Their physical boundary is above 80%, as they can achieve higher combustion temperatures than continuously working gas turbines; hence, the maximum thermodynamic efficiency is higher.

Thorough investigations into efficiency losses, or in other words, the potential for required efficiency gains, have revealed that there are two main sources: exhaust and cooling, including intercoolers in super-charged engines. Efforts to reduce wall or cooling losses, however, have not yet been successful. Using thermally insulated materials, such as specially-designed ceramics, as well as other proposals such as opposed-piston-opposed-cylinder engines, have not proven effective. Wall losses have only become negligible for very large engines, basically the two-stroke engines of large marine vessels. This is due to their unique geometry, which allows their cylinder volume to grow at a higher magnitude to its surface area.

Combining highly fuel efficient ICEs (60% efficiency) and hybridization, where appropriate – including plug-ins to drive daily commuting distances with zero emissions – may be more efficient than BEVs for a considerable period of time. It is estimated that a specific fuel consumption of only 140 g/kWh is possible in the long-term.

Moreover, in regions where clean power generation is limited, such highly efficient ICEs are likely to not only be the most economic solution, but may also result in lower CO_2 emissions. Such technological advances are expected to see ICEs retain their dominance as the most economical transportation technology in the long-term, especially in non-OECD countries.

Pollution and exhaust gas cleaning

Air quality is a major concern today, especially in densely populated areas. Road transportation is often blamed, although other sources may pollute substantially more, such as the burning of low-quality fuel in power plants that lack adequate exhaust cleaning. Vehicle manufacturers, on the other hand, have historically experienced more continuous pressure to improve exhaust gas cleaning.

This is also true for the new generation of diesel vehicles that now have appropriately dimensioned catalysts and additive tanks – a fact which had not been the case in recent years and had led to emissions beyond allowed levels. Selective catalytic reduction (SCR) reduces their NO_x emissions to very low levels. Unfortunately, this had not always been the case in the recent past. Today, maintaining the catalyst at a sufficiently high temperature– typically above 250°C – ensures that this cleaning reaction is carried out in all driving conditions. Furthermore, particulate emissions from diesel and gasoline direct injection engines can be eliminated with a state-of-the-art filter.

It should be mentioned that increasing an engine's combustion temperature – mainly by adjusting the ignition and fuel injection timing – also increases the efficiency due to the physical laws of thermodynamics. An unwelcome side-effect, however, is that more NO_x is produced. Before efficient, reliable and economic exhaust cleaning systems were available, the combustion temperature needed to be restricted to limit the emission of NO_x (and to a certain extent soot too). Today, emission abatement measures, such as filters and additives, mean higher combustion temperatures can be used without increasing emissions. Advances in fuel efficiency and exhaust cleaning are co-dependent and are a good example of the complexity of modern combustion engines, where an improvement in one area may have negative impacts on another.

7.1.2 Technological advances in electric mobility

A decade ago electric mobility was only a small niche market, limited to very specialized vehicles. In recent years, however, a combination of factors has seen it become mainstream in the road transportation sector. First, the development of lithium-ion batteries with vastly improved energy density has made it possible for EVs to extend their range to meet the daily needs of most drivers. Second, the ongoing development of renewables-based power generation has increased the potential for zero-emission mobility. And third, a few charismatic and determined entrepreneurs saw a business opportunity in electric mobility and used their marketing expertise to make EVs appealing to the general public.

Currently, batteries are still far too big, heavy, and expensive to compete with diesel engines for long-distance trucks. Nonetheless, several manufacturers of commercial vehicles have announced medium-heavy delivery trucks with an electric range of up to 200 km. The amount of oil displaced by electric power in the commercial vehicle sector will, however, be limited for the foreseeable future. Fuel cells are regularly presented as an alternative in this regard, but they also bring challenges that are discussed later.

Battery and electric motors

Battery technology is advancing quickly in terms of charging and discharging efficiency and improving the battery usability for daily use. A couple of years ago, usable battery capacity was typically between 20% and 80% of the load state, while today 10% to 90% has become standard. Nevertheless, the overall efficiency of an electric powertrain, including the battery, is already very high – battery charging/discharging is above 96% and the efficiency of electric motors is typically between 90% and 96%. This means there is limited room for future improvement. The focus for future batteries will be on making them smaller and lighter, which reduces the overall vehicle weight and, consequently, the amount of energy needed for propulsion. These aspects combined will likely help contribute to more customers considering the acquisition of an EV, provided their price also continues to fall.

Part of the reason that batteries are so heavy is that the energy density of Li-ion batteries is substantially less than 10% of conventional fuel – even when considering the limited efficiency of

ICEs. A modern ICE (40% efficiency) has net fuel power density equivalent to around 4.5 kWh/kg. This is more than 20 times higher than that of a lithium-ion battery. More efficient ICEs may lift that value substantially beyond 6 kWh/kg in the future.

Intense R&D is currently underway to take battery technology to the next level. This is expected to be solid state batteries. These typically have a ceramic or glass-like solid material to separate the electrodes instead of a liquid electrolyte. One advantage of such batteries is that they would be approximately 50% more compact and lighter than conventional Li-ion batteries. Moreover, costs would also likely decrease significantly towards a level where specific battery costs were $100/kWh, or even less.

Another important advantage of this future battery type is that it can withstand far higher temperatures than those on the market today. Re-charging an EV's battery is currently limited by battery characteristics and power connection issues – a 60 kWh battery requires a 750 kW connection, or the equivalent of more than 100 homes, to be re-charged within five minutes. The limited efficiency of the charging process converts part of the charge power into heat, which can raise the battery's temperature beyond the operating level; destruction is then inevitable. However, commercial solid-state batteries are not expected before the end of the next decade, and it is unlikely that electric mobility will take off at a large scale before then.

Another consideration is the battery range. A major share of the trips undertaken with passenger vehicles today is far below 100 km – a distance that can easily be met by most current BEVs. In many cases, however, a significant share of the distance driven each year per household is the result of a few long-distance trips. This is a strong argument in favour of PHEVs, which combine local zero emissions in urban areas (over short distances, including daily commuting), and liquid fuels for longer distances.

Despite all the potential technological advances, it should be noted that large batteries (80 kWh and more) will still be quite heavy and expensive even if they reach the cited $100/kWh target. It has yet to be seen whether a substantial number of customers are prepared to pay up to $10,000 for the battery when purchasing a vehicle. Innovative financial instruments may be required to manage this, which in turn requires a solid and easily accessible financial market. This is particularly relevant for developing non-OECD countries, given that they are expected to see the majority of the overall fleet increase in the period to 2040.

From a conceptual point of view, the final step for battery technology is the development of air-breathing batteries. They take the oxidizer from the air when required – specifically, when the battery is discharged – and release it into the environment when it is not required upon charging. Air breathing batteries may achieve an energy density of up to 11 kWh/kg as a physical limit. Combined with future high-speed charging at rates of up to the MW range (between 0.5–5 MW), they may finally address the efficiency difference between electric and ICE-powered vehicles. However, this potentially game-changing battery technology is currently only in the laboratory phase, with more substantial development work required than for solid-state batteries. Hence, air-breathing batteries are not expected to be commercially available before the middle or end of the 2030s.

Turning to the engines themselves, when low weight and high efficiency is required, brushless direct current (DC) motors with permanent magnets are the first choice. Unlike asynchronous motors, their magnetic field cannot be managed by external currents but is set according to the material characteristics of the installed permanent magnets. The strongest permanent magnets are made by adding rare earths – mainly neodymium – to an iron-boron mixture to make a neodymium magnet ($Nd_2Fe_{14}B$). This is one of the most powerful permanent magnets. Other rare earth metals, mainly samarium, dysprosium, praseodymium and terbium, can also be used, particularly if high temperatures are needed. It is important that the engine temperature remains below the magnet's Curie temperature as beyond this magnets lose their magnetic force and instantaneously become useless. Therefore, DC motors must be closely temperature-monitored so that this de-magnetization does not occur. Otherwise they will need to be re-magnetized by external means, for example, in the manufacturing plant.

It should be noted that the expression 'rare earths', for neodymium and other elements, suggests that these are only available in limited quantities. However, they are far less scarce than gold or platinum. Moreover, the widely used neodymium, for example, is more common than copper or lead. The difficulty arises from the fact that rare earth metals are – apart from a few exceptions – rarely found in concentrated deposits. Intense prospecting is underway in Australia and a few other countries to identify large and mineable reserves of these strategically important metals. Most already-known locations are in China, which currently contributes more than 90% of the global rare earth metal production. In parallel, scientists and engineers are continuously looking to reduce the amount of rare earth metals required in batteries, as well as seeking alternatives. These developments may substantially lower the amount of rare earth metals needed per vehicle.

High-performance DC motors may have a specific weight as low as 0.2 kg/kW of sustained power. That is only twice as heavy as a gas turbine with the same power development. Such DC motors have been developed for electric or hybrid airplanes because weight in these cases is vitally important. DC motors for EVs typically show values of 0.5 kg/kW (and even less), or half the value for a conventional ICE when considering auxiliary devices such as, super-charger and coolers. They have the potential to reach an impressive efficiency of between 95% and close to 99%.

Electric vehicles – overall emissions

To judge the lifetime GHG emissions of vehicles, a cradle-to-grave approach is necessary. This includes the mining of the required ores and other materials; their transformation into appropriate components (iron ore to steel sheets, for example), as well as development, manufacturing and vehicle assembly. It also includes the cumulative emissions from the vehicle throughout its active use, including from fuel, lubricants and other consumables, such as tyres and block pads, as well as the emissions resulting from scrappage once the vehicle has been removed from the active fleet.

Generally, GHG emission measurements in the road transportation sector have only taken into account fuel consumption. It is a fact that conventionally powered vehicles do generate by far most of the related CO_2 emissions during driving, when fuel is being burnt, especially given the long lifespan of passenger and commercial vehicles. Manufacturing – even when using a cradle-to-grave approach that includes iron ore mining and its subsequent upgrading to steel, and the production of plastics – still produces far fewer GHG emissions. Nevertheless, the increasing use of aluminium and other light metals, most recently magnesium for engine blocks or wheel rims, has emphasized the importance of including vehicle manufacturing when calculating GHG emissions, both for EVs and conventional vehicles. Aluminium and magnesium production requires a substantial quantity of electric power and generates higher CO_2 emissions than steel, as graphite electrodes are consumed in the course of aluminium and magnesium production.

EVs need to compensate for their significant battery weight, which may easily weigh half a ton or so. This means they need to use lighter materials for the chassis so that the overall vehicle mass does not go beyond reasonable limits. For reference, there are many passenger vehicles or 'light' SUVs that weigh more than 2 tons without passengers or luggage. Their higher use of aluminium, and even carbon components, increases the upfront CO_2 emissions of EVs significantly – before they have driven a single kilometre.

As a consequence, EVs with low specific CO_2 emissions require a low-carbon power source for both manufacturing and active driving use. Only countries with a very high share of renewables or nuclear power, or both, in their energy mix may fulfil these conditions. Close-to-zero emissions, in most countries, and at a global level, will not be possible for quite some time given the still small share of renewables in power generation.

In this outlook, renewables are seen expanding in the near and mid-future and throughout the longer-term . China, the country with the highest number of BEVs, may be able to reduce the specific CO_2 emissions of EVs when driving – without considering the CO_2 emissions during the manufacturing phase – from the current 140g CO_2/km to around 115g CO_2/km for an average EV by 2030. Battery production adds another 10–30g of CO_2/km over the vehicle and battery's lifetime, however, this largely depends on the manufacturing process and the capacity of the installed battery. These emissions upon circulation correspond to fuel consumption for conventional vehicles today of 5.9 l/100 km for gasoline and 5.1 l/100 km for diesel, and in 2030 the expected levels are 4.8 l/100 km for gasoline and 4.2 l/100 km for diesel. Such levels can easily be matched by both current and expected future ICE technology.

Strict fuel efficiency standards for ICE-powered vehicles have already been in place for some time, and continue to be tightened, as referenced in Chapters 1 and 8. Despite the current US administration's move to loosen certain regulations, the industry is already prepared for stricter standards and the new generation of vehicles is expected to comply with the tighter standards. In general, this is likely to mean that ICEs will have lower net emissions than EVs for an extended time period, given the current and expected future power mix in many regions.

The importance of recycling for EVs

Recycling is prudent for EVs as neodymium, lithium and cobalt resources are limited or difficult to mine, or in the case of aluminium and magnesium, the transformation from ore to metal consumes a substantial amount of electric power. The recycling process also contributes to the emissions footprint for EVs.

However, the expectation is that recycling aimed at reducing the associated energy consumption and GHG emissions of EVs is a project for the distant future, given the need to build up a sufficiently large reserve of such metals to be recycled. Even with the complete recycling of aluminium, for example, converting a major share of the global fleet from steel to aluminium chassis to reduce weight and, hence, energy consumption during driving, requires enough recycled aluminium to be available to effectively reduce energy consumption. The same applies to lithium, which also consumes a substantial amount of energy to render into 'battery grade quality'. In other words, recycling old EVs will not be enough to offset the emissions from their manufacturing until a large majority of the fleet is already electric. Therefore, recycling will not significantly reduce the additional requirements for lithium, cobalt and neodymium prior to 2030, because the EV fleet and the associated number of used batteries and scrapped material required for recycling would not be large enough.

The proposed 'second life' for older batteries as stationary battery storage to ease the storage issue discussed in section 7.5.3 may push recycling even further into the future, since round-trip efficiency is more important than maintained capacity in stationary storage. By extending the active lifetime of batteries, this would shift the accumulation of substantial amounts of recyclable material to the end of the 2030s. This strategy generates competition between CO_2 reduction, due to improved storage capacity for renewables, and the amount of CO_2 generated in the manufacturing of new non-recycled batteries for EVs and additional GHGs for mining and the refining of raw materials, as well as the production process itself.

7.1.3 Hydrogen, fuel cells and natural gas

The current discussion about de-carbonizing the transportation sector has revolved only around electrification based on batteries and renewable power, although most of the electricity is currently generated from fossil fuel sources and converting to renewables requires substantial time and enormous investments. In countries with a strong emphasis on electricity generation through coal-fired power plants, electrifying the transportation sector may even increase GHG emissions. As already discussed, it is also necessary to consider CO_2 emissions from battery and vehicle manufacturing. Although batteries may be produced in regions where carbon-free power sources are largely available, and then imported into the battery-consuming countries, this strategy may collide with economic and trade issues. Therefore, it is necessary to consider alternatives to the electrification strategy.

It is essential in this context to distinguish between energy sources and energy carriers. For example, electricity is not an energy source, but rather a carrier, as electricity must be generated from more basic sources and consumed instantaneously. An energy source may, in this case, be a very broad range of substantially differing materials. Examples include the water used in hydropower turbines, the coal combusted to generate heat, which in turn produces steam to drive a steam turbine, the gas combusted directly within a gas turbine, the solar radiation captured and converted in photovoltaic (PV) cells or the wind driving a large wind turbine.

The same applies to hydrogen, since it does not occur naturally in significant quantities on earth. Currently, hydrogen is mainly produced from natural gas and oil-based hydrocarbons through steam reforming. In the future, it will likely be provided through electrolysis using renewable power sources. The roughly 116 mt of hydrogen produced in 2018 would have required renewable power generation (including hydro, biomass and other renewables) of around 5,700 terrawatt hours (TWh), assuming electrolyser efficiency of 80%. This is basically all of the renewable power generated in 2017. Solar and wind only contributed around 24% of renewable power generation in 2017, and so these sources would have only been able to provide 25 mt of hydrogen.

Substantially more ambitious plans to decarbonize the road transportation sector by 2040 using hydrogen would mean replacing at least a third of conventional fuel with hydrogen, requiring at least 180 mt of hydrogen per year. From the refining sector, 10 to 15 mt may be spared because less conventional fuel would be required. However, providing such amounts of renewably-sourced hydrogen is a major challenge because all the available renewable energy is expected to be used for the decarbonization of the power sector.

These numbers suggest that an additional pathway for providing large amounts of hydrogen is needed, especially if sufficient amounts to make a significant impact are to be produced in the foreseeable future. Hydrocarbons in the form of oil and natural gas are a potential solution. Steam reforming is an established technology that can be scaled up to provide appropriate amounts of hydrogen and which can be used in most locations where hydrocarbons can be supplied. If combined with CCS – preferably at the source, close to production wells – the produced hydrogen can be considered carbon-free, although not a renewable energy carrier.

This would not be a complete decarbonization of the energy landscape, a prospect that would be financially impossible for most of the world, and particularly non-OECD countries. Nonetheless, decarbonizing the energy carrier derived from the hydrocarbons as the original energy source – by producing hydrogen via steam reforming or competing methods and capturing the generated CO_2 for long-term storage – may be a far more workable strategy towards fighting climate change and finding a pathway towards complying with the Paris Agreement from a financial and technological standpoint.

It should also be noted that hydrogen can also be used in combustion engines even though most research is focused on fuel cells. ICEs are far cheaper than fuel cells and will remain so for a long time. Additionally, ICEs are already available and future ICEs specifically designed to run on hydrogen may be substantially more fuel efficient than today's engines. Efficiency of 50% could be achievable in the medium- to long-term. The higher fuel efficiency would lower ICE hydrogen consumption to less than 20% more than a fuel cell – an acceptable value in light of projected future low hydrogen costs and the fact that such carbon-free hydrogen would not be harmful to the climate. Obviously new concepts would need to be developed for traditional reciprocating piston engines because hydrogen tends to increase engine knock; however, fuel cells also have challenges which would need to be overcome – and they appear to be far more serious.

The first successful experiments to generate electricity directly from hydrogen and oxygen without combustion date back to the middle of the 19th century. In the 1950s, fuel cells again became of interest as power generating devices for unmanned and manned space craft; batteries and solar panels would have been by far too heavy, or have insufficient capacity and power development. Therefore, it is logical to investigate fuel cells as a potential rival for ICEs. A fuel cell is far more than a simple stack of alternating electrodes and diaphragms and can be as large and heavy – or even larger and heavier – than a modern ICE delivering the same power. Today, the typical fuel cell in the transportation sector uses hydrogen and air – compressed to two to four bar typically – as reagents. Their efficiency may reach 60%, which, despite being higher than diesel engines, is still far from the physical limit of approximately 95%. Fuel cells using methanol or other fuels currently convert far less of the fuel's energy to electric power and deliver an efficiency of 40% or so.

A major challenge when using hydrogen in fuel cells (or ICEs) is the low energy density of hydrogen per volume. While every kg of hydrogen has a very high specific combustion enthalpy of around 120 megajoule (MJ/kg) – nearly three times that of gasoline or diesel and nearly 2.5 times that of natural gas – the picture changes significantly when considering how to store hydrogen onboard vehicles.

Today, 700 bar chambers are state-of-the-art for storing compressed hydrogen. This pressure requires high-tech materials able to withstand not only the pressure, but also to resist strong reactive forces if there is an accident. Even so, the corresponding energy density relative to the power developed – the vehicle distance driven – is only 20% that of diesel. In other words, to go the same distance on a full tank, a hydrogen tank would need to be five times larger than a diesel tank. The mandatory cylindrical shape needed to withstand pressure considerably limits the freedom of vehicle designers. While this may be acceptable for commercial vehicles, passenger vehicle designers are accustomed to making use of the available volume to give passengers – and their luggage – the maximum space possible.

The alternative of liquefying hydrogen at –252.8°C (or below) has been proposed and pursued in the past. It does not change the picture significantly – the corresponding hydrogen density remains around 71g/dm^3, which is far less than 10% of gasoline or diesel fuel. Fuel cells and ICEs would still require a hydrogen tank three times larger – and better insulated – than for conventional liquid fuels. Losses from the boiling-off of liquid hydrogen during prolonged standstills is also a major challenge.

Currently, CNG is the most common alternative fuel for passenger vehicles, and potentially LNG for commercial ones. Apart from broadening the fuel base, natural gas has lower GHG emissions and generally lower particulate emissions than conventional fuels. Some car manufacturers have, therefore, announced that they will increase their offer of CNG-fuelled vehicle models. Using CNG and LNG is an obvious strategy in gas-rich countries. However, engine technology must carefully avoid the emission of unburnt methane, which has a far higher GHG warming potential (GWP) than CO_2, as much as 32 times higher over a 100-year period. Limiting the horizon to 2040, the GWP of methane is 100 times higher than that of CO_2. Therefore, to maintain the GHG advantage it is necessary that substantially less than 1% of the methane is released to the environment unburnt.

An important advantage of CNG over LNG vehicles and BEVs is the fact that advanced gas distribution grids already exist in many countries. Compressing distributed gas to the CNG pressure of 300 bar or more could be carried out at de-centralized refuelling stations using simple multi-staged compressors.

A general disadvantage of gaseous *versus* liquid fuel is the significant amount of energy needed for compression or liquefaction. For CNG at 300 bar, the (lowest) physical limit is below 2% of the heating value of the fuel. For LNG, it is only a little above 2%. However, in practice around twice that amount is consumed as mechanical power. Largely depending on the actual source of the mechanical power, the amount of energy required may rise up to 8% if a combustion engine is used to drive the compressors.

The situation worsens again substantially for hydrogen. Compressing hydrogen to 700 bar requires the equivalent of around 7% of the hydrogen's energy content as the lowest physical limit. In reality, it is likely that more than 10% is required as mechanical power or even more than 20% when using a combustion engine to compress the hydrogen. Liquefying hydrogen consumes far more mechanical power – the lower physical limit is around 10% and the actually-consumed power increases accordingly when compared to compressed hydrogen. Altogether the energy content of hydrogen available to run the vehicle may be as low as 80% for compressed hydrogen and 70% for liquefied hydrogen.

Although a portion of the mechanical power initially used to compress or liquefy hydrogen may be recovered during the vehicle's operation, such devices are unlikely to be installed in vehicles and may recover only around a third to a half of the initial mechanical energy. This improves the efficiency but does not change the overall picture.

It is unrealistic to assume that hydrogen will be generated close to consumers in the future – in fact, the envisaged renewable energy sources, such as wind and solar, are typically generated at a substantial distance from final consumers. Thus, further transportation losses must be taken into account. The overall efficiency of the renewable-to-hydrogen chain can even be considerably lower, although actual numbers may vary depending on the origin of compression and liquefaction power or actual losses along the chain. Careful investigation must be undertaken to compare the total energy invested into propelling vehicles.

The far higher efficiency of the electricity chain from (renewable) power generation to the vehicle's battery suggests that the use of BEVs is preferable. However, hydrogen has the undeniable advantage of longer-term storage capability (in the form of the 'fuel' hydrogen). These aspects again hint towards a future with a broad range of powertrain technologies complementing each other, even within a single vehicle.

It is also important to bear in mind that the substantially higher well-to-tank efficiency of conventional (liquid) fuel grants certain advantages to oil-based fuels. Additionally, oil-based fuels themselves do not contribute to global warming as is strongly the case for methane, the main component of natural gas.

7.2 Aviation

Aviation remains the fastest growing transportation segment and has garnered a lot of attention, mainly because airplane emissions go directly into the upper atmosphere. However, new generations of airplanes and gas turbines have made important technological leaps in recent years, ranging from the use of advanced materials to new engineering designs and systems. High-end composites based on carbon fibres are state-of-the-art, used in the latest generation of commercial airplanes, such as Boeing's Dreamliner 787 and the Airbus A350XWB.

Technology advances have substantially reduced fuel consumption, increased comfort and improved the environmental friendliness of air traffic. A major aspect is noise reduction – essential for the acceptance of high flight frequencies, as well as an airport's night operations. It should also be noted that air transportation generally occupies the land airports are built on and thus largely affects only the immediate surroundings. Extensive road and rail infrastructure, on the other hand, spreads to far larger areas and their construction may have a far broader environmental impact. Multi-line highways and railway lines requiring frequent tunnels and bridges are just some examples.

A fully-occupied last-generation commercial airliner consumes at most 3 kg of fuel per passenger km – roughly similar to the consumption of a modern passenger car with a typical 1.5 person occupancy. However, because a plane moves substantially faster, the passenger can travel a much longer distance in the same time. In the end, people may opt to travel greater distances, which in turn would mean rising energy consumption per person. This is nothing new, the invention and then mainstream use of trains and automobiles saw similar trends.

The air transportation industry has committed to reducing its specific fuel consumption by 2% p.a. – a value substantially above commitments made in the road transportation sector and three times the value of those made by companies in the marine transportation sector. However, the steep increase in the popularity of air transportation as a whole makes it questionable as to whether the intended industry-wide CO_2 reduction can be achieved without further strategies beyond making planes increasingly efficient.

While prototypes for air taxis have already been presented – and in a few years they may even operate fully autonomously – it will be many years before most of the recently presented concepts and studies for reviving supersonic passenger aircrafts will be seen in the skies. The recently-presented prototypes for air taxis are one potential application of electric air transportation. However, it is important to keep in mind that the rotor of a conventional helicopter – and most taxi prototypes require such rotors – produces more noise than the gas turbine typically used to drive it. It has still to be seen whether urban populations are prepared to accept the noise and air turbulence of many air taxis operating at the same time.

Impulsion

The first plane flight in history took place because engine technology was sufficiently advanced, in view of the power to weight ratio, to lift the plane and the engine into the sky. A focus on low weight has continued ever since and, as a consequence, gas turbines are the engines exclusively used today for commercial airliners. They offer by far the best power-to-weight ratio, with the exception of some older and smaller propeller planes that still use piston engines.

Engine efficiency and fuel consumption strongly depend on the engine's compression ratio. Modern flight gas turbines have reached a compression ratio of 50:1. Hence, reducing the fuel consumption of an airplane's gas turbine has become increasingly difficult, although there remains potential for further improvements, mainly by cutting down on internal losses.

Apart from gas turbine efficiency, the associated conversion of turbine power into thrust to propel the aircraft is important. The power developed by the turbine is converted into kinetic energy as the turbine emits an accelerated jet of air. The velocity difference produces the desired thrust. The specific thrust increases considerably with larger bypass ratios, which in turn requires larger fans; geared fans are state-of-the-art for today's most efficient aviation gas turbines.

Electrification has gone from being an 'exotic' topic to a serious consideration in future air transportation. Small airplanes have been designed and developed that run entirely on battery-electric power. Nevertheless, it remains to be seen whether this concept can be extended to commercial airliners, even if they are only intended for short-distance flights. As already discussed, ICEs still have considerable potential for efficiency improvements and it is likely that the competition from electrification may speed up their development too. The combination of an electric motor and a battery may only be sufficient for short-haul flights, even taking into consideration expected battery developments, such as solid-state batteries.

Even so, electrification is already becoming a reality, particularly in auxiliary systems used to power A/C, cabin pressurization and even taxiing. Electric systems may assist the main engine when more power is required for a limited time; take-off is a perfect example. An immense amount of thrust is required to accelerate the airplane and to push it upwards against gravity for a rapid climb. While cruising, air resistance is the biggest force to be overcome and substantially less thrust is required.

Another important aspect, especially from the passenger's point of view, is that such hybrid systems may add another level of security. By providing an independent second power source, it reduces the risk of a serious accident if there is a problem with the main engine.

Alternative fuels

The fuel itself is another potential area of focus for limiting and eventually lowering GHG emissions. Biofuels are already being tested by several airlines and some have been approved for wider use. However, they are currently comparatively expensive, and biofuels, in general, have come under pressure as they are less environmentally-friendly than initially expected or claimed. GTLs fuels made from natural gas have the advantage of making use of an energy source with a large resource base, but their production is costly and both the production process and the final products do not provide substantial advantages in view of CO_2 emissions. The direct use of natural gas as LNG is possible. The same applies to liquefied hydrogen, which could be used to power aviation gas turbines. Nevertheless, the use of LNG and liquid hydrogen remains in the early planning stages.

Additionally, passenger concerns play an important role, as they often connect gaseous fuel with the idea of immediate explosion should there be an accident. In reality, airplanes (and road vehicles) rarely explode, but simply burn in most accidents because there is abundant fuel to feed the fire. Nonetheless, it will be a challenge to get passengers to board an aircraft running on LNG or liquefied gas without significant awareness campaigns to overcome this misperception.

In the more distant future, concepts such as power-to-liquid (PTL) might provide a zero or low-carbon fuel alternative for the aviation sector. An attractive aspect is that current, highly-reliable technology can be further optimized with the emissions-control aspect transferred mainly to the fuel.

Looking ahead, bearing all of the highlighted issues in mind, it will be challenging to meaningfully replace the currently used engines – which are efficient and powerful combustion engines – or the presently used jet fuel with alternative technology concepts or propellants within the projection horizon of this WOO. Thus, it might be more efficient to opt for compensatory measures. Hence, aviation represents a sector with expanding oil demand, as reflected in Chapter 3.

IT

Airplane manufacturers have always been at the forefront in terms of integrating the most advanced computing systems. The first planes were built more on a trial-and-error basis, relying on increasing experience, which is one of the reasons why this industry is quite conservative from a security standpoint in its design decisions. Aerodynamics can be very complex when it comes to solving physical equations. Even today, intensive tests with physical models are carried out, although these are now strongly complemented, if not replaced, by numerical calculations carried out by the most powerful computing systems. The efficient design and construction of an airplane consisting of millions of parts would not be possible without the assistance of sophisticated computer-assisted design (CAD) and warehouse systems.

Beyond the increasingly complex application of IT in the design and development of an aircraft, the operations themselves rely increasingly on the assistance of sophisticated and fast-acting computer-based avionic systems. These are necessary because many of the wing designs that reduce resistance also cause aerodynamic instability. Quick and reliable response systems actuate the flaps to maintain a safe flight path. Most advanced military planes, for example, could not be flown by a pilot without the assistance of IT systems; human response times are too slow. Several fatal accidents in the recent past indicate how important reliable and fail-safe on-board systems have become. Once the intelligent support system fails it may become very difficult for the pilots to regain control because the airplane quickly diverts into unstable – and often unrecoverable – flight patterns, including stalling.

7.3 Rail transportation

Advances in rail transportation mainly focus on expanding the network of electrified rails. This means not only building new electrified rail lines, but also electrifying what is still served by locomotives running on other energy sources. One major success has been the full electrification of the world's longest railroad line, the Trans-Siberian Railway. China is also advancing quickly in this respect, mainly in connection to the strong expansion of its high-speed rail network. The One Belt One Road initiative is part of this strategy.

Non-electrified railroad lines are nearly exclusively serviced by locomotives running on diesel engines. Stricter pollution regulations, as well as the low price of natural gas in North America, have given rise to the use of LNG as an alternative fuel in some regions. Prototypes for small local or regional passenger trains powered by hydrogen fuel cells have also been tested in various countries.

In general, fuel consumption patterns of fuel-powered railroad engines are comparable to medium- and large-sized stationary engines, as they employ the same technology. Their specific fuel consumption may be below 200 g/kWh. Future improvements will broadly take place at the same pace as those expected for heavy-duty commercial or stationary engines. The rail segment alone is too small for independent engine development.

Nevertheless, railroad lines provide some unique advantages. One such advantage is that the power generated at one point in the rail network can be used elsewhere. For instance, this has been the case for some time already in brake recuperation, which is a natural win-win situation – a braking train, or one going downhill, generates power that may be used by another to accelerate or go uphill. Electrification is the main requirement because only then can the interconnected trains – of all sizes, from small commuter trains to large and very heavy cargo trains – interchange electric power through the grid. This is to a certain extent the future role model for BEVs to cope with the charging issue. BEVs may act as power storage when they are not in use, so that other BEVs that need recharging can access their battery through the grid.

7.4 Marine transportation

Marine transportation is an essential element in global trade - around 80% of internationally traded goods or their initial components have been moved on a ship before delivery of the final product to customers. Large ocean-going vessels are responsible for around 4% of global oil demand. A large and fast container vessel may burn 100 to 200 tons of fuel oil per day, in some cases even 300 tons.

Emissions – both CO_2 and polluting gases such as SO_2 – are a significant topic of public discussion and there is substantial pressure on the shipping industry to become more environmentally-friendly. Possible fuel displacement, using LNG instead of oil-based fuels, is a focus in this context. LSFO and LNG will be in direct competition as neither requires the use of scrubbers for vessels to comply with IMO regulations.

In line with an ongoing modernization of the container vessel fleet, combustion engines – typically large two-stroke engines directly coupled to the propeller – are the most advanced of all marine engines. Nevertheless, in the past 20 years or so, only minor advances have been achieved towards improving fuel efficiency. In light of the IMO's intention to quickly and substantially tighten fuel efficiency standards for large ocean-going ships – by 30% for newly built ships in 2025 compared to 2014 standards (IMO) – and to cut aggregate CO_2 emissions from the shipping industry to half of 2008 emission levels by 2050, all technology innovations must be considered and the most efficient ones implemented.

Main engine

Today, enhancing engine efficiency plays an important, and even decisive, role in the context of global warming. However, although CO_2 is currently the most recognized GHG, it is important to reduce other emissions as they may also significantly contribute to global warming. Methane – nearly the only component of natural gas – is one such example, since gas engines may emit unburnt methane in exhaust gas.

The area with the highest potential for improvement is WHR using the hot exhaust, as it has a high energy content and high temperature. WHR using thermal energy contained in the cooling water, lubrication oil and compressed air from the supercharger may also contribute in a limited manner. Together, another 5% (absolute) of efficiency may be gained. With LNG, the exhaust gas temperature may be reduced to lower levels than for LSFO, because there is no risk of sulphuric acid condensing. This makes exhaust gas WHR far more efficient and, thus, more economically attractive; an overall 7% or 8% – in absolute terms – is possible for LNG.

As in other transportation sectors, the engine itself can be a target for improvement. Reducing internal friction – losses caused by scavenging and other fluid flows, as well as improved combustion processes, among others – can all yield improved efficiency and lower fuel consumption. Upgrading the charger subsystem has an attractive potential of 2% to 4%. Expanding the exhaust gas in a turbine instead of carrying out a blow-down – also called compounding – may deliver a further 1% to 2% of power once advanced expansion turbines are available. Even LNG re-gasification may produce some power if the engine is running on LNG. In total, overall engine efficiency may rise from current levels of roughly 48% for a large two-stroke engine to more than 60%, entailing a corresponding drop in fuel consumption. If using an oil-based fuel, CO_2 emissions would decline at the same rate.

The only option to further significantly lower CO_2 emissions while using a fossil fuel-based energy source is to use LNG. The CO_2-reduction potential of switching to LNG is higher than 25%, considerably above the combined effect of main engine improvements, WHR and supercharger optimization. It should also be noted that technical efforts, investment and the adoption time needed for implementing these improvements are also substantially more advantageous when switching to LNG.

Logistics and IT

Optimizing logistics through route and demurrage planning or improving shipping routes prior to sailing offers interesting potential to increase efficiency. This includes taking into account ocean currents and wind conditions, for example. More flexible port-to-port connections are another option, with the help of improved logistics, as is already the case in the airline industry. The principles of AI, big data and other innovative IT concepts are already playing, and will continue to play, an important future role in marine transportation.

Today, highly-optimized cargo management systems have reduced handling overheads considerably. In the future, further optimization can be expected with the introduction of AI based on big data. A large number of real-time connected transportation methods, such as warehousing, road, rail, domestic and international ships, and participants, from individual workers to globalized freight forwarders and shipping companies, can feed into these processes. In conjunction with autonomous – or at least highly automated – operations, crew costs will drop substantially. Currently, they are typically the second largest cost (after fuel).

The advancing computing capability of modern IT systems are also rapidly improving hydrodynamic calculations and, as a consequence, the optimization of a ship's hull, as well as its propeller. Re-fitting existing ships with improved propellers – or in some cases just with an appropriate propeller hub cap – may reduce fuel consumption by 2–3%.

Air lubrication

The most important source of resistance is friction caused by the relative movements of the hull surface through the surrounding water. The boundary layer theory of fluid dynamics is the basis for scientific investigation into associated effects and points towards significant efficiency improvement if the flow resistance of the hull can be reduced.

As a logical consequence, engineers have attempted to establish a boundary layer of air between the hull and the surrounding sea water. This is usually achieved by constantly injecting air into the boundary. As air is far lighter than water, the air bubbles tend to escape towards the sea surface and cannot then be used for lubrication purposes. Air lubrication is consequently best suited for the bottom of a ship.

In the end, drag from friction could be reduced by up to 5% in practice, resulting in a 3.5% reduction in overall fuel consumption when considering the power consumed by the air compressors used to produce the air cushion. Future improvements may raise that value to roughly 6–8% – a considerable, but not decisive amount in terms of reducing GHG emissions or fuel costs.

IMO's 2020 sulphur cap

The most important change in the near future is the implementation of the IMO's sulphur cap for marine shipping emissions. The sulphur content of bunker fuel oil will need to drop from the current 3.5% (by weight) to only 0.5% by 1 January 2020.

The obvious solution is to use only fuel that complies with the new regulations, but that is also a costly option. In Singapore, HSFO prices were hovering around $420/ton (380cst) and $460/ton (180cst) in May 2019, while LSFO was priced at around $570/ton and marine diesel (MD, 0.5%S) at a level of $620/ton.

IMO regulations, on the other hand, allow for exhausts to be cleaned to meet the emissions standards. A similar regulatory approach has been used since the 1970s for coal or fuel oil-fired power plants. On ships, this can be done by means of a scrubber. Scrubbers remove most of the sulphur compounds from the exhaust so that SO_2 emissions drop to a value equivalent to the use of 0.5% LSFO. Both open- and closed-loop systems can be employed. The basic operating principle is the same, with the difference that the open-loop system discharges wash water into the sea after only minor treatment, while the closed-loop system re-circulates the wash water.

In an open-loop system, ordinary sea water is sprayed into the exhaust gas stream, causing a chemical reaction between the naturally alkaline sea water (typically 2,200 μmol/litre, pH=8.2) and the sour sulphurous acid (H_2SO_3) produced by the contact of SO_2 and water. The acid is quickly oxidized to sulphuric acid (H_2SO_4), which then reacts with carbonates and other salts in the seawater, forming sulphates. These are already a natural component of sea water. The product can then be simply discharged into the sea.

In a closed-loop system, caustic soda (NaOH) is added to neutralize the sulphuric acid. Afterwards, the product is re-processed and recycled to be delivered in port for further treatment. The closed-loop systems are more expensive to install and to operate. State-of-the-art closed-loop scrubbers achieve a SO_x reduction efficiency of more than 97%, equivalent to reducing the fuel's sulphur content from 3.5% to only 0.1%. This implies compliance with even the most stringent regulations in ECAs. However, caustic soda must be loaded on a regular basis. Around 6% to 15% of the weight of fuel oil consumed by the engine needs to be added as caustic soda to the exhaust stream for cleaning. Several hundred tons of NaOH may be required for a large container vessel crossing an ocean. This increases not only operating costs, but also takes up valuable ship space and reduces the payload.

To complete the picture, it should be mentioned that hybrid systems are also used. These operate as closed-loop systems while manoeuvring in port, or in sensitive areas, but as soon as the vessel is at high sea, the system can be switched to operate as an open-loop scrubber.

Nevertheless, several issues have been recognized as matters of local concern regarding the wash water from scrubbers. MARPOL has set out recommendations and/or limits (Resolution MEPC.259 (68), as of 15 May 2015) for ship discharge that consider Chemical Oxygen Demand (COD) because the transformation from sulphurous (H_2SO_3) to sulphuric (H_2SO_4) acid consumes oxygen, which is then no longer available for aquatic organisms. These recommendations also limit the discharge of metals, nitrates and Polycyclic Aromatic Hydrocarbons (PAH). Finally, the discharged wash water's pH must not be below 6.5 (equivalent to slightly acidic) so as to keep the ion balance of the sea water in the immediate environment of the ship at acceptable levels. However, environmentalists consider such wash water discharge simply a shift from polluting the atmosphere to polluting the sea.

Scrubbers may also reduce NO_x emissions by around 10% and particulate matter emissions by as much as 60% or even more. When using a scrubber, a ship's chimney no longer emits soot and the exhaust appears transparent – an advantage which must not be underestimated in coastal areas or in port. On the other hand, substantial power is needed to run the pumps that take sea water and lift it up to the scrubber – which could be 20 to 30 m above sea level – as well as atomizing and eventually re-circulating the wash water. This typically amounts to an additional power requirement of between 1% and 2% of the main engine power.

Another solution to the IMO regulation is for ship owners to use LNG as their sole fuel instead of burning a number of different fuels depending on the vessel's location. In ECAs, a limit of 0.1% is imposed and several regions or ports have already banned open-loop scrubbers entirely, meaning ships may need to carry multiple fuels even if they have a scrubber installed. That is to say, rather than using HSFO when at high sea, then LSFO or Ultra LSFO close to shores or in ECAs zones, ship owners could simply use LNG all the time. This would dispense with the cost of filling and maintaining various tanks, frequent fuel switching or even employing a scrubber.

If sufficient LNG bunkering facilities to ensure global coverage are quickly set up starting in the mid-2020s, then LNG might be adopted at a far quicker pace than currently expected. It could in fact become the dominant fuel, especially for large ocean-going vessels. A positive side-effect would be substantially lower CO_2 emissions compared to liquid fuel, although special care must be taken to limit the emission of unburnt methane.

An analysis of CO_2 emission projections reveals that even an accelerated implementation of advanced technology, combined with large-scale switching to LNG (reaching a share of 60% in 2040) would be insufficient to meet the IMO's emissions reduction goal. Such a shift would only result in emission levels from the marine sector stabilizing near 830 Mt/yr in 2040. This is still 10% higher than the 760 Mt/yr estimated for 2010, and 8% higher than the emissions estimates for 2018.

The challenge is emphatically underlined by the fact that assuming a 3% p.a. increase of global marine trade over the forecast horizon, a 6% p.a. improvement in specific marine transportation efficiency (MJ/ton-mile of goods transported) would be required to meet the IMO 2050 target of reducing emissions by 50%. It is clear that reducing emissions by such an extent will require more measures than just rapidly implementing new technology – and these need to start soon. The IMO 2050 emissions target may only be achievable if CO_2 emissions from fuel are cut by 80% from CO_2 emission levels of LNG. This means that future fuels would need to emit only 20% of the CO_2 emitted by LNG, or less than 15% of current emissions from oil-based fuels.

On-board carbon capture with subsequent carbon storage at appropriate sites may be part of an eventual solution. This would involve the capture and temporary storage of CO_2 on-board, followed by its delivery in port, as well as transport to and storage at final storage sites. Another option would be to use hydrogen to propel ships and store the CO_2 released during hydrogen production, using the hydrogen production methods described earlier in this Chapter. In this context, it is important to emphasize that the use of conventional (fossil) fuels may become carbon-free, although they are not renewable. Using fully-synthetic fuels (also called e-fuels) made from renewable – or at least carbon-free – power, including fission and future fusion nuclear, CO_2 and water, or simply extracting a corresponding amount of CO_2 from the atmosphere to store it at appropriate CCS sites for an extended time, may also be part of an eventual solution.

Finally, it should be noted that neither electric power, nor alternatives such as sails, will play a substantial role in the shipping sector, even in the distant future. Even when assuming technology leaps for batteries they remain inappropriate for international marine transportation across the oceans.

7.5 Power generation

Power generation is one of the largest consuming activities in terms of primary energy and electricity demand will continue to expand in the future. Beyond the traditional demand sectors such as industry and housing, IT and communication systems are quickly expanding and need ever more power. Bitcoin mining, the most well-known blockchain application, is already consuming more power than a number of small countries.

Today, electricity is mainly generated from coal and natural gas. Coal has been, and generally remains, an affordable primary energy source at a global level. However, the US shale gas boom has provided enormous quantities of inexpensive natural gas, allowing it to displace coal there to a significant degree, without additional impetus from regulations or incentives. Fossil fuels will continue to remain important in power generation and the related technology is also undergoing constant development.

The scientific discovery of nuclear forces and their use in nuclear power plants enabled the access to a new, powerful energy source. Scientists are already working to take the next step in nuclear power – nuclear fusion. However, it will still be some decades before commercial nuclear fusion plants begin operations.

In many respects, the focus has turned towards renewables, making wind and solar energy available on a large scale, not only from a technical, but also a commercial point of view. Technological advances and economies of scale go hand-in-hand in this case. The importance of the availability of a large amount of funding should not be underestimated in this context.

7.5.1 Fossil-fuelled power generation

China has built up substantial coal-fired plant capacity that will be in service for decades. It will be interesting to see whether India, as the next largest developing country, will do the same or opt for a more renewable path. In the end, economic aspects may take precedence over environmental concerns.

Coal and steam power plants

Modern coal-fired power plants are among the most mature, technology-wise, in the power generation sector. The introduction of supercritical plants with steam temperatures above 600°C and steam pressure well above 220 bar has marked an important step forward; such plants now attain efficiency of 45% or more. Temperatures above 1,000°C for coal combustion would allow for higher efficiency from a purely physical point of view; however, the cost of the high-temperature heat exchangers required in the external heat engines limit their attractiveness from a cost-benefit standpoint. The efficiency of supercritical steam power plants may rise to nearly 55%, but no future game-changing breakthrough can be expected. All steam and vapour-based power plants are approaching a limit imposed by natural laws.

This Outlook considers existing and future coal-fired power plants as important sources of electricity generation. Nonetheless, no technological advance can change the fact that coal is the power source with the highest GHG emissions. Electric vehicles consuming power generated from coal are less environmentally friendly than the average ICE-powered vehicle.

Water is the preferred choice for large and especially high-temperature power plants, but any other liquid that may be condensed at room temperature to an acceptable pressure can be used instead. At a typical condenser temperature of 30°C, water has vapour pressure as low as only 42 mbar. Today a broad variety of organic compounds including hydrocarbons, partially fluorinated hydrocarbons (FHCs), or silicon-based oils are employed in so-called Organic Rankine Cycle (ORC) power plants.

This flexibility regarding fluid choices can be of use in geothermal energy, or for WHR, as well as in smaller decentralized plants. Nearly all temperatures between 100°C and 300°C can be used by choosing the appropriate liquid to generate steam. There is still substantial potential for efficiency gains by improving the expansion engines and the usually mandatory economizer, generally a type of heat exchanger.

Natural gas and CCGTs

Gas turbines are a type of ICE, since the fuel is combusted inside the engine and thus does not require a heat exchanger to raise the temperature of the enclosed working fluid. Not using a heat exchanger allows for higher operating temperatures – provided that the turbine's first set of blades after the combustion chamber can withstand them.

Most advanced, heavy-duty gas turbines are now operating at temperatures up to 1,600°C. When using hot exhaust gas for a bottoming steam cycle, the overall fuel-to-power net efficiency can rise above 62%, approaching the thermodynamic limit of perhaps 73% to 75%. This limits the potential for a major breakthrough in fuel savings from the technology side. Nevertheless, these generators will remain by far the least CO_2-emitting fossil-fuelled power plants, an advantage which should not be underestimated as countries and regions look to tackle climate change at reasonable costs. They may also serve as the inspiration for engineering developments in other areas, especially piston engines in the transportation sector.

The segment of gas turbines that can generate between 5 MW and 50 MW has seen large efficiency gains as technology initially developed for the air transportation sector has been adapted for stationary use (aero-derivative gas turbines). Their efficiency may surpass 40% and their low maintenance requirement is an asset, especially in conjunction with the combination of heat and power generation – or CHP for short. The maintenance aspect may help offset their lower efficiency compared to large piston engines within the same power range, the latter often reaching conversion rates above 48%.

CHP generators have an additional advantage of harnessing the heat created in the power generation process, and thus, reducing energy loss. Often, the power is supplied to the grid and the exhaust heat is used for industrial processes or district heating. The combined efficiency can be as high as 90%. Increasingly, such CHP plants are used by large factories to generate their own power and to use the waste for heating, A/C or for industrial purposes in-house. This Outlook considers the potential increased use of these power generation methods in line with the drive in many countries to improve efficiency and reduce GHG emissions.

7.5.2 Renewable power generation

Hydropower and biomass are currently the most important renewable energy sources. While hydropower is entirely used for power generation, biomass is mainly used for cooking and other household applications. Hydropower plant technology is mature, with efficiency above 90%. Consequently, no important advances can be expected, although the re-fitting of older units does have leave some potential for improvement.

For large scale power generation, biomass either needs to be converted into a higher quality fuel, for example, gas or liquid fuel for ICEs, or it can be used in external combustion engines, as is the case for coal-fired power plants. In the first case, pyrolysis or biogas plants are used to convert the biomass. Biogas plants use mature technology, but there is still significant room for development in pyrolysis plants to improve their conversion efficiency.

Another difficulty with pyrolysis is that it can be difficult to collect sufficient quantities of appropriate biomass to constantly supply a medium-sized steam power plant. ORC power plants have been developed which allow the downsizing of the plant size to 10 MW without overly penalizing its efficiency. ORC plants also take into account the typically lower combustion temperature of biomass compared to coal – biomass has a lower specific energy content of around 18 MJ/kg *versus* 30 MJ/kg for coal. It is important to highlight that the density of renewables is very low compared to conventional power plants as solar and wind farms naturally occupy large areas.

Correctly interpreting the addition of renewable power

The expansion of global renewable power generation in 2018 saw an addition of nearly 100 GW of solar and 50 GW of wind power. However, a careful interpretation is needed when comparing these numbers to conventional power plant capacity. Detailed numbers from the International Renewable Energy Agency (IRENA) for both renewable capacity and actually generated renewable power in 2017 (more up-to-date numbers are not yet available) reveal an average capacity factor for the whole renewable power sector of only around 32%. This means that all renewable power sources combined delivered only a third of the nameplate capacity. This number would be substantially lower if considering solar alone, which has a capacity factor of less than 13%. Wind has a capacity factor of around 25%.

The capacity factor is very important in judging the actual contribution of additional power capacity. For example, 1 MW of PV solar capacity delivers only around 1,100 MWh in the course of a year, 1 MW of onshore wind capacity already delivers approximately twice as much (2,170 MWh) and 1 MW of offshore wind capacity delivers again substantially more at around 3,030 MWh. However, modern coal-fired power plants used for base-load generation have a capacity factor of 80% and nuclear power plants are typically intended to deliver a capacity factor of 90%. In these cases, significantly more electricity is generated throughout the year, namely 7,000 MWh and 7,900 MWh, respectively. To catch up with a typical coal-fired power plant generating 600 MW of electricity, 3,800 MW of PV power or 1,940 MW of onshore wind would need to be installed. Replacing a large

1,300 MW nuclear power plant would require 8,200 MW of PV, 4,200 MW of onshore or 3,000 MW of offshore wind (or 600 very large offshore wind turbines).

This puts the 2018 record additions of renewable power capacity in a new perspective. Carefully interpreting the amount of generated power reveals that despite headline capacity additions, most of the additional power being generated in recent years has come from fossil fuels rather than from renewable sources. This means that there is still a long, challenging and costly way to go before power generation can be considered renewable to any significant extent. Fossil fuels will therefore remain a large component of the power generation sector for the foreseeable future. However, this does not necessarily mean that GHG emissions will not decline at a far quicker pace; adding CCS and CCU will lower CO_2 emissions significantly even as the primary energy source remains a fossil fuel.

Looking at the different primary sources of renewable energy, PV solar power has by far the lowest capacity factor of 12.6% only. Concentrated Solar Power (CSP) plants regularly use molten salt storages to expand power generation into the late evening and night – apart from maintaining stable power generation on cloudy days – and correspondingly have a substantially higher capacity factor of more than 26%. Due to their higher costs, however, they represent only 1.3% of the globally installed solar capacity, but generate 2.6% of solar power. Although global installed solar capacity accounts for nearly 18% of the overall renewable capacity, the share of solar power in global renewable power generation is much lower at 7.1%.

Hydropower accounted for more than two-thirds of all renewable power generated and has a capacity factor of 37%, while representing 58% of renewable power capacity. Geothermal power generation has a capacity factor of 77%, by far the highest among all renewable power sources, making it a perfect choice for baseload operations. However, installed geothermal capacity accounts for only 1.4% of all renewable capacity.

Currently, wind is the second most important renewable power source, behind hydropower, both in view of generated power and installed capacity. It accounts for 18% and 24%, respectively, in the renewable energy mix. In 2017, 96% of wind power generated was onshore; however, offshore has been increasing quicker than onshore because it has a higher capacity factor of around 34.5%. In 2017, all wind technologies combined generated around 18% of the total renewable power, more than 2.5 times the share of solar.

Renewables depend strongly on weather conditions (wind, sunshine) and, hence, y-o-y values can fluctuate significantly.

Hydropower

Hydropower is the largest renewable power source – as mentioned earlier, it represents 58% of installed renewable power capacity and accounts for more than 65% of all renewable power generated. There are two main types of power plants, depending largely on their location – river plants and mountain plants. River power plants depend on the actual current of the river, have only limited storage capacity and are characterized by dams which are typically not more than 10 m to 15 m in height. They do not serve as pumped storage power plants. The height differential between the dam and the off run is low, so a lot of water must flow through to generate large amounts of power. As a consequence, they are typically built on large rivers.

The other type, in the mountains, are also typically storage power plants. They collect and store the water produced by melting snow and from the continuous melting of glaciers in higher regions. They are characterized by high dams of 100 m and more. A head of water of up to 1,000 m (in some cases even more) reduces the amount of water needed to generate a given amount of power. With a drop height of 1,000 m, only around 0.1 m^3 of water needs to flow through the turbines to generate 1 MW of electric power.

Both hydropower plant types may be affected in the future if precipitation patterns deviate from the initial planning base on which the hydropower plants were designed. Another consideration is that the large flooded areas behind the dams can collect organic material, which then rots. The associated methane emissions may harm the GHG balance of such hydropower plants. This phenomenon of having a renewable power source, which nevertheless contributes to global warming, is a sign that "obvious" truths need to be profoundly investigated to obtain clear numbers based on science.

OECD countries have been using hydropower for a long time and, hence, their potential is already largely exploited. The regional focus for new plants is now on developing countries in Asia, mainly China, with some potential additions also in Africa and Latin America. It should also be kept in mind that hydropower plants have a substantial impact on the surrounding, and in some cases, even distant ecosystems. For example, fish migration routes, which are necessary for maintaining the population of some species – salmon and eel to name two – may be cut and so fish populations at large may be affected.

This Outlook assumes that hydropower will be among the most reliable future renewable sources, considering a typical levelized cost of energy (LCOE) between $35/MWh in developing Asia, where there is still substantial potential for new plants, and $100/MWh in Japan. From a technology point of view, hydropower can be considered a mature technology because modern water turbines have reached an efficiency of 95–98%. Even the partial load efficiency has been elevated to near physical limits; only very limited further improvements are possible. It is important to mention that hydropower's ability to serve as a baseload energy source is a substantial advantage over other fluctuating sources.

Geothermal

Geothermal power is among the renewable energy sources with the highest capacity factor, meaning it is well-suited for baseload operations. However, it needs very special geological conditions that are typically only met in certain regions. Iceland, and also Kenya, have opted for an extensive use of geothermal energy because these countries are situated on very geologically active rims. Roughly half of Iceland is situated on the North American plate and the other half on the Eurasian plate, drifting apart several centimetres per year. At such locations – which can be found also along the Great Rift Valley in Kenya and along the Pacific fire belt – hot rocks are close to the surface, reducing the amount of drilling needed to access the corresponding thermal reservoirs.

Thermal energy is usually extracted with water which either flows naturally through porous formations and is heated up, or by artificially producing cracks in the rocks by injecting water into boreholes at high pressure, similar to what is done in tight oil production (hot dry rock method). The hot water is extracted and usually transfers its thermal energy in a heat exchanger to a working fluid based on organic compounds (ORC turbines) or into a mixture of water and ammonia (Kalina method).

Due to the quite low source temperature – 200°C is rarely exceeded – the conversion efficiency is typically as low as 10% to 20% in practice. This means that a geothermal power plant produces a lot of waste heat. Many of these plants are consequently used in CHP mode, and provide heat for buildings or swimming pools, as well as greenhouses for agricultural purposes.

It should be noted that geothermal energy is not strictly renewable because it is obtained by cooling down large volumes of the earth's crust near the surface. The thermal flow from the inner part of the Earth is far too slow to replace this amount of heat on a continuous basis – the thermal transfer coefficient of rock is too low. The cooled rock shrinks, causing seismic events, similar to those experienced in regions with high fracking activity to produce tight oil or shale gas. For this reason, several projects in Europe have been stalled or put on hold.

Wind

Wind is currently among the cheapest renewable energy sources with an LCOE between $60/MWh and $110/MWh. This comes close to, or is already competitive with conventional sources – at least so long as energy does not need to be supplied constantly and over a prolonged period. Significant advances in technology have mainly improved the generation potential from low- and high-speed winds, increasing their capacity factor. The location of wind power plants must be selected carefully, as evidenced by the often low capacity factor of existing wind power plants. A high capacity factor can only be obtained where wind blows forcefully in a more or less constant manner. This is typically the case offshore, which is where there is significant development potential for this basically mature technology.

Further improvements, therefore, are mainly related to scaling up existing technology and expanding on the experience gained in the deployment of offshore wind turbines. Currently, offshore wind power generation is limited to shallow shelf regions such as the North Sea. The rigid platforms used to hold the wind turbines limit the regions where such offshore wind farms can be built because, in most cases, the sea depth quickly exceeds 30–50 m, which is currently the limit for their deployment.

The use of semi-submerged wind turbines could extend the range of potential offshore windfarm sites to include large parts of the North American and Latin American coast, as well as large coastal areas off China and Japan, among others. The first proof of concept tests are already being carried out and the results – if positive – may substantially enlarge the usable geographic base. Currently, offshore wind farms are among the most expensive renewable energy production methods, with an LCOE of between $120/MWh and $135/MWh, but experts project that by the 2030s, offshore wind power costs will approach those of onshore wind power and conventional power production. In the end, global wind energy potential will increase considerably and this Outlook considers wind power to be a growing source of energy going forward.

Transmission bottlenecks

An important aspect to bear in mind with renewable energy, especially in conjunction with wind power (and to a certain extent also solar power), is the fact that their power generation depends on natural conditions. In the case of wind this concerns whether and how strong the wind blows. If there is surplus power that either cannot be carried away because of bottlenecks in the grid or immediately consumed, then the usable capacity factor drops significantly, although the capacity factor of the wind turbine itself might be substantially higher. This highlights the importance of upgrading distribution networks. However, there is the potential for resistance from local populations where transmission line projects need to be built.

Underground cabling is considered a solution for populated areas because there are then no visible towers or cables – although many people consider a concentration of turbines a disfigurement of natural landscapes. Nonetheless, underground cabling for the transmission of several GW of power is not straightforward. If electricity is transmitted as AC – as is the case for typical air cabling over short-to-medium distances – then a compensator must be installed every few kilometres to reduce the electrodynamic effects. The solution of converting AC to DC and then back to AC to avoid such electrodynamic effects reduces the transmission efficiency and increases costs substantially.

Solar

Solar energy also has enormous potential. PV capacity exceeded 486 GW in 2018 and the LCOE is typically between $60/MWh and $140/MWh for PV plants which can produce at least 10 MW at peak capacity. Furthermore, there is still significant improvement potential for solar cells; improved multi-layer models may increase the sunlight-to-power conversion efficiency, maintaining it above 30% over the cell's lifetime. This would reduce the area needed for PV cells and allow for more power generation in, or close to, urban areas for immediate consumption there.

CSP technology, on the other hand, has not developed at the same pace. PV modules have become relatively cost-effective far quicker. CSP relies mainly on proven and mature technology; basically, a CSP is a small steam power plant with solar mirrors instead of fuel combustion generating heat. Scaling up CSP could lower the LCOE, which is currently between $120/MWh and $180/MWh, around twice as high as PV. Nevertheless, the substantial advantage of CSP over PV is the possibility to incorporate storage directly at the CSP site.

Most CSP plants incorporate thermal energy storage (TES) based on molten salt, which is mostly a mixture of sodium and potassium nitrates. Electric power is not stored directly but is stored in the form of thermal energy produced by the concentrating mirrors. The thermal energy is then fed to the plant's steam generator to make steam for the turbine. This means it may generate electric power for an extended time even when the sun is not shining. Moreover, power generation would be stable even on cloudy days due to the hot water reservoir acting as a thermal buffer. If a cloud partially blocks the sun for a short time, then the temperature of the water/steam system simply drops a few degrees, but power generation is not interrupted.

Solar-chemical cell technology – currently under intense research – is an interesting application of solar energy that may have future potential. The aim is to produce fuel from CO_2, water and solar radiation. The fuel produced is mainly hydrogen but could also be simple hydrocarbons, for example, methanol. The cell is essentially carrying out artificial photosynthesis. Today, the same effect may be obtained by using renewable power to produce hydrogen as a first step. CO_2 is then added and, using appropriate catalysts, methanol or gasoline and diesel-like fuels – so-called e-fuels – may be produced for later use in combustion engines or cells. Several vehicle manufacturers are supporting this approach as one of several concurring powertrain concepts. Although it is too early to judge the technology's potential, it clearly indicates the dynamics of ongoing scientific research and technology development in the energy sector.

In general, solar energy plants cover vast areas because the average energy density is low. The most-productive solar farm locations may receive up to 3,000 kWh of solar radiation per square metre annually. In comparison, a coal or uranium mine, or an oil well, can provide a million times more energy than a solar cell in the same time period. Thus, areas with low population densities that receive a lot of sunlight are the preferred locations for large solar power plants.

Recognizing the build-up of solar power plants of all sizes, from a few kW to multi MW, this Outlook expects solar power to continue expanding at a rapid pace.

7.5.3 Power storage

Renewables – apart from hydropower, geothermal and biomass – are considered less suitable for power generation because of their intermittent availability, as reliable back-up plants or large amounts of storage are needed to avoid blackouts. Conventional fuels can be produced a substantial time before their consumption and stored in simple tanks; a typical 20,000 litre tank at a gas station is equivalent to more than 70,000 kWh of power for a vehicle or more than 400 tonnes of fully charged Li-ion battery. In general, electric power needs to be consumed within a few milliseconds after generation – the distribution system acts as very short-term storage due to the capacity and inductivity of the transmission lines, and so lacks the flexibility of liquid energy sources.

One of the biggest concerns for renewable grids that rely mainly on wind and solar power are the 'dark doldrums', when neither the sun is shining nor the wind is blowing. All required power must then be provided by back-up plants or storage. Although this is a rare situation, there needs to be sufficient back-up capacity, which is expensive and can substantially impair investment performance. Large-scale grids, spanning entire continents, may be a partial solution, but they are seen as extremely expensive.

On the other hand, interest in e-fuels, or power-to-fuel, produced from renewable power, CO_2 and water mainly, has been expanding. Together with hydrogen – bearing in mind the already discussed restraints stemming from compression or liquefaction – they may be a long-term storage option. If storage technology for renewable energy can be improved over the longer-term , renewables have the potential to substantially increase their share in the power sector.

Pumped hydropower

Pumped hydropower is a proven technology but requires specific topographic characteristics, as well as large upper and lower water reserves. The required topographic characteristics can only be found in mountainous regions with abundant water resources. Given that the water levels of the upper and lower reserve can fluctuate by 10 m or more (between fully charged and fully discharged), such reservoirs can present a serious environmental conundrum, contradicting the environmentally-friendly argument in favour of pumped hydropower.

Nevertheless, pumped hydropower is currently the leading storage technology in view of power and efficiency, with 80% or more of the supplied power able to be recovered. Traditionally, pumped hydropower storage plants have been used to balance peak and off-peak power generation. However, peak power demand is now being covered largely by solar power. As a consequence, even though pumped hydropower is technically feasible, it is becoming less financially attractive, and there is also an increasing lack of appropriate locations to build new plants. In 2017, only around 2% of consumed power came from pumped storage. Developing countries with favourable topography are nevertheless planning to expand their pumped hydropower capacity, headed by China where capacity is expected to reach around 20 GW by 2030.

Several alternatives to the traditional open upper and lower reserve configuration have been proposed. These range from flooding abandoned mines to building so-called ring wall storage, which may be built on flat lands. Other suggestions include the extension of such ring wall storage power plants to shallow offshore regions, where a ring wall would be built on subsea soil. Sea water could then be pumped out when there is surplus power and flooded back into the emptied space later to recover power. However, these proposals are currently in the design stage and it is questionable whether they will resolve the large scale storage issue in the foreseeable future.

Thermal energy storage (TES)

Molten salt storage used in CSP plants are currently the only TES used. They have proven to work well and are able to store a significant amount of energy. In existing systems, the molten salt remains at atmospheric pressure since the salt has a vapour pressure substantially below atmospheric pressure. This allows the fluid to be easily pumped through heat exchangers, which is a significant benefit.

It is, therefore, not a surprise that the principle has been extended to solid-state TES systems that use concrete or rocks as the storage medium. The advantage of abundant and cheap storage materials contrasts with their slow charge and discharge rate because the thermal energy must propagate through solid material. This limits the charge/discharge power and causes significant temperature gradients in the storage material itself. However, it has an added benefit of being easily scalable and with virtually unlimited and readily available storage materials, supply constraints should be easily avoidable.

It must be noted that TES systems do not store or regenerate power directly, unlike battery storage, but produce thermal energy, which must be converted later to power in thermal engines, typically steam or ORC turbines. TES currently accounts for less than 1% of global storage capacity and costs are currently substantial ($200 or more per MWh generated). Technological development is currently focused on raising round trip efficiency by improving the thermal engines. Operating TES systems in a CHP mode may also help to reduce costs because the waste heat could then be used for other purposes (space heating, hot water, heat for low-temperature processes).

Battery electric storage (BES)

Renewable power generation is naturally decentralized due to the low energy density of most renewable sources, especially solar. BES systems are, therefore, well-suited as back-up systems, especially since they can be installed close to consuming centres. Private households may then generate a large portion of the power they consume at moderate costs because no transmission expenses are added. A broad variety of such systems are already commercially available although their pricing is rarely attractive. Overall BES investment costs – including inverters, control units etc., in addition to the actual battery cells – are currently in the range of $600 to $800/kWh of storage capacity. This is a price that can only be justified by a large number of round trips per year. Costs may go down in the future because BES technology is advancing at a similar pace as battery technology for EVs.

Larger BES systems are being used for grid stabilization and for short-term power storage of typically a few minutes to one hour, but rarely longer. One major advantage is their short installation time. For example, the large BES in South Australia, which has a capacity of 129 MWh and a rated power of 100 MW, was put into operation only a couple of months after construction started. The prices of such large BES systems are also falling in parallel with the cost of batteries, in general, and are now around $250 to $300 per kWh, including the electronic components to connect them to the grid.

E-fuels as power storage

As has already been mentioned, electric power cannot be generated in advance and stored in significant quantities. BES and TES systems are inappropriate for storage beyond a couple of hours and even pumped hydropower has a storage life limited to a few days at most. A global – or even regional – transition towards renewable energy, therefore, urgently needs the development of medium- and long-term storage options to cope with seasonal fluctuations.

E-fuels, which have already been discussed in an earlier section of this Chapter, have been proposed. The first pilot plants have already proven the technical viability of the concept and optimization efforts are now underway. Optimization is focused on finding the optimum process parameters (mixture, temperature, pressure) and improving or developing new catalysts.

Other forms of power-to-fuel may include the production of synthetic methane. This could then be introduced into existing natural gas distribution – and consuming – systems without any problem.

Some concepts are already being designed to use captured CO_2. Interesting advances are being made in technology designed to capture and remove CO_2 from the atmosphere – a process that has been carried out by plants for hundreds of millions of years. It is hoped that AI will help to understand and optimize the associated processes – especially artificial photosynthesis. Nonetheless, it remains unclear whether and when such technology may be available and commercially feasible. There is a degree of scepticism about whether these ideas can be made reality; however, it is important to bear in mind that solar and offshore wind power faced similar scepticism only a few decades ago.

7.5.4 Nuclear power

In the 1960s and 1970s, nuclear power was expected to be an abundant and cheap power source. However, increasing security concerns and the corresponding tightening of security standards have made nuclear power substantially more expensive than coal. Today, as public discussion focuses on CO_2 and other GHG emissions, nuclear power is regaining prominence as a potential energy source to meet growing demand, especially in non-OECD emerging economies.

Recent technology developments point towards inherently safer reactors, the so-called fourth generation. However, the important question of how to store and treat nuclear waste remains unresolved. It should be noted that transmutation reactors may convert the long-term radioactive actinides into short-living fission products, reducing the radioactive lifespan of nuclear waste to less than a thousand years.

Apart from waste and security issues, overall power generation costs are a major issue for nuclear energy. In many OECD countries, the power produced may be more expensive than wind – nuclear has an LCOE of around $105/MWh compared to wind's $60/MWh to $80/MWh. However, nuclear is typically used for baseload power – an aspect which becomes increasingly important as fluctuating renewables grab a rising share of overall power generation. Additionally, storage costs for renewables should be included when providing a real cost comparison.

Apart from costs, the extended timespan of projects, from decision-taking through planning, sanctioning and construction to commissioning – which may take more than a decade – is viewed as a liability.

7.6 Carbon capture and storage or utilization

CCS typically focuses on the separation and capture of CO_2 from an exhaust gas stream, also called after-combustion CCS. The exhaust stream may originate from carbon or hydrocarbon combustion (coal, oil, or gas-fired power plant), steel and aluminium plants, refineries and petrochemical plants, among others. It should be noted that an average coal-fired power plant must capture more than two-thirds of the produced CO_2 to reach the same specific CO_2 emission level of a modern CCGT running on natural gas. Coal can, therefore, only be considered a cheap fuel so long as no serious CO_2 countermeasures are required.

CCGTs, in combination with moderate CCS, may be one way to complement renewables. It could be one quick and economically feasible way of substantially reducing GHG emissions in the power sector, especially if CCS is carried out close to wells and/or if CCS is expanded to the concept of CCU to maintain the hydrocarbon production of a well.

Another interesting approach is to capture CO_2 before combustion, close to the point of fuel production. Then, a CO_2-free fuel stream may be generated even from fossil hydrocarbons. Pressurized oil and gas reserves are compelling proof that the reserve itself has been impermeable for gas for an extended time period, often over millions of years. This makes them a natural and ideal storage for CCS – assuming that their geological characteristics allow for large concentrations of CO_2. In fact, (re-)injection of CO_2 is already being carried out around the globe as part of EOR efforts. Steam reforming of natural gas is an example of pre-combustion CCS; the produced CO_2 is captured and the produced hydrogen is transported for use in petrochemicals or chemicals – without GHG emissions.

7.7 Tight oil

The tight oil boom is in part a consequence of rapidly advancing technology. Although high oil prices may have been the trigger behind this sector's emergence, the steep learning curve of participants quickly reduced production costs. The number of wells served by one single rig has increased substantially – in some case to more than 10 – and the drilling length of the wells has become as long as 2,500 m.

In general, tight oil reserves are characterized not only by the low permeability of the enclosing plays, but also by a fine distribution of oil in tiny pores. Surface or adhesion forces are far larger than the gravitational gradient that separates gas and oil phases in conventional reservoirs. This makes it necessary to use a combination of horizontal or directional drilling and fracking. Nevertheless, considerable advances in seismic, sensing and data processing are also contributing to the development of this sector.

Directional drilling

Horizontal and directional drilling had been in use for several decades before the start of the tight oil boom. However, it has become associated with tight oil in recent years because it is the main technique used in the sector since the drilling head needs to follow the typically thin layers containing hydrocarbons. This is carried out by incorporating a downhole motor into the drill head, increasing the manoeuvrability of the head so it can continuously change orientation.

As an added advantage, the drilling pipes do not then need to be rotated to drive the head. Today, such heads are usually equipped with sophisticated sensors so that the drilling crew is always aware of the position and direction of drilling with a degree of resolution unknown a decade ago. Although incentivized by the needs of tight oil production, such advanced technology is now increasingly also used at conventional wells to improve oil production.

The impressive advances in directional drilling can be seen from the fact that initially the achievable horizontal displacements were a mere 400 feet or so. Today, after around a decade of intense technology development, directional drilling can be carried out over a lateral extension of over 8,000 feet (2.5 km).

Fracking

Geological formations typical for tight oil reserves are comprised of tiny pores that are not well interconnected. This means that there are typically two major challenges to overcome: to open or at least enlarge a flow path between the pores and towards the extraction well, and to drive the oil out of the pores, overcoming their tendency to cling to the pore's surface. Fracking is the standard method to cope with both challenges. First, a liquid – typically already containing proppants – is injected into the well at very high pressure (at least several hundred bars) so that the rock starts to crack along already existing natural defects in the rock and multitudes of small and thin channels (typically a few μm wide) are opened.

A well is divided into clusters and each cluster is fracked individually, improving the fracture density. Initially, very fine natural sand was used as a proppant to hold open channels between pores, but today special ceramics with higher pressure resistance such as synthetic corundum (aluminium oxide) are often used. These can better withstand the rock pressure as soon as the well is depressurized to start production. The tiny grains keep the fractures open, allowing tight oil to flow towards the extraction well.

If the pores are very small, then the surface tension and wetting forces may exceed the pressure forces; as a result, the oil remains trapped in the pores and only the associated gas is released towards the extraction well. Chemical agents are used to reduce surface tension and wettability to drive the oil out of the tiny pores so that they may travel along the fracks to the production well.

Advanced sensing and AI

Acoustic waves are the natural choice to investigate geological structures below the surface because electromagnetic waves cannot travel well through soil, regardless of their wave length. The acoustic sensing can be compared to ultrasound diagnostics in the medical sector where, for example, sounds waves are sent through the human body and one or more sensitive detectors (microphones) receive the echoes. Sophisticated data processing then creates a detailed pattern of the body – although some experience and training is required to interpret the pictures correctly.

Seismic imaging used for oil, gas and other exploration works in the same manner, only the waves and power needed to generate them are of quite different magnitudes. Earlier, seismic imaging was used to determine where large reservoirs were located. Production itself was then more or less 'blind', with seismic used far less frequently to observe the production process. With tight oil, real-time monitoring of the production process has become standard procedure. Technological developments from other areas, specifically in acoustic applications, have been adapted and implemented in the production process. For example, optical fibres are now used as sensing equipment. Varying pressures and temperatures alter the optical characteristics of such fibres, and the changes in the fibre can then be detected by Raman scattering.

Such sophisticated in-hole sensing produces an enormous amount of data that must be analyzed in real-time, creating an additional challenge. However, it has the potential to offer unprecedented details about the soil build-up and the ongoing fracking and extraction processes. Together with AI, it is expected that technology will allow companies to virtually look down into the soil to view drilling and fracking processes in the near-future. This will allow a far more detailed real-time approach for exploration and production, particularly in view of locating and rapidly assessing the value of reservoirs.

The technological advances in the tight oil sector are based on a combination of several disjointed technologies (horizontal drilling, fracking), alongside advanced sensing and data processing. Moreover, the role of IT is changing from being merely a supportive element to being a major player. Technology developed in conjunction with tight oil production is increasingly also being applied to conventional resources to improve oil and gas production. Hence, the supply projections in Chapter 4 take into consideration the impact of these technologies.

7.8 Residential, commercial and industrial sector

Maintaining living spaces at comfortable temperatures and humidity levels is one of the major power consumers in the residential and commercial sector. This is generally achieved through space heating in cold seasons and A/C in hot and/or humid conditions. While heating has received most of the attention in the past since most of developed countries are located in moderate to cool regions with extended cold weather periods, nowadays A/C is rapidly gaining in importance. Hot and humid weather may not directly threaten lives to the same degree as freezing temperatures, but it does negatively impact productivity. As a consequence, homes, offices and commercial spaces are increasingly equipped with air conditioners that regulate not only temperature, but also the humidity to keep them within a bandwidth of conditions considered comfortable and appropriate.

The adoption of A/C, in particular, is directly linked to the income of the population. One example is power demand during hot summers. Before countries saw their wealth expand, hardly any A/C was used and the population accepted the corresponding temperatures. Traditional architectural concepts, such as open structures allowing wind to carry away hot air, had been the only choice to cope with hot temperatures. Additionally, modern A/C devices need to consider other local conditions too, for example, humidity and solar radiation.

Space heating and A/C both require that there be as little heat transfer as possible between the surrounding environment and the cooled or heated space. Unlike in Northern Europe, measures to reduce specific energy needs are still largely underutilized in hot environments. Insulating spaces against the cold is already a well-established strategy, with a broad range of insulation measures available off-the-shelf. Examples include oil- or mineral-based insulation layers made of styrofoam (or comparable polymer foams according to environment conditions) or organic insulation such as braided straw mats.

Windows are a major source of heat transfer. Consequently, windows with two or even three glass panes separated by a special gas instead of ordinary air have been designed to limit thermal losses. Argon (Ar) and krypton (Kr) are the most commonly used gases, but xenon (Xe) is also used in rare cases despite its high cost.

Visible and invisible radiation may enter buildings through the windows. This is an additional source of thermal energy, energy which must also be pumped outside by the A/C. Hot environments typically also mean higher radiation levels, mainly sunlight, but also infrared radiation from surrounding buildings and the atmosphere itself. It should be mentioned that self-radiation is proportional to the fourth power of the absolute temperature (T^4), which means that radiation levels increase by 30% when raising the temperature from 20°C (comfortable room temperature) to 40°C (high outside temperature). It is therefore essential, for cooling purposes, to not only insulate the walls and roofs, but also to reduce the radiation passing through windows. The latter can be achieved by coating the glass with special layers that do not block much visible sunlight, but which do block basically all infrared radiation.

Thermodynamic laws have long shown that a given amount of mechanical or electrical power can be converted into a far higher amount of thermal energy at elevated pressures. This is the principle applied in heat pumps. Heat pumps are increasingly being installed in countries where renewable energy sources already play an important role, such as Switzerland. In Switzerland, 90% of newly built homes are equipped with heat pump systems. With the build-up of renewables on a global scale, this trend will accelerate as it is the obvious choice for efficiently using renewable power generated far from the consumer. Their performance is measured in terms of a Coefficient of Performance (COP) which indicates the multiple of thermal energy generated per unit of power consumed by the system. Currently, heat pumps may have COPs reaching typical values of around 3.5 to four on an annual average basis, but this could rise to six within the next 10 to 20 years. Such an improvement would reduce their power demand by roughly 33%.

In the future, intelligent buildings will attempt to combine all of these processes, for example, by using excess heat to produce hot water. Other innovative concepts such as green facades or optimized window systems may further reduce the primary energy consumption of buildings. The concept of smart homes and smart buildings can be integrated into smart cities, optimizing cooperation between individual elements to an unprecedented level using AI and Big Data concepts.

7.9 Refining

Refiners often face a decision between investing in refinery configurations that may take in high quality and relatively expensive crudes, or in configurations that are capable of dealing with low quality, less expensive crudes. Additionally, refineries now need to plan for more volatile demand. The decision between adapting an existing refining system or implementing a more state-of-the-art one, in view of the changing crude and product slates, is truly challenging.

Trends in refining are toward integrating petrochemical production plants, which adds another set of difficulties. Industry 4.0 was presented as a concept in 2011 to reflect the fourth industrial revolution. It applies also to the oil and gas industry and refers to leveraging a large amount of information for the benefit of the whole value chain, which is evidently crucially important to refiners.

All these new developments and changes form the challenges that refiners need to solve to succeed in an ever-changing landscape. For today's refining industry, going digital is key for optimizing energy efficiency and reducing operating costs. Moreover, the advantage of economies of scale and integrating modular construction concepts are more important than ever before, with new refineries all tending to be larger. Accommodating a flexible approach in a refinery is an expensive option that is not affordable for all refiners. Together, these effects are exerting substantial pressure on vulnerable refineries that lack adequate flexibility.

Climate change awareness and concerns are tightening the oil product market, mainly the market for oil-based fuel. It may also be threatened by product substitution. Converting fuel oil to lighter products is getting more complicated as long-term market prospects for light products themselves are coming under pressure. Residue conversion is largely focused on coking and residue hydrocracking, and combining bitumen and lubricant production whenever feasible. The IMO bunker oil specifications are pushing towards hydrotreating refinery residues, but this poses a challenge for hydrogen management.

In the longer-term, COTC remains the most versatile and flexible option for the refining industry.

7.10 Big data and blockchain

Apart from IT applications in exploration and production – where the oil industry has always been at the forefront – the use of modern concepts of data use, data processing and data interpretation has gained traction in the energy sector. The complexity of the business when considering its global extension from remote wells to a large number of customers in urban or highly-industrialized regions, generates an overwhelming amount of valuable data. Before the advent of the Internet, which serves as the backbone for worldwide communication and powerful data processing and storage, it had been impossible to make use of this data.

A refinery serves as a helpful example to demonstrate the data streams that can be analyzed and processed. Sensors continuously provide information about process parameters, such as pressure and temperature, product characteristics at the various levels of processing, as well as reporting energy consumption and staff activities. The end result is a collection of a huge amount of data – or 'big data' as it is often called. Through IT, the information streams are put in order, analyzed and processed to provide staff on all levels – from process supervision to management – with timely and reliable results that can be used as the basis for decision making. Without advanced IT, such large amounts of data would be left unexploited, instead of being leveraged to enable valuable conclusions to better optimize the refinery. In the future, intelligent systems may even take decisions autonomously based on such data. Similar developments are rapidly spreading through the whole industry.

Another segment of business-oriented data processing that is becoming increasingly important is blockchain. This is a far broader concept than cryptocurrency with which it is regularly associated. It has an inherently forward-oriented structure wherein approved actions cannot be reverted at a later stage (immutability of transactions), but only compensated for by a future action, making blockchain an interesting concept to accelerate international trade, among others.

The unique time stamping of individual transactions will also be helpful in many other time-critical areas, particularly those with a clear cause-effect structure. Disintermediation and decentralization are also contributing factors to the rise of blockchain, reducing the need for middle-men in trading, as well as the increase ability to track assets throughout the trade process. There is evidently significant potential for its use in the energy industry. LNG trades have been already conducted over blockchain platforms, reportedly reducing delivery time by weeks. It can be expected that such blockchain-based trading will increase substantially in the coming years as it reduces costs and accelerates the exchange of goods and payments.

Energy policy and climate change

Key takeaways

- This Chapter reviews a wide range of currently enacted or soon-to-be ratified policies that are relevant for the energy sector, both on the demand and supply side.
- In the transportation sector, there are a number of international, regional and national policies designed to increase safety and efficiency, while also reducing emissions.
- The emphasis in the road transportation sector is on efficiency improvements and cleaner emissions, but increasingly also on subsidies for EVs, hybrids and other AFVs. In most regions and countries there is an ongoing drive to tighten fuel specifications.
- The current focus in the marine transportation sector is mainly on the imminent sulphur cut as mandated by the IMO, which will come into force from 1 January 2020. Looking long-term, the IMO is working on strategies to put tight CO_2 emissions caps in place.
- In the aviation sector, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), will gradually increase efficiency in engine and aircraft design, as well as improve operational efficiency, thus curbing emissions.
- With regard to power generation, policies are mainly concerned with a shift away from coal to energy sources with lower emissions, including natural gas and various types of renewable energy. Some EU countries have also put plans in place to phase out the use of nuclear energy.
- The Paris Agreement is the main policy framework that aims to achieve climate change mitigation on a global level, and to date 187 countries have ratified the treaty. Subsequent global efforts to accelerate implementation include this year's UN Climate Action Summit 2019 in New York, at which 65 countries and sub-national regions committed to cutting GHG emissions to zero by 2050. Many countries have also pledged to enhance their own national action plans by putting in place concrete measures for climate change mitigation.
- The Green Climate Fund, a financial mechanism and global platform for investment into low-emissions and climate-resilient development projects and technology, has been successful at attracting new funding.
- On the oil supply side, policy is not as significant a factor when compared to the resource base, technology and economics. Still, to complement the shale boom, the current US administration has pledged to open up large areas of untapped federal land, including the eastern part of the US Gulf of Mexico and large parts of Alaska. However, this faces significant opposition from the Democratic Party. In fact, some Democratic contenders for the 2020 presidential elections hope to curtail oil and gas production on federal lands again, as well as curb exports.

This Chapter provides a brief overview of recent energy and climate change-related policies. As already mentioned in Chapter 1, energy policies are significant energy market drivers, influencing both energy demand and supply. Policies are geared towards different objectives, some of which can be contradictory. The most common energy policy goals include climate change mitigation and energy security, as well as energy access and sustainability. In most cases, energy-related policies look to balance these respective goals, while also taking into account social developments and pressures, technological advancements and geopolitics. This can often result in a complex set of regulations to navigate, which are furthermore subject to regular revisions and rearrangements.

Furthermore, energy and climate change policies are shaped at different levels. At the global level, UN SDGs and the Paris Agreement represent the frameworks under which national climate change policies are designed. For some sectors, such as marine transportation and aviation, given their international nature, energy-related policies are largely enacted at the global level. At the same time, country-specific policies such as regulations related to energy security, fuel taxation policies and fuel specifications are determined at the national level. Concurrently, specific subnational authorities can shape local energy policies to address specific local problems. For example, addressing local pollution problem through diesel bans in several European cities, the 'blue skies' policies in China, as well as setting subsidies and indirect fees.

Furthermore, energy and climate change policies are regularly part of wider national or international (energy) strategies. In other words, specific policies are often designed in line with the targets laid out in these strategies. This is why the assessment of strategies is an important element in assessing the potential impact of policy, especially in the long-term.

Specific to the oil sector are so-called supply-related policies, which impact the fiscal terms and conditions of oil production. They also target upstream operations, including regulations related to available land for drilling activities, as well as midstream activities.

Energy-related policies are phased in through different mechanisms, including fiscal measures, subsidies, market-based approaches or quality standard definitions. Even though policymakers can steer the energy market with these mechanisms, they can be constrained by various obstacles related to state budgets, public opposition, consumer behaviour and market fundamentals. These are the reasons why policies are typically evolutionary in nature and evolve gradually over time. Accordingly, the monitoring of policies, their implementation path and impact remains critically important.

This Outlook takes into account policies that impact oil and energy markets directly or indirectly. It considers and assesses currently enacted energy policies and recognizing the evolving nature of energy-related policies, it also anticipates future long-term policy developments in an evolutionary way and assesses the feasibility of relevant energy strategies.

8.1 Climate change mitigation

Policies related to climate change mitigation cover a wide range of different measures in various areas of the energy industry. This includes policies related to energy production, energy transformation, as well as energy consumption (including energy efficiency measures). Furthermore, climate change policies in many cases overlap with other policies and regulations related to local pollution, but also energy security and diversification.

At the global level, the major policy framework for climate change policies is the Paris Agreement. The outcome of the COP24 meeting in Poland in December 2018 was the Katowice Climate Package, which provided more clarity on the implementation of the Paris Agreement (Chapter 9). As of late

September 2019, 187 countries have ratified the Agreement, including Russia as announced at the UN Climate Action Summit 2019 and 10 OPEC Member Countries.

NDCs are the cornerstone of the Paris Agreement and the achievement of the long-term goals for limiting global warming, through the mitigation of GHG emissions, adaptation to enhance resilience to the impact of climate change, and addressing the provision of support to developing countries.

The Paris Agreement stipulates that each Party shall prepare, communicate and maintain successive NDCs that it intends to achieve. NDCs are clear directions to domestic stakeholders on national policies to address climate change and the role of different sectors in the climate actions for adaptation and mitigation. The features and information to facilitate clarity, transparency and the understanding of NDCs may include quantifiable information on reference points, including a base year, timeframes, and/or periods for implementation, scope and coverage, planning processes, assumptions and methodological approaches, including those for estimating and accounting for anthropogenic GHG emissions and removals.

Almost all developing country NDCs indicate the need to enhance support to assist them to increase their ambitions for climate action. For most emerging developing countries, the provision of support to help materialize their conditional NDCs could contribute significantly to an enhancement of actions and a reduction of their GHG emissions. International support is a critical factor for the implementation of the conditional NDCs of developing countries.

Based on the invitation to update NDC plans, 59 parties have expressed the willingness to enhance their NDCs by 2020, while 11 countries (mostly European) have already started revising their national policies.

Furthermore, the UN Climate Action Summit 2019, held in New York in September 2019, brought numerous commitments. This included the commitment of 65 countries and sub-national regions to cut GHG emissions to net zero by 2050. At the same time, 70 countries announced enhancements to their national action plans by 2020. Commitments were not limited to countries. More than 100 cities also offered pledges to address climate change through concrete measures in the coming years. These announcements were partly based on plans announced earlier this year by individual countries and/or other entities in preparations for the aforementioned September 2019 UN Summit.

Several countries had pledged significant commitments by late August 2019. This included additional pledges to the Green Climate Fund that raised the total commitments to around $7.5 billion, mostly from the UK, France and Germany. The UK has also increased its funding for international climate projects to £11 billion for the period 2020–2025. A number of major international banks and large asset-owners (with cumulative investments of around $2 trillion) have stated their readiness to adjust their investments in line with the Paris Agreement targets.

8.1.1 US

Although the US has suspended its support and announced its intention to withdraw from the Paris Agreement, the earliest date the country can leave the treaty is November 2020. In fact, the actual withdrawal date is one day after the next US presidential election. It remains unclear whether the country would re-enter the treaty and under what terms. This evidently may be dependent on the outcome of the next presidential election. Originally, the US was obliged to cut GHG emissions by 26–28% by 2025, relative to 2005 levels, as stated in its NDC.

Following the country's announced withdrawal from the Paris Agreement several states and/or cities established their own positions and rules, affecting different sectors, such as transportation and the power generation mix. The main target is to continue support for climate change policies and a reduction of CO_2 emissions at the state and local level. This includes different initiatives, such as the US Climate Alliance and America's Pledge initiatives, both established in 2017.

Several policies and initiatives continue to impact the country's energy landscape, despite its withdrawal from the Paris Agreement. Just under 40 US states have market-based policies to support renewables, based on the State Renewable Portfolio Standards that affect renewable energy from different sources including solar, wind, biomass and geothermal. In line with sub-national efforts to reduce GHG emissions, California had already established the so-called 'cap-and-trade' scheme in 2013 (linked with similar schemes in the Canadian provinces of Quebec, Ontario and Manitoba.) The scheme covers the power generation sector, large industrial units and fuel distributors.

As already mentioned, in September 2019, the US EPA started the process of unifying fuel economies and GHG emission standards under the title 'One National Program Rule'. This may affect the right of California to have stricter rules; the right originally granted by the 1970 Clean Air Act. California, as well as 22 other states, the District of Columbia and the cities of New York and Los Angeles have sued the federal government over the move. The final outcome resulting from this regulation is still uncertain at the time of writing this publication.

8.1.2 EU

As already noted in the WOO 2018, the EU climate and energy policy is structured around targets for different time horizons – 2020, 2030 and 2050. Policies are focused on the reduction of GHG emissions, an increase in the deployment of renewables and an advancement in energy efficiency.

The EU 2030 climate and energy framework, covering the period 2021–2030, includes the following targets:

- Reduce GHG emissions by at least 40% (from 1990 levels);
- Increase the share of renewable energy to at least 32%; and
- Improve energy efficiency by at least 32.5%.

While the overall framework was adopted as early as 2014, the targets for renewable energy and energy efficiency were revised up in 2018. Furthermore, the EU targets are also reflected in national plans with the obligatory adoption of the so-called National Climate and Energy Plans (NECPs) for the period 2021–2030, to be finalized before the end of 2019. The plans will be monitored with regular updates on the implementation of the respective NECPs. Finally, EU Member States are also obliged to develop national long-term strategies, which would be consistent with the respective NECPs.

One of the important pillars of the EU climate policy is the EU-ETS system, which covers around 45% of total EU GHG emissions. In order to reach the above-mentioned target of a 40% emission reduction by 2040, relative to 1990 levels, GHG emissions covered by the EU-ETS system have to be cut by 43% by 2030, relative to 2005 levels.

To help address the issue of the EU-ETS allowance surplus since 2009, the EU-ETS system was amended in a way that saw a significant amount of allowances back-loaded to the 2019–2020 period. In addition, the so-called 'market stability reserve' was created, which became operational in January 2019. The effects of the measures have already been visible in 2019, with the EU-ETS price reaching levels above €20/tCO_2 in 2018 and 2019.

On top of the 2030 climate and energy framework, in late 2018 the European Commission presented the strategy to reach net zero GHG emissions by 2050. As stated by the EU, this is compliant with the Paris Agreement targets to keep the temperature rise to below 2°C. The strategy includes different policies targeting industry, finance, technology development and research. In order to reach carbon neutrality by 2050, the strategy focuses on seven so-called 'building blocks'. This includes improvements in energy efficiency, renewables deployment, measures in the transportation sector as well as establishing 'smart network infrastructure', support CCS and natural carbon sinks. The costs of these measures between 2031 and 2050 are estimated at between €1.33 trillion and €1.42 trillion annually.

In terms of national targets, some of which are part of the NECPs, several countries have introduced, or are planning to introduce, carbon taxes. These mostly target the transportation sector, but other industries too.

Germany, for example, has proposed to introduce a carbon tax in the transportation and building sector, which increases from €10/tCO_2 in 2021 to €35/tCO_2 in 2025. After 2025, the CO_2 price would be market-based, potentially rising to around €60/tCO_2 in subsequent years according to current estimates. However, the current draft of the German climate protection package still needs to be officially adopted by the Parliament. France introduced a carbon tax in 2013, which also included annual increases. This has ultimately led which resulted in increased fuel costs by 3 cents per litre in 2018 and ultimately led to the 'yellow vest' protests. Consequently, the policy related to carbon tax was put on hold in 2018, with ongoing discussions on the policy's continuation.

Furthermore, EU leaders are discussing the potential introduction of a carbon border tax, which would protect European companies investing in carbon-free technologies from competition beyond the region.

8.1.3 China

China's climate change policy can be viewed as part of the country's overall energy and environmental policy. Combined with CO_2 reduction targets, China also aims to limit local air pollution (transportation policies) and increase energy efficiency. This affects the energy system in many ways.

Overall, the targets related to climate policies are part of the 13th Five Year Plan for the period 2016–2020, including:

- A reduction of CO_2 emissions per unit of GDP by 40–45%, below 2005 levels (according to official sources, the reduction was already 46% in 2017);
- Increasing the share of non-fossil fuels in the overall primary energy mix to 15% (in 2017, this share was observed at around 13.8%); and
- Increasing forestation by 40 million hectares by 2020, relative to 2005.

The unconditional 2030 targets as laid out in its NDC foresees a peak in CO_2 emissions by 2030, with efforts in place to reach the peak before this date. Furthermore, CO_2 emissions per unit of GDP should be reduced by 60%–65% by 2030, relative to 2005, as laid out in the country's NDC. In addition, the country plans to further increase its share of non-fossil fuels in the overall primary energy mix to around 20% by 2030. China still needs to submit its long-term strategy to the UNFCCC, which should then provide more details on the country's climate change-related policy.

China has also made its first steps to establish a national emissions trading system, with simulation trading conducted during 2019. Trading should start in 2020 and the scheme will initially include coal and natural gas power plants with cumulative CO_2 emissions of around 3 billion tonnes per year. The market, although initially limited only to the power sector, will be the world's largest emissions market, even larger than the EU-ETS system. Following its introduction, China's ETS could be extended to other sectors, including aviation and selected industries.

Furthermore, with the primary aim to reduce local pollution caused by old and inefficient coal-based heating systems, the National Development and Reform Commission (NDRC) introduced the 'Plan for Clean Heating in Winter Season in Northern Areas (2017–2021)' in 2017. The main target of the plan is the phase-out of scattered coal plants, replacing them with natural gas. This is also in line with the target to increase the share of natural gas in the overall energy mix, especially in the power and heat generation sector.

8.1.4 India

In India, climate change policy is developed together with targets related to the eradication of energy poverty and increasing energy access. This is also underlined in its current draft national energy policy published in 2017 (the final version has still not been confirmed at the time of writing this publication). The policy targets full electrification by 2022 and an increasing access to clean fuels, especially for cooking.

Furthermore, India's NDC foresees the reduction of GHG emission intensity per unit of GDP by 33%–35% by 2030, relative to 2005. In addition, the target for the share of renewables in the power generation mix is projected to increase to around 40% by 2030. As already noted, the country expects to have 175 GW of renewable power capacity by 2022 (mostly wind and solar). Recently, India announced that its renewable capacity will be increased to 450 GW in the long-term.

At the same time, India is also stressing the importance of finance for climate change policies and the fulfilment of the country's commitments. In a discussion paper published by India's Ministry of Finance in September 2019, the government is calling for improved support for developing countries by developed countries, in terms of finance, technology transfer and capacity building.

8.2 Transportation

The transportation sector accounts for a large part of oil demand and its growth. As discussed in detail in Section 3.3., oil demand in this sector rose to 56.8 mb/d in 2018 and is projected to grow by more than 6 mb/d in the period to 2040. The largest part of this oil demand by far relates to road transportation (78% in 2018), followed by aviation (11%) and marine transportation (7%).

These relative shares for oil demand in the transportation sector are also clearly reflected in the amount of regulation and policy measures related to the specific sub-sectors. Historically, road transportation was, and continues to be, subject to tight regulations covering various aspects ranging from safety to efficiency and emissions. For the other two sectors, aviation and marine transportation, regulatory initiatives have focused on safety issues. Recently, however, efficiency and emissions in these sectors are also increasingly becoming the focus of policymakers.

Another important difference is in the way regulation in each sector is drafted, adopted and enacted. Policies related to road transportation are primarily developed at the national, regional (such as the EU) and even the local level (major cities), while some other elements of regulation are developed internationally, such as the WLTP. In contrast, policy measures in aviation and marine transportation are primarily driven by international institutions such as the International Civil Aviation Organization (ICAO) and the IATA in the aviation sector and the IMO in the maritime sector. These are often supplemented by national or regional regulations, such as port-specific rules and the inclusion of the aviation sector in the EU's ETS.

8.2.1 Aviation transportation

The two major policy thrusts in the aviation sector that most impact oil demand have been in the areas of fuel efficiency and GHG emission abatement. In 2016, the ICAO, in cooperation with major industry stakeholders and the IATA, adopted Resolution A39-3. This resolves to stabilize net aviation-related CO_2 emission at their 2020 levels (in other words, to achieve carbon neutral growth) through a set of measures, as well as to introduce step-wise aspiration goals for fuel efficiency improvement. In turn, this led to the adoption of a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in October 2016 during the 40th Assembly of the ICAO. A review of the progress in implementing this policy was part of the agenda for the 2019 Assembly held end-September/early-October 2019.

The CORSIA is anchored on four pillars, namely:

- Development of efficient aircraft engine technologies and aircraft design. This includes the deployment of sustainable (renewable) alternative fuels (SAF) in addition to existing fuels. The new engine and aircraft design should demonstrate fuel efficiency improvement between 15–20 % of the model it replaces, including the use of SAF;

- More efficient operation techniques that involve new air traffic control, weight savings, single-engine taxing, idle reverse thrusts and other traffic flow management that mitigates emission growth;

- Infrastructure improvement, streamlining routes and airport ground operations; and

- A global market-based measure (GMBM) to complement the other three pillars and offset any remaining surplus emissions.

It is to be noted that the CORSIA affects only international air-travel since emissions from domestic flights are mostly covered in nationally determined contributions (NDCs) submitted to the United Nations Framework Convention of Climate Change (UNFCCC). The CORSIA is therefore a global carbon offsetting scheme that regulates international aviation operators with the overall objective of offsetting any additional CO_2 growth above 2020 levels. As of August 2019, 116 of ICAO's Member States had submitted a 'State Action Plan' with climate change and emission mitigation measures.

Offsetting the carbon emission requirements comes into effect in 2021 after which period operators need to demonstrate compliance to an emission reduction strategy. The GMBM provides a common accountability platform for filling any emissions gap. It was necessary to develop such a platform as many airlines cross several international borders. This mechanism permits an operator to settle for excess emissions by sponsoring emission reductions mainly in developing regions. ICAO Member States agreed and adopt its implementation in two stages: from 2021 until 2026 only for volunteer countries (including the pilot phase of 2021–2023), while from 2027–2035, all ICAO Member States will be subject to offsetting requirement for carbon reduction. It will require all operators with annual emissions above 10,000 tonnes of CO_2 to report reduction measures and credits.

With regards to fuel efficiency improvement measures, the CORSIA targets an average annual fuel efficiency improvement of 1.5% p.a. It is worth noting that the aviation sector has already attained fuel efficiency of around 2% p.a. since 1990 mainly due to the use of enhanced technology in aircraft manufacturing, including the incorporation of lighter composite polymers and improvements to the engine and aerodynamic properties of wings, as well as additional use of SAFs.

Furthermore, in 2017, the ICAO Council adopted what it claims is the first global certification standard for aircraft CO_2 emissions, enshrined in Annex 16 to the Convention on International Civil Aviation. The standards are based on the ratio of CO_2 emissions to the mass of the aircraft and specific air range, and will apply to all aircraft designs from 2020 and starting in 2028, any aircraft that does not meet the standard will not be allowed to enter into production. All new propeller-driven and large subsonic airplane designs will need to comply with the standard as of 1 January 2020.

8.2.2 Marine transportation

Similar to the aviation industry, IMO regulations target both emissions reduction (including air pollution) and efficiency improvements in seaborne shipping. With respect to GHG emissions, the IMO's MEPC adopted an initial long-term strategy to reduce GHG emissions from ships in April 2018 (Note by the IMO to the UNFCCC Talanoa Dialogue). The objective of the strategy is to achieve at least 50% emissions reduction by 2050, compared to 2008, while, at the same time, pursuing efforts towards phasing them out entirely.

The strategy paper also outlines several options and ways of fulfilling this objective, such as improvement of the existing energy efficiency framework, technical and operational energy efficiency measures for both new and existing ships, speed optimization and speed reduction, measures to address methane emissions and incentives for the development of new technologies, *inter alia*. However, a detailed path for achieving these challenging targets is yet to be developed.

Contrary to this, specific regulations are already in place to address air pollution from shipping mainly in the form of sulphur oxide (SO_x), NO_x and particulate matters. These are controlled by MARPOL Annex VI regulations, which includes specific rules for ECAs, as well as other areas. Within ECAs, only marine bunkers with a maximum 0.1% sulphur content (on mass basis) are allowed. Starting on 1 January 2020, a sulphur limit of 0.5% will be applicable in all areas outside ECAs (compared to the 3.5% limit currently in place). Needless to say, this regulation will have significant implications for both the shipping and refining industry worldwide, as discussed in detail in Chapters 3 and 5.

Regarding energy efficiency requirements, these are also regulated by amendments to MARPOL Annex VI adopted in 2011 and affective as of 1 January 2013. As already indicated in Chapter 3, the target is to achieve 30% efficiency improvements, by 2025, for all new ships compared to those built in 2014. The main tools to enforce the regulation are the EEDI, mandatory for new ships, and the Ship Energy Efficiency Management Plan, mandatory for all ships. The MEPC drafted amendments to phase three of the EEDI at its 74th session held in May 2019, and in 2020 the committee will vote on the adoption of the amended targets. The proposed targets include efficiency improvements as high as an EEDI reduction rate of 50% for the largest container ships from 2022 onwards. A fourth phase of EEDI requirements is also expected to be discussed at upcoming meetings.

8.2.3 Road transportation

US

In the US, the CAFE standard is the major policy initiative to steer developments in the road transportation sector. This was enacted by the US Congress in 1975 (later amended by Energy Independence and Security Act (EISA) in 2007) with the primary objective of reducing energy consumption and GHG emissions by increasing the fuel efficiency of all vehicles. In 2018, however, the National Highway Traffic and Safety Administration (NHTSA) and the US EPA announced plans to reject the 'second phase' CAFE standards for 2022–2025 MY cars, which would require a fleet-wide average of 54.5 mpg on a GHG-equivalent basis. At the same time, a new Safer Affordable Fuel-Efficient (SAFE) vehicles rule was proposed which would amend existing CAFE standards. The SAFE rule includes a proposal to freeze fleet-wide fuel efficiency standards at the 2020 level (41.7 mpg) through the year 2026.

However, as stated in the WOO 2018, there are numerous uncertainties regarding the potential US fuel economy standards and their application. The rule-making process to formally establish the new CAFE and SAFE standards is expected to face legal objections from California. The state has traditionally been able to obtain a waiver from the EPA to set higher CAFE standards than the federal level, and other states are able to choose to follow California's lead. To pre-empt this option, in September 2019, the NHTSA and EPA proposed to establish a One National Program for fuel economy regulation in the US, which would nullify California's option to seek a waiver to set its own efficiency standards. This, in turn, will likely lead to California undertaking legal steps to revoke such a decision. Therefore, it remains to be seen how the entire process will affect US vehicle efficiency standards.

With regard to emissions, the EPA is mandated to regulate air emissions in the US and to set up standards for control of emission pollutants from various energy sources. Accordingly, the EPA determines emission regulatory mechanism for CO_2, un-combusted residual hydrocarbons, particulate maters, nitrous and sulphurous compounds for both on-road and non-road engines and equipment. Currently adopted emission standard for vehicles in the US is Tier 3, with a phase-in period 2017–2025, which also specifies sulphur limits for gasoline and diesel. The certification and fleet average are now expressed as cumulative of non-methane organic gas (NMOG) and nitrous oxides (NO_x). Compared to the phase-in time (2016), the tail gas emission of Tier 3 are expected to reduce both aggregate (NMOG plus NO_x) and particulate matter by 70% and 60% respectively by 2025. Moreover, the Tier 3 rule pushed gasoline sulphur levels to below 10 ppm. The Tier 3 rule is equivalent to California Air Resource Board's low emission vehicles III rule with similar phase in period. Moreover, it is anticipated that by 2025, both Tier 3 specification for passenger cars and light duty trucks converges at 0.03 g/mil of the combined (NMOG plus NO_x) emissions.

The EPA is also adopted Tier 4 for non-road emissions in 2015 which incorporated use of advanced exhaust emission control to target significant emission reductions from machines and equipment. It also lowered SO_x emissions. For non-road emissions, the rule anticipates reduction of NO_x and PM by up to 90% at the end of the phase-in period.

In a related development, the EPA withdrew California's waiver for setting separate emission standards for automobiles and related equipment, which presents a setback to California's Advanced Clean Car and Zero Emission Vehicles programs.

Another important policy element in US road transportation is the Renewable Fuel Standard (RFS) programme, established by the Energy Policy Act of 2005 and EISA of 2007. According to EISA, the US must produce a minimum of 36 billion gallons of renewable fuels annually by 2022. The RFS programme is administered by the EPA, which sets targets for the volume of renewable fuels to be blended into gasoline or diesel each year. Refiners are obliged to fulfil these requirements either by blending the mandated amounts of biofuels into final products or by purchasing credits called Renewable Identification Numbers (RINs) to offset missing volumes of biofuels.

In 2019, the EPA proposed an RFS target for 2020 at 20.04 billion gallons of renewable fuels for blending into the conventional refinery gasoline pool. This is marginally higher than the 2019 target of 19.92 billion gallons.

In addition to the CAFE/SAFE standards and the RFS programme, oil demand developments in the road transportation sector are also affected by various incentives supporting new EV sales. These are provided at the federal, state, city or even utility levels. It should be noted, however, that these incentives tend to be reduced or removed altogether once EV sales start to pick up. At the federal level, the key instrument is a tax credit in the range of $2,500–$7,500 per new EV, depending on the vehicle's size and battery capacity. This credit is applicable to the first 200,000 EVs sold by a manufacturer, then it is reduced by 50% and 25% of the initial amount before the incentive is phased out. The two major EV producers in the US – Tesla and Chevrolet – are already in the final stages of receiving tax credits. For Tesla, according to current regulations, no credits are to be provided as of 1 January 2020, while Chevrolet will reach that stage in the second quarter of 2020.

Besides providing incentives for the purchase of EVs, several states are considering other forms of taxation for EV owners to compensate for lost revenue previously generated by gasoline and diesel sales. For example, Colorado already charges an annual fee of $50 for using public electric charging equipment. Similarly, Nebraska charges $75 each year for any vehicle powered by a source that is not already subject to the state motor fuel tax. In North Carolina and Georgia, the annual fee is $130 and $200–$300, respectively, for the renewal of EV licenses. California plans to introduce a $100 annual registration fee as of 2020.

EU

The regulatory framework for energy, fuel demand and emissions in the EU is very complex. It includes a wide set of policy measures, such as corporate targets for average emissions, differentiated taxes for new car sales and for specific fuels (especially oil-based products), incentives for the purchase of lower emission vehicles, various stringent environmental standards and even outright bans on diesel or ICEs. These policy tools are all used to steer the region's consumption patterns towards a desired fuel slate and to achieve an emissions reduction within the framework of the EU's wider energy and climate change policies.

The current framework regulating CO_2 emissions was established in 2009. It sets specific binding emissions standards for new passenger cars. The current regulation assumes a target of 95 gCO_2/km to be achieved by 2021. In April 2019, the European Parliament and the Council adopted Regulation (EU) 2019/631 setting stricter CO_2 emission performance standards for new passenger cars and for new light commercial vehicles from 2020 onwards. The key element of this regulation is a progressive target for reducing emissions from the 2021 starting point for:

- Cars: 15% reduction from 2025 on and 37.5% reduction from 2030 on; and
- Vans: 15% reduction from 2025 on and 31% reduction from 2030 on.

The specific emission targets for manufacturers are based on the EU fleet-wide targets, taking into account the average test mass of a manufacturer's newly registered vehicles.

Incentives for car manufacturers to increase the sales of zero- and low-emission vehicles (ZLEV – a passenger car or van with emissions between 0 and 50 g CO_2/km) are part of the regulation. These incentives include relaxed CO_2 emissions targets for those manufacturers that exceed a share of 15% ZLEV from 2025 and 35% ZLEV from 2030 for passenger cars in a given year. The EU governing bodies believe that this regulation will lead to a significant reduction in gasoline and diesel consumption, hence, contributing to the EU's commitments under the Paris Agreement.

Two other important provisions in the regulation concern 'pooling' and testing procedures. The regulation maintained the possibility of pooling emission credits between manufacturers. However, pooling between car and van manufacturers will not be allowed. CO_2 emissions will need to be consistent with the WLTP measurement and testing methods. Moreover, actual data on CO_2 emissions and energy consumption will be regularly collected using on-board monitoring devices. The EU Commission also plans to develop a common methodology for the assessment and reporting of the full life-cycle CO_2 emissions of all cars and vans.

In respect to exhaust emissions and fuel specifications, the current standard applied in the EU for light-duty vehicles is Euro 6, while new heavy-duty vehicles must comply with the similar Euro VI standard.

Other important road transportation policy instruments, predominantly taxation and subsidies, are set by individual Member States. Historically, diesel has benefitted from lower levels of taxation in most EU Member States. Therefore, diesel cars have reached high penetration levels in those countries with lower levels of taxation, both in terms of new sales (in some countries above 50%) and in absolute share. This changed in 2015, however, with the emergence of the 'dieselgate' scandal. As a result, the share of diesel cars in new registrations began falling significantly. Given the potential implications on trucks and buses, no major changes were introduced to the fuel taxation schemes within the EU. Moreover, with the rise of Euro 6-compliant vehicles and a rising share of hybrids, the debate around diesel engines is fading.

Most EU Member States offer some incentives to promote EV sales, especially countries with higher GDP per capita. Incentives are provided in the form of tax discounts and exemptions (as is the case in Austria and Germany) and via bonuses and premiums (such as France, UK, Slovenia, Sweden and Spain). In contrast, several countries (Slovakia, Lithuania, Estonia, Poland, Bulgaria and Estonia) currently provide either no, or marginal incentives for EVs, although some are considering introducing new EV schemes.

Nonetheless, in the midst of dynamically changing subsidies for EVs sales in the EU, it is also important to note the ongoing policy-driven investments in expanding the necessary infrastructure to support the use of EVs.

China

Policies related to road transportation in China are in a period of rapid adjustment as they 'leapfrog' through emerging EU and US best practices, while still reflecting the specifics of the Chinese market. One of these is that vehicle registrations in China are heavily regulated via a lottery system, where consumers are subjected to auctions and/or lotteries before being awarded vehicle registrations. The main reason for this system is to limit the uptake of vehicles in major cities and prevent further worsening congestion. In some cities, the lottery program favours electric and alternative vehicles, as opposed to ICE vehicles, by assigning them higher winning probabilities or by allowing them to bypass the lottery system.

Recently, however, reflecting slowing economic activity and lower new car sales growth, the central government has called on local authorities to relax registration restrictions. Some cities have already responded to the call and increased quotas for new registrations. This is the case for Guangzhou and Shenzhen, for example, while others, such as Beijing or Shanghai, are still resisting the move due to concerns of increased traffic congestion.

Change is also on the way with respect to new emission standards and fuel specifications to address air pollutants such as carbon monoxide, NO_x, particulate matter and nitrous oxide. As of 1 July 2020, China will introduce China 6 vehicle emissions standards nationwide. This will consist of two phases. In the first phase, China 6a (effective as of 1 July 2020) will be a combination of Euro 6 and US Tier 2 regulations (including E10 biofuel). In the second phase, effective July 2023, the China 6b standard will also include mandatory real-driving emissions testing, besides other requirements. In a similar way, China will also move to China VI standards for heavy-duty vehicles.

Turning to policies supporting EVs, these were also changed significantly in 2019. Until the end of 2018, China supported the sales of BEVs through direct subsidies in the range of $10,000 per vehicle on average. These subsidies, however, were significantly reduced in 2019 with a complete revamping of the subsidy scheme. As already summarized in Chapter 3, the highlights of the changed policy (which could also be called the 'cap-and-trade' policy) are:

- Automobile manufacturers producing over 30,000 cars must manufacture fleets with an average fuel consumption of 42 mpg by 2020, and 54.5 mpg by 2025;

- Manufacturers that fail to satisfy the fuel economy measures will be required to buy credits from other companies or reduce their production of non-compliant vehicles;

- Increased subsidies for EVs with a range of at least 180 miles per charge matched with significantly lower subsidies for EVs with a range from 90–180 miles. EVs with a charge range below 90 miles will no longer receive any subsidies; and

- The subsidy for an EV with a battery pack density over 140 Wh/kg will be boosted by an additional 20%, battery pack densities lower than 120 Wh/kg will receive 40% less subsidies, while EVs with battery pack densities under 105 Wh/kg will no longer be eligible for any subsidy.

Obviously, there are many similarities between this new policy and the one recently adopted in the EU. Moreover, the fuel economy targets in China are almost as ambitious as those in the EU. Nonetheless, it remains to be seen how successfully these policies will be implemented.

India

India's road transportation sector is one of the fastest growing, especially when compared to other markets of a similar size. New passenger car registrations in India increased by around 9% in 2018, which translates to almost four million vehicles. Combined with rapid urbanization in recent years, traffic congestion and local pollution has become part of daily life, especially in large cities. Therefore, road transportation sector regulation is high on the government's agenda, together with other pressing issues such as energy security, economic development and environmental risk mitigation. It is interesting to note that findings by the Indian Institute of Technology Kanpur in 2016 indicated that the majority (almost 60%) of particulate matter pollution in New Delhi came from dust, and that diesel vehicle emissions only contributed around 10% of emissions in the city centres.

To combat local pollution, the Indian government introduced Bharat standards to regulate vehicle emissions and fuel efficiency. Bharat IV (similar to Euro 4) fuel quality standards were introduced in April 2017 and are still the most advanced standards in place. The Indian government has already announced its intention to 'leap-frog' to Bharat VI (Euro 6 equivalent) standards, skipping the Bharat V transition entirely by 2020.

In addition to Bharat standards, a transition to electric mobility is also perceived as a solution to local pollution in Indian cities. Policymakers are therefore discussing ways and means to support the production and sales of EVs in India, which is also in line with India's intention to become a leader in developing electric mobility technology.

So far, however, the announced policy measures, including subsidies, as well as stated targets for EVs, have not resulted in any significant expansion of EV sales in India. In 2017, India stated its goal to sell only EVs by 2030, however, just one year later, this target was reduced to 30% of new registrations. Moreover, in 2019, the focus of policymakers shifted to the electrification of two- and three-wheelers with the objective to sell only electric two-wheelers by 2025. In this regard, a lack of clarity and consistency in policies discourages large-scale investment necessary for the significant electrification of the road transport sector.

Other regions

Road transportation policies in other regions typically follow Euro or the US Tier standards (occasionally a combination of both). In many cases, however, the adoption of these standards becomes effective with a significant time lag, especially in developing countries.

An exception to this is Japan where vehicle fleets are among the most efficient worldwide, with the most stringent fuel and emissions standards. Fuel efficiency in Japan is regulated by a wider governmental programme called Top Runner Programme which, besides vehicles, also applies to various appliances, computers and heating and cooling systems. In respect to emissions standards, these are currently broadly in line with Euro 6 for light-duty vehicles and Euro VI for heavy-duty vehicles. Moreover, since 2018, all vehicles in Japan are tested using the WLTP.

Strict vehicle and emissions standards are also in place in South Korea. Efficiency standards for 2020 MY vehicles were set at 97 gCO_2/km for passenger cars and 166 gCO_2/km for light trucks. For fuels and emissions, current standards in Korea are equivalent to Euro 6/VI.

Somewhat lower standards are currently used in Australia and Russia. Both of these countries use Euro 5/V equivalent standards for vehicles emissions and fuel specifications. This is also the case for heavy-duty vehicles in Brazil. However, Brazil has its own specific standards for light-duty vehicles that accommodate higher biofuel volumes through minimum blend requirements.

Several other large countries currently use Euro 4/IV equivalent standards such as Argentina, Thailand and Peru, among others. Indonesia also requires Euro 4 standards for all new gasoline vehicles. However, Euro 4/IV for new diesel vehicles will come into force in April 2021 in Indonesia, leapfrogging directly from Euro 2/II that are required until then. In Africa, most countries use Euro 3/II and Euro 2/II standards. However, several countries have plans to adopt higher standards and the expectation is that both efficiency improvements and tighter emissions regulation will progress rapidly in the continent.

8.3 Power generation

Power generation is a crucial and strategic sector in the development of most economies and thus was generally a quasi-monopoly restricted to state-owned companies in most countries for decades. The electricity sector has moved, or is moving swiftly, toward privatization in many regions of the world, opening it up to competition. Additionally, climate change and energy efficiency policies are both putting pressure on grid operators to move toward a cleaner, greener and more energy efficient sector. In many countries, the power generation mix is shifting from fossil fuel-based generation to renewable energy generation. This is taking place, in general, through an evolutionary process driven by policy, which reflects the determination of various countries to incorporate the latest feasible economic, technological and social developments that best fit their interest.

Regulation in the power sector is manifold, from regulations and policy encouraging energy efficiency through cogeneration (CHP), best practices and the adoption of state-of-the-art technology, as well as applying minimum energy performance standards. Good examples for expanding the use of CHP are the US Public Utility Regulatory Policies Act enacted in 1978 and the Energy Efficiency Directive (2012/27/EU), which includes measures to promote cogeneration. Other country-level regulations are focused on abating GHG emissions by changing the power generation energy mix.

Globally, the power sector needs to transition to a low carbon pathway by 2050 to stay within the Paris Agreement's long-term temperature goal. The following section will focus on policy developments related to power generation that are intended to reduce carbon footprints.

8.3.1 US

The US, which under the current administration has withdrawn from the Paris Agreement, is dismantling key regulations passed by the previous administration, such as the CPP and Mercury and Air Toxics Standards (MATS), which forced the power industry to look at power generation sources other than coal. However, the CPP has been temporarily blocked by the Supreme Court, having been the subject of lawsuits from around 30 states.

One policy mechanism relevant to power generation in the US is the ITC for solar power, introduced as part of the Energy Policy Act of 2005. It allows business and homeowners to deduct 30% of the cost for solar installations in tax filings. The ITC was extended in 2015, but it will see allowable deductions lowered to 26% in 2020, 22% in 2021 and 10% from 2022 onwards.

It should also be noted that US policies can also be set at the state level, resulting in a large range of independent policies across the country. In 2018, for example, the state of California announced its target to be carbon neutral by 2045, based on 100% 'clean' electricity and an increase in the share of renewables.

However, it is a careful balancing act between state and federal policy, and states are limited by the federal framework governing each sector. This can sometimes lead to clashes between the federal government and states when state level legislation is overruled, most recently observed in the case of California.

8.3.2 EU

The UN Secretary General's challenge for "no new coal" after 2020 is being followed and challenged at the same time. In 2018, two thirds of emissions in the EU's power sector still came from coal-fired power plants even though the share of coal in power generation is falling; between 2017 and 2018 emissions from hard coal fell by 9% and from lignite by 4%.

Poland, Germany, Bulgaria, the Czech Republic and Romania still use a significant amount of coal in their power generation mix. Thus, EU policies focused on the decarbonization of the power generation sector directly impact these countries. Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Portugal, Slovakia and the UK have recently reiterated that they will work to phase out coal.

France plans to phase out coal power plants by 2022, while the UK and Italy are targeting 2025, and Portugal is aiming for its energy mix to be coal-free by 2030. Finland and the Netherlands have accelerated their coal phase-out target, bringing it forward from 2030 to 2029 and the Austrian Minister of Environment has announced a coal phase-out by 2020 instead of 2025. Greece has committed to end coal use by 2028, with a plan to start dismantling plants in 2020. Germany has joined the global coal-phase-out coalition and is resolute that it will achieve its coal phase out target set for 2038. A phasing out of coal is also currently being discussed in Spain, Slovakia and Hungary.

In Poland, the government still plans to build a new coal-fired plant, but it is expected to be unprofitable unless it receives subsidies that are still allowed under the EU ETS until the end of 2019. A new political party, Wiosna, is calling for a coal phase-out by 2035.

The UK has seen a rapid phasing out of coal plants in recent years after the government imposed taxes on coal emissions and created incentives for renewables. It should be noted that perhaps the biggest upcoming issue for the UK in terms of the impact on energy markets is Brexit. Upon leaving the EU, the UK could be in a position to revise a number of rules and regulations set by the EU.

Nuclear energy is also a focus of policy at the moment throughout the EU. Germany, France, Belgium, and Sweden have all pledged to phase out their existing nuclear power plants, although there is mixed support for these pledges among politicians and the wider population. France has already pushed back its initial targets to reduce nuclear capacity by 50% from 2025 to sometime between 2030 and 2035.

8.3.3 China

Disconnecting GHG emissions intensity from economic growth is challenging, and with one of the fastest-growing economies, China has seen its GHG emissions soar in recent decades. To help mitigate and eventually reverse this trend, China is restricting investment in new coal power plants. It has announced it was halting the construction of 104 planned coal-based power plants with a total capacity of 120 GW, of which around 54 GW had already begun construction. China is also committed to pursuing a 'greener' energy process and to meet its commitments under the Paris Agreement.

8.3.4 India

India has a booming power market with significant private sector investment, and its focus is increasingly turning toward renewable energy. The country has pledged to increase its renewable energy capacity to 175 GW by 2022 and further to 500 GW by 2030. The target also includes achieving 40% non-fossil fuel generation capacity in the power sector by 2030.

To help achieve these goals. India and other stakeholders have announced a Leadership Group for Industry Transition that will drive transformation in hard-to-decarbonize and energy-intensive sectors. However, in the Ministry of Power's monthly report for July 2019 (the most recent at the time of writing), the only capacity additions in that month were two thermal coal power plants each of 660 MW. Over the first seven months of 2019, only one hydro project had been brought online, a 330 MW plant, compared to 11 thermal plants with a combined capacity of nearly 4.8 GW.

The Ministry of Power has undertaken a number of initiatives to improve electricity access and expand the country's energy grid, notably the Integrated Power Development Scheme in 2014. This scheme includes the build-out of transmission lines, metering, the provision of solar panels, as well as other projects.

8.3.5 Other regions

In 2018, Japan had 45 GW of operating coal-fired power generation and it currently has plans to add 15 GW more. The mandatory environmental impact assessment process that includes the need for consistency with Japan's NDC to the UNFCCC, could be seen as a limiting factor against some new coal-fired power plants. Plans to restart more nuclear reactors in the country could also limit the need for additional coal plants. Despite some vocal opposition, Japan is targeting to restart 30 nuclear reactors by 2030 to raise the share of nuclear in its power mix to 20%–22%.

South Korea has announced it would shut down four coal-fired power plants, and six more are expected to be closed by 2022. The country has also stated that it will double its contribution to the Green Climate Fund. South Korea and Singapore are pioneering the implementation of 'Intelligent Energy Systems' and a smart grid network is being adopted as part of a policy to enhance the efficiency and resilience of power systems.

Elsewhere in Asia, Indonesia has plans to reduce the number of coal power plants and triple the share of renewable energy in the power sector by 2030.

Although Mexico joined the Power Past Coal Alliance at COP23, the government still plans to add new coal-fired capacity in 2020. A 'modernization' of coal, diesel, gas and oil-fuelled power plants is in process in conjunction with expanding natural gas pipelines and distribution networks under the country's Energy Reform.

Chile has announced that it will close eight of its oldest coal-fired power plants – equivalent to 20% of its current electricity capacity for coal by 2024. To put this in some context, coal currently accounts for about 40% of the country's electricity mix. Chile is expected to phase out its remaining 20 coal plants by 2040.

South Africa is highly dependent on coal for generating electricity, with its reliance expected to expand with the commissioning of new units at the Medupi and Kusile coal plants. At least two more units at these coal plants are anticipated to enter into commercial operation in the medium-term.

The Sub-Saharan Africa region is facing challenges, specifically related to energy poverty. A large number of countries have limited access to electricity and weak regulatory environments. These have been identified as a key factor in the slow development of the power sector. Efforts are being made to put in place adequate regulatory frameworks in order to ensure greater access to electricity. It should be noted that only 44.5% of Sub-Saharan Africa had adequate access to electricity in 2016, according to estimates based on World Bank and UN statistics.

8.4 Supply

8.4.1 US

Major advances in technology related to tight oil exploration and production have turned the US into the largest oil producing country in the world and on the verge of becoming a net oil exporter (crude and refined products). In the case of tight oil, its success is built on a combination of several technologies in tandem with advanced sensing and data processing.

The current US administration is aiming to encourage further development in the US oil and gas sector, by opening up more federal lands to oil and gas drilling, reducing environmental regulation and cutting red tape with regard to permitting and fast-tracking pipelines and other infrastructure.

Notably, the government has been pushing to open up the eastern Gulf of Mexico, thus far off limits to drilling, as well as other parts of the US coastline – though local opposition is proving an obstacle. The government has also called for the NPRA and the ANWR in Alaska to be accessible to drilling. ConocoPhillips is already set to start up production in the former in the next couple of years and first lease sales in the ANWR area are expected to be held in 2020.

However, the economic viability of developing new resources in frontier areas, for example, new Alaskan acreage, has yet to be proven. Moreover, there remains significant political opposition against opening up some of these areas. In September 2019, the Democrat-controlled House of Representatives passed a bill to block oil and gas drilling in the ANWR, as well as the US Atlantic and Pacific coasts and the eastern Gulf of Mexico. It is unlikely that this bill will make it through the Republican-controlled Senate, or if so, it would likely be vetoed by President Trump. However, it is an indication of how a possible future Democratic administration might attempt to reverse some of the recent decisions.

Indeed, leading Democratic contenders for the 2020 presidential elections have promised as much. Most candidates have talked about a ban on oil and gas drilling on federal lands. Joseph Biden has said he will consider curbs on exports of US oil and natural gas. Elizabeth Warren and Bernie Sanders have both called for a nationwide ban on fracking, one of the keys to developing tight oil and shale gas and which, if enacted, would clearly have a very significant impact on US liquids supply.

8.4.2 Mexico

In late 2013, Mexico announced a change in its constitution, thus enabling a significant overhaul of its energy sector and its legal framework in a planned series of reforms. Crude oil production had been in decline since 2004, even though refined product imports had increased sharply. Through dismantling the monopoly that national oil company Petróleos Mexicanos (Pemex) had on oil and gas production, the stated goal was to open up the energy sector, create competition and attract foreign investment.

The primary objective was to liberalize the upstream sector, but almost six years after the energy reforms were announced the impact has been relatively limited. A couple of upstream acreage auctions have been held, with modest interest. The new government of Andrés Manuel López Obrador has also put new upstream auctions on hold for up to three years.

Nonetheless, the current government hopes to boost production by as much as 300 tb/d by 2020, and raise it by as much as 2.5 mb/d by 2024. It has instructed Pemex to focus on areas where it has experience and existing infrastructure, including notably the shallow-water areas and some onshore fields, while also halting activities in higher-risk frontier areas including tight oil and deepwater. Furthermore, the government has expressed its determination to cut red tape, accelerating the time required to obtain regulatory permits, and the duration required to realize upstream projects.

8.4.3 Russia

Russia has recently revised its petroleum fiscal regime. In 2018, amendments were made to the Russian Tax Code and the 'Customs Tariff' law, altogether known as the 'end of tax manoeuvre (ETM)'. This production policy took effect on 1 January 2019. Previously, in November 2017, Russia's government approved a plan to introduce a new petroleum fiscal policy based on profit rather than volume.

The new revision aims for oil companies to develop marginal greenfields, and invest in EOR methods on depleted brownfields with high water content of extracted liquids. The new oil and gas fiscal regime addressed the downstream sector too. The upgrade of the current refining system by encouraging the export of light and middle distillates *in lieu* of heavy fuel oil, as well as improve the quality of domestic oil products, will be also incentivized.

Energy and sustainable development

Key takeaways

- UNFCCC Parties' NDCs are expected to be enhanced progressively to be consistent with the long-term goal of the Paris Agreement.

- The progression of the NDCs could lead to increasingly stringent mitigation actions that could have important implications for developing country economies and their sustainable development.

- Energy-exporting developing countries are likely to be disproportionately affected by the impacts of the implementation of response measures; therefore, the enhancement of an understanding of the measures' impacts and a proper treatment of their implications are vital.

- Economic diversification is considered an approach to mitigate risk arising from the implementation of climate response measures. This approach has been at the centre of multi-year development plans in energy-exporting developing countries, including OPEC Member Countries; however, the diversification and complexity of the structure of these economies remains low compared with other economies worldwide.

- Policies and actions consistent with a below 2°C pathway would have a significant impact on global primary energy demand – decelerating energy demand growth is expected at a global level in primary terms. Concurrently, energy-exporting developing countries, including OPEC Member Countries, could experience adverse impacts on their future sustainability and growth.

- Although there is no one-size-fits all prescription for economic diversification efforts, different options for energy-exporting developing countries, including OPEC Member Countries, to diversify their economies (within and outside the energy sector) are considered in this scenario analysis. These indicate that generated benefits through diversification efforts would not compensate them for the adverse impacts from which their economies would suffer owing to challenges created by climate response measures.

- The role of governments and international cooperation should be highlighted, as these could contribute to economic and structural reforms, as well as the identification and sharing of best practices and experiences of countries that have successfully diversified their economies. Non-domestic barriers could also be identified, such as trade barriers, along with ways in which the international community could facilitate increased foreign investment and support in the form of technology transfer and financial support.

In December 2015, Parties to the UNFCCC agreed at the 21st session of the Conference of the Parties (COP21) on a landmark agreement, the Paris Agreement, to combat climate change and increase actions for a sustainable future.

The Paris Agreement, in enhancing the implementation of the Convention, brings together both developed and developing countries, with a common cause to strengthen the global response to the climate change challenge, in the context of sustainable development and efforts to eradicate poverty. Concurrently, it aims to hold the increase in the global average temperature to below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

To achieve the long-term temperature target of the Paris Agreement, Parties are called to take action by implementing NDCs and increasing their efforts in the years ahead, while considering national circumstances and priorities. The Paris Agreement sets a five-year cycle for Parties' contributions to the global response to climate change, with the objective to enhance ambitions progressively. Thus, a global stocktake is to be taken in five-year cycles and two years prior to the periodic submission of NDCs.

In addition, Parties to the Paris Agreement recognize that they may be affected not only by climate change, but also by the impacts of the measures taken in response to it. Owing to the intrinsic relationship that climate change actions and response measures have with equitable access to sustainable development and the eradication of poverty, Parties should consider, when implementing the agreement, the concerns of Parties with economies most affected by the impacts of response measures, particularly developing countries.

The Paris Agreement further states that mitigation co-benefits resulting from Parties' climate change actions and economic diversification plans can contribute to mitigation outcomes. This is aligned with the Convention that calls Parties to take into full consideration the specific needs and concerns of developing countries arising from the adverse effects of climate change and the impact of the implementation of response measures.

In this context, the progression of Parties' NDCs towards the ultimate temperature target of the Paris Agreement is likely to lead to increasingly enhanced mitigation actions that could have important implications for the economies of developing countries and their sustainable development. Therefore, addressing climate response measures requires the establishment of a paradigm to enhance the understanding of the impacts of these measures and to ensure the proper treatment of their implications, to prevent their adverse effects on the sustainable development of developing countries; including energy-exporting developing countries.

With these in mind, it should be reiterated that Parties' contributions inscribed in the already submitted NDCs have been assessed as not sufficient to put the world on a pathway consistent with the long-term temperature target of the Paris Agreement. Thus, following the adoption of the Katowice climate package at COP24, Parties are now expected to begin working towards significantly accelerating the pace of climate action.

While intensifying further climate action, it is still important to consider different national circumstances, evoke the principles of the Convention – including those of equity and common-but-differentiated responsibilities and respective capabilities – balance mitigation, adaptation and means of implementation, such as climate finance, technology transfer and development, and capacity-building support, and take into account the overriding priority of sustainable development.

In addition, economic diversification could be considered as an approach to reduce or eliminate risks and adverse impacts that developing countries, in general, and energy-exporting developing countries, in particular, are expected to face from mitigation actions aimed at reducing emissions.

Energy-exporting developing countries are likely to be disproportionally affected by the impacts of the implementation of response measures; therefore, economic diversification could be used as a strategy to tackle climate change, while achieving sustainable development too.

Therefore, this Chapter considers a renewed sense of urgency around economic diversification in energy-exporting developing countries and in the context of sustainable development. It addresses different options for energy-exporting developing countries to diversify their economies, including within and outside the energy sector. Analysis shows that there is no one-size-fits all prescription for economic diversification efforts. Economic diversification may have been at the centre of multi-year development plans in energy-exporting developing countries; however the diversification and complexity of their economies' structure remains low compared with other economies worldwide.

In addition, three scenarios and a sensitivity are considered on potential economic diversification in order to reduce the adverse impacts arising from stringent climate change action. It appears that such efforts are not sufficient to fully mitigate the adverse impacts of response measures to climate change. Thus, international cooperation is crucial to support energy-exporting developing countries and allow them to grow sustainably.

9.1 Adverse effects of response measures

The impact of the implementation of response measures on energy-exporting developing countries depends greatly on the assumptions made about how world regions could evolve over time in terms of economic growth and energy use, among others. Regardless of the uncertainties surrounding how world regions might evolve, there is a growing perception that energy demand growth is likely to slow over time as efficiency improvements, technological advances, policy measures to reduce emissions, and changing consumer behaviour lead to the energy transition.

The speed of the energy transition is therefore highly uncertain and is heavily driven by fundamental factors that are not uniform across world regions. Yet, as energy demand growth slows, global energy markets are expected to become increasingly competitive.

In this context, energy-exporting developing countries, as natural resource-based economies that depend mainly upon the income from the export of undifferentiated resource commodities – namely, oil and gas – have recognized the need for economic diversification. It has been identified as a strategic necessity in national development plans to enact changes that could increase their economies' resilience in the future.

Using the Reference Case presented in previous chapters of the Outlook, a below 2°C-compatible pathway (Scenario A – below 2°C) is herewith considered to estimate the potential adverse effects of the implementation of response measures, while assuming policies and actions beyond those already announced in Parties' NDCs.

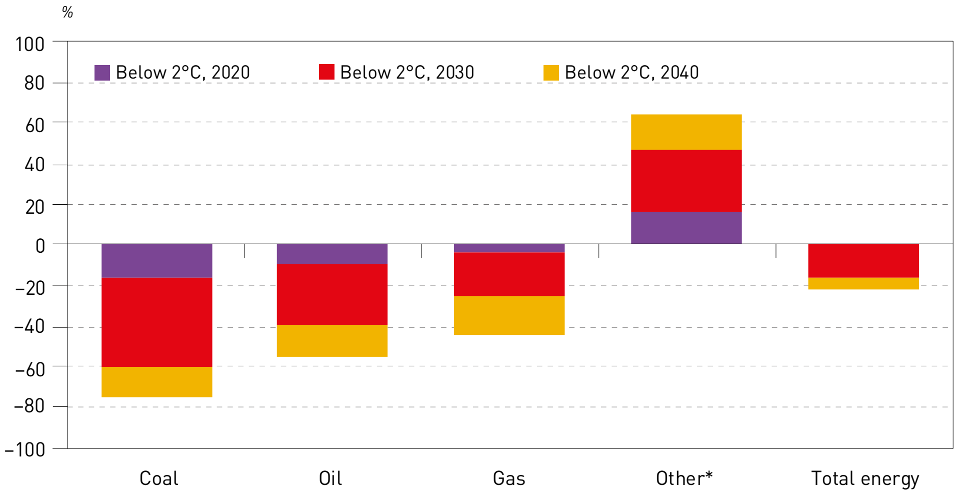
Policies and actions consistent with a below 2°C pathway would have a significant impact on global primary energy demand. In 2030, a more than 20% reduction of global primary energy demand is estimated, when compared with the Reference Case, with total demand falling to 258 mboe/d. The respective figures in 2040 see a reduction of about 26%.

The below 2°C-compatible scenario further suggests that the reduction in energy from fossil fuels is expected to start early in the projection period. In contrast to fossil fuel energy sources, the growth of renewable energy (including nuclear) would further accelerate.

The range of changes in global primary demand for major fuels for the years 2020, 2030 and 2040 relative to the Reference Case is summarized in Figure 9.1. Regarding the energy mix under

Scenario A – below 2°C, a reduction of almost 20 pp in the share of coal in total primary energy demand is estimated in 2040, compared with 2018, along with an estimated decline of about 14 pp in the share of oil and a more than three pp decrease in the share of gas. The share of demand for renewables/other energy sources would increase by more than 35 pp by the end of the projection period.

Figure 9.1
Energy demand relative to the Reference Case



** Including nuclear, hydro, biomass and other renewables such as wind, solar PC, geothermal etc.*
Source: OPEC.

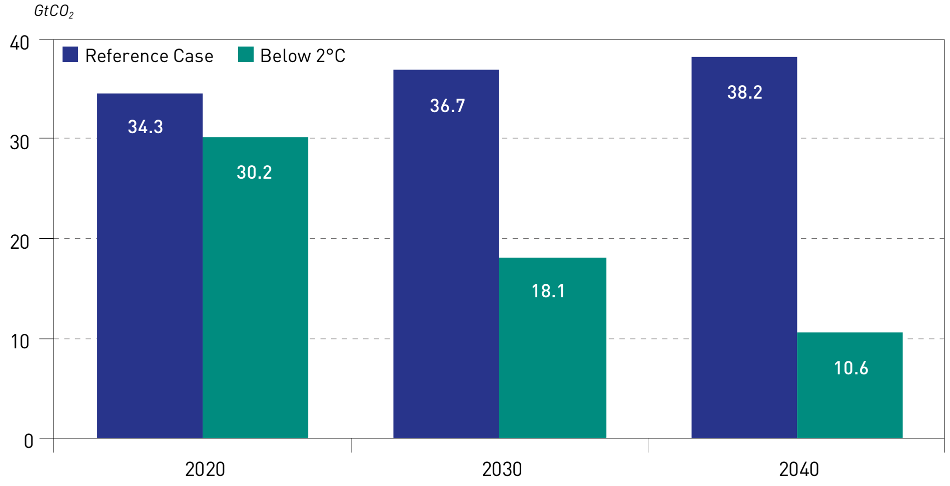
The higher penetration of renewables/other energy sources expected under Scenario A – below 2°C is evident. Combined, they would contribute an additional 34 mboe/d to the global energy mix in 2030 and an extra 58 mboe/d in 2040. For the remaining fuel types, oil consumption is reduced in 2030 from about 98.6 mboe/d in the Reference Case to 60.2 mboe/d in Scenario A – below 2°C, and further to 44.9 mboe/d in 2040. The respective figures for gas are from 79.7 mboe/d to 59.4 mboe/d in 2030, and then to 50.4 mboe/d in 2040.

On the environmental front, as presented in Chapter 2, global energy-related CO_2 emissions are projected to increase over the Reference Case forecast period, reaching the estimated level of 38.2 gigatonnes (Gt)CO_2 in 2040. It underscores that emissions continue to grow at a decelerated pace, owing mainly to economic growth and increasing energy demand. In 2040, annual global energy-related CO_2 emissions are expected to be around 13% higher than in 2018. Cumulative CO_2 emissions in developed countries (Annex I countries) are anticipated to represent approximately 55% of the total in 2040, compared to about 66% in 2018. In addition, CO_2 emissions from coal consumption are estimated to account for almost 40% of the total emissions in 2040.

Figure 9.2 shows that global CO_2 emissions should be substantially reduced in a below 2°C-compatible pathway, when compared with the Reference Case by 2040. This corresponds to about 10.6 GtCO_2 emissions at the end of the forecast period; whereas immediate action to reduce emissions is necessary to proceed with a below 2°C-compatible pathway.

In light of the above-presented impacts on global primary energy demand, it is likely that energy-exporting developing countries could face adverse impacts arising from the implementation of

Figure 9.2
Impact on CO_2 emissions



Source: OPEC.

enhanced climate action. To this end, economic diversification could be considered as a means to reduce the adverse effects of response measures and allow for economic sustainability.

9.2 The concept of economic diversification

The previous section shows that stringent climate change policies and measures would be required to address the challenge of reducing emissions, leading also to significant transitions in the energy system.

Without a sufficiently diverse production base, countries such as energy-exporting developing economies are bound to experience relatively lower economic growth in the medium- and long-term, with significant socio-economic implications. Economic diversification could potentially ensure a more stable revenue stream, contributing to *inter alia*, higher prosperity for citizens, continuous economic growth and more sustainable job creation.

The concept of economic diversification has therefore become an increasingly prominent topic in the policymaking agendas of many countries, including energy-exporting developing economies. It has been a primary goal of investments made in many economies, in terms of activities, sectors and infrastructure, to enable broader diversification in the context of sustainable development.

Although there exists neither a common definition of economic diversification, nor metrics to measure, it could refer to countries' intensified efforts to diversify their economies and sources of income away from extreme dependence on a single dominant industry or a few natural resource-based commodities, as well as a change toward increased complexity and quality of output.

Countries also tend to diversify by developing commodities that are close in the production space to those they already export. As a result, capabilities embedded in export products determine diversification opportunities. They condition future capabilities and consequently shape changes in the economic structure and support the branching out into related or nearby products that are close to pre-existing capabilities.

Moreover, different factors determine the pathways for changing the structure of an economy. These include wide ranges of existing natural resources, as well as capabilities related to infrastructure and knowledge, such as innovation capacity. The role of institutions in the creation of new pathways for growth and economic diversification is considered vital too.

In particular, the following elements are of most importance to help achieve economic diversification:

- Develop an appropriate incentive framework;
- Invest in transportation and communication and introduce coordinated policy reforms to reduce trade costs;
- Design effective policies to support the reallocation of economic resources to new activities, especially in labour-market policies and access to finance;
- Focus on sectors related to a local advantage;
- Use labour skills that already exist;
- Focus on developing the required skills through training of highly skilled workers; and
- Increase private sector involvement, with a focus on entrepreneurship and innovation.

9.2.1 Key determinants of economic diversification

The key drivers to enhance economic diversification are elaborated below.

Economic determinants (such as economic growth and productivity): An important part of a country's economic success is defined by its ability to produce goods and services it can also export. As already noted, diversifying an economy could happen within existing industrial structures or by establishing new industries for which a country has natural advantages. The term 'natural diversification' is often used to describe economic diversification taking place to a significant degree due to economic growth and as the service sector gains in importance.

In countries where the economy is largely natural resource-based, the energy sector could indeed encourage diversification by boosting services and/or manufacturing. For instance, a strong energy sector could create positive externalities by contributing to economic growth through linkages between related economic activities. Technological advancement within the energy sector could be leveraged to its maximum advantage to create a dense network based on linkages between sectors, and also allow diversification into the service sector too.

Energy-exporting economies could therefore develop further through interaction between their natural resource base and the emergence of 'added value' industries. Besides successfully managing export revenues, energy-exporting economies could promote knowledge investments and high levels of productivity, which in turn could lead to sustained diversification.

Economic reforms (including trade liberalization and access to finance – for example inflows of foreign direct investments (FDI)): Market conditions prevailing in natural resource based economies may provide limited incentive to encourage diversification efforts. Appropriate policies and supporting regulatory frameworks are required to expand economic activities in prospective markets, as well as domestic and foreign investments to create national capabilities pursuing radical innovation and R&D activities, and to support the development of science, technology and innovation (STI) systems. The diversification of energy-exporting economies towards future-oriented sectors and industries that address global demand and create new markets could also result in higher international trade flows, and therefore higher export revenues.

The role of governments in this regard is vital, in terms of introducing policies and measures that relate *inter alia* to innovation and international trade. Governments could take the lead by investing in sectors with productivity potential, whereas policies such as for STI could allow some sectors to become attractive to (foreign) private investors too. In this case, the evolution of policies could leverage public sector commitments to create new industrial opportunities for private investment, which is mainly solicited from foreign investors due to the benefits of technology transfer and management know-how.

Moreover, trade regimes could allow for the removal of trade barriers and the identification of new destinations so as to also diversify export markets geographically. A diversified export portfolio could help energy-exporting economies to increase their resilience against terms-of-trade shocks, stabilize long-term export revenues and safeguard investment rates.

Structural factors (such as population, human capital and quality of institution and education): In addition to promoting diversification and economic growth through more flexible and competitive markets and a higher degree of exposure to international trade, natural resource based-economies could also proceed with structural transformation. This could refer to significant public spending increases on R&D activities, as well as more flexible labour markets and adequate training and education.

The quality of educational institutions could be enhanced to build up human capital; whereas knowledge created in the energy sector could be transformed and relate to products and services of specialized high-value sectors and exports. Policies that support an efficient allocation of resources and ensure the long-term viability of high-quality jobs are therefore needed.

Infrastructure and non-economic determinants (such as volume of products and trading markets): Diversified economies depend not only on effective institutions and a well-educated labour force, but also on the construction of infrastructure. Highways, bridges, telecommunication facilities and electrification, as well as hospitals and schools could contribute to this, promoting a wide range of economic activities and competition in all sectors – including potential export sectors.

In light of the highlighted drivers, the sectors for natural resource based-economies to diversify and subsequently export could be the ones that realize the highest productivity gains for labour and other resources. Air transport, energy engineering, telecommunications, petrochemicals, fertilisers, real estate, healthcare, tourism, financial services, logistics, electrical machinery and equipment, and agriculture may be viewed as viable options.

Considering the above and prior to examining whether energy-exporting developing countries are already pursuing efforts to diversify their economies, a brief overview of indexes used to measure economic diversification is presented.

9.2.2 Measurement methods for economic diversification

Different measurement methods for economic diversification are used in literature, including the so-called *Herfindahl Index* – also known as the *Herfindahl-Hirschman Index* (HHI), or the *concentration index* – that is considered a reliable proxy. It has been widely used to measure economic concentration and diversification.

The *Herfindahl Index* is a measure of the size of firms in relation to the industry, and an indicator of the amount of competition among them. The index ranges from zero to one, with one being a market with just one firm, and zero a market with infinite firms. It could also be used to measure the relative size of export sectors and the degree of concentration of the export basket of a country.

In that sense, the *Herfindahl Index* shows whether the structure of exports by product of a given country differs from the world average. An index with a value closer to one indicates a bigger difference from the global average and hence a relatively more concentrated (or specialized) economy. On the other hand, a country with a perfectly diversified economy, with more homogeneously distributed exports among a series of products, will have an index close to zero.

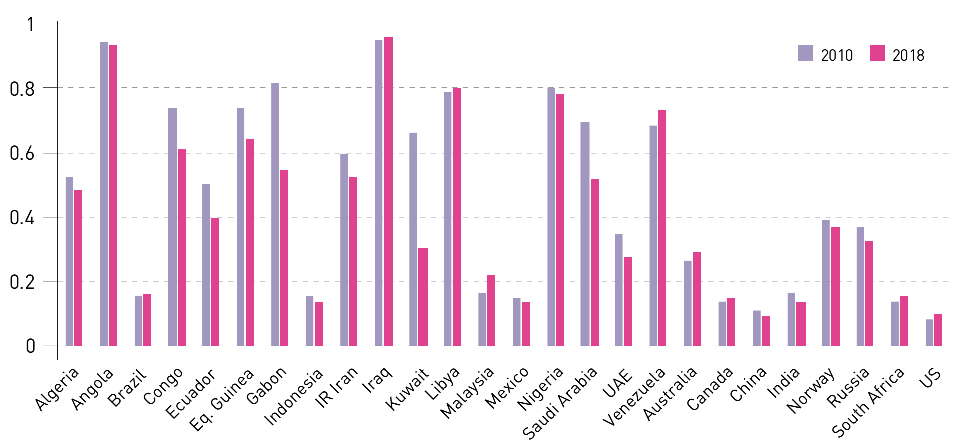
As none of the measures used for economic diversification is considered optimal, some alternatives to the HHI index are also presented. The *Diversification Index* is computed by measuring the absolute deviation of the trade structure from the world structure. This index also ranges between zero and one; with a value closer to one indicating a greater divergence from the world pattern and, therefore, a relatively more concentrated economy. Moreover, the *Number of Products* is used to show the number of commodities exported at the three-digit SITC, Rev. 3 level. This is a basic classification that groups all commodities into headings suitable for economic analysis. Finally, the so-called *Economic Complexity Index* (ECI) measures the relative knowledge intensity of an economy and it can be used as a proxy for economic diversification and production capabilities to the global market. Less complex economies tend to have less competitive manufacturing firms. This index ranges from –2.6 to 2.8.

9.2.3 Economic diversification in selected energy-exporting developing countries

Energy-exporting developing countries are, in general, natural resource based-economies that have emerged as major exporters of oil and gas, having vast endowments of these natural resources. Subsequently, their economic activity, fiscal revenue, export earnings and foreign exchange are directly or indirectly dependent to a large extent on oil (and gas) production.

In regard to economic diversification, Figure 9.3 and Table 9.1 show the figures related to the four indexes already described for selected energy-exporting developing countries and other major economies worldwide. The *Herfindahl Index* fell for selected energy-exporting developing countries from

Figure 9.3
Herfindahl Index



Source: UNCTAD.

Table 9.1
Product concentration and diversification indices of exports

	2000	2010	2018	2000	2010	2018	2000	2010	2018
	Concentration index			Diversification index			Number of products		
Algeria	0.5	0.5	0.5	0.8	0.8	0.8	101	108	121
Angola	0.9	0.9	0.9	0.8	0.5	0.5	40	6	7
Brazil	0.1	0.2	0.2	0.5	0.5	0.6	246	251	252
Congo	0.8	0.7	0.6	0.8	0.8	0.8	55	141	170
Ecuador	0.5	0.5	0.4	0.7	0.7	0.8	154	193	191
Equatorial Guinea	0.8	0.7	0.6	0.7	0.8	0.8	16	57	33
Gabon	0.8	0.8	0.6	0.9	0.8	0.8	68	137	149
Indonesia	–	0.2	0.1	–	0.6	0.6	–	246	246
IR Iran	0.8	0.6	0.5	0.8	0.7	0.7	228	244	257
Iraq	1.0	1.0	1.0	0.9	0.9	0.9	77	107	140
Kuwait	0.6	0.7	0.3	0.8	0.8	0.7	171	213	223
Libya	0.8	0.8	0.8	0.8	0.8	0.8	79	95	131
Malaysia	0.2	0.2	0.2	0.5	0.5	0.4	249	252	253
Mexico	0.1	0.2	0.1	0.4	0.4	0.4	250	252	251
Nigeria	0.9	0.8	0.8	0.9	0.8	0.9	131	197	206
Saudi Arabia	0.7	0.7	0.5	0.8	0.8	0.8	245	247	248
UAE	0.5	0.3	0.3	0.7	0.5	0.6	254	257	258
Venezuela	0.6	0.7	0.7	0.8	0.8	0.8	224	210	202
Australia	0.1	0.3	0.3	0.5	0.7	0.7	256	254	247
Canada	0.1	0.1	0.2	0.4	0.4	0.4	256	257	256
China	0.1	0.1	0.1	0.5	0.5	0.4	254	255	256
India	0.2	0.2	0.1	0.6	0.5	0.5	246	255	252
Norway	0.5	0.4	0.4	0.7	0.6	0.7	237	235	240
Russia	0.3	0.4	0.3	0.7	0.7	0.6	246	247	254
South Africa	0.1	0.1	0.2	0.5	0.5	0.5	249	256	252
US	0.1	0.1	0.1	0.3	0.3	0.2	257	259	260

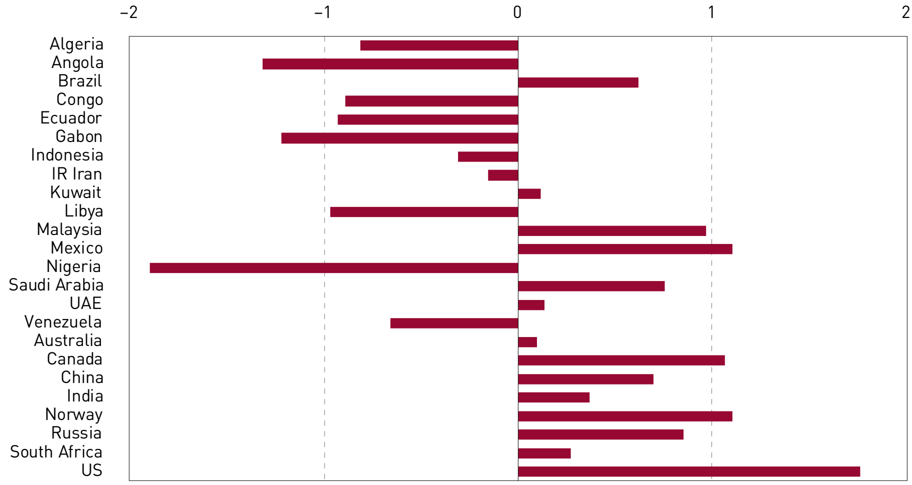
Source: UNCTAD.

0.58 in 2010 to 0.51 in 2018. The majority of these economies were therefore more concentrated in 2010 compared to 2018. Some energy-exporting developing countries became more diversified in the period, yet, they remain more concentrated than other major economies, including energy-exporting developed countries.

This trend is similar to the performance seen when using another measure for economic diversification, such as the *Diversification Index*. It further appears that energy-exporting developing countries have diversified less than other economies when using the index for the *Number of Products*. Differences are also observed within these economies. For instance, the UAE has a diversified economy at a level similar to other energy-exporting developed countries. Ecuador and Equatorial Guinea have become less concentrated in spite of a less diversified number of products. In Iraq, the emergence of new products has compensated for the concentration of the existing export basket.

Figure 9.4 illustrates the ECI measure in energy-exporting developing countries compared to other major and/or energy-exporting countries. It appears that economic diversification is generally low in energy-exporting developing countries, reflecting the heavy weighting of the energy sector. As in Figure 9.3, these economies lag behind other countries and each country seems to be differentiated. It should be also noted that the *ECI* value has been rather stagnant in recent years.

Figure 9.4
Economic Complexity Index, 2017



Source: IMF.

Regarding future trends, it should be kept in mind that diversification could come from either a rebalancing of the existing export basket or from new sectors. Some energy exporting countries also start with a more diversified export basket. Different starting points may therefore justify differences between, and within, groups of countries.

9.3 Economic diversification as a means to address the adverse impacts of response measures

This section includes a quantitative analysis on the potential options for selected energy-exporting developing countries (OPEC Member Countries, as well as Brazil, Indonesia, Malaysia and Mexico) to diversify their economies; with the aim to reduce the adverse impacts from the implementation of response measures. Scenarios developed on economic diversification consider options both within the energy sector and the wider economy.

The Reference Case projections in Chapter 2 and in Scenario A – below 2°C presented earlier in this Chapter referring to a below 2°C-compatible pathway, are also used for analysis of the scenarios.

The objective of analyzing scenarios is to examine whether, and to what extent, the estimated adverse impacts for energy-exporting developing countries related to the implementation of stringent climate change measures could be offset through economic diversification options. There are two main scenarios, as well as a sensitivity (Table 9.2). Scenario B focuses on economic diversification potential within the energy sector only, and Scenario C focuses on diversification potential also outside the energy sector. Scenario C builds on Scenario B, and the sensitivity then builds on Scenario C.

In both scenarios, it is assumed that energy-exporting developing countries may meet investment requirements without receiving any international support. Both cases assume a crowding out

Table 9.2
Scenarios and sensitivity

	Scenarios	Description
Scenario B	Energy sector diversification: electricity & hydrogen exports	Exports of hydrogen, as well as electricity produced in energy-exporting developing countries using low-cost renewables and/or fossil fuels with CCS
Scenario C	Non-energy sector diversification: industry localizing	Boost in domestic production and exports of non-oil industries, in addition to Scenario B
	Sensitivity	**Description**
Sensitivity Ca	Non-energy sector diversification: with international support	Foreign financing (FDI) and increased labour productivity added to Scenario C

Source: OPEC.

effect for investment; whereas Sensitivity Ca considers the Scenario C analysis, but also assumes international support through FDI and increased labour productivity.

9.3.1 Economic diversification within the energy sector (Scenario B)

The diversification strategy adopted by energy-exporting developing countries could depend on the speed of the energy transition and technological advancement, during which the natural resource-based extraction sector would continue to play a key role in these economies, including in their diversification efforts. The energy sector could adapt and ensure that it acts as a platform for sustainable development and transformation. This could result in an economy wherein the energy sector generates a larger multiplier effect in terms of domestic employment, along with spill over effects to help foster other sectors.

Accordingly, Scenario B explores the potential for energy-exporting developing countries to supply and export electricity using low-cost renewable energy sources (e.g. solar), as well as oil and gas with CCS. Potential importing countries are selected based on their distance from the producers and their potential electricity demand. Demand is further based on various factors, including the levelized cost of energy (LCOE) for electricity in the importing and exporting country and transmission costs. Supply is also determined by factors such as the maximum generation building capacity of the exporter. Moreover, existing and new transmission lines are considered.

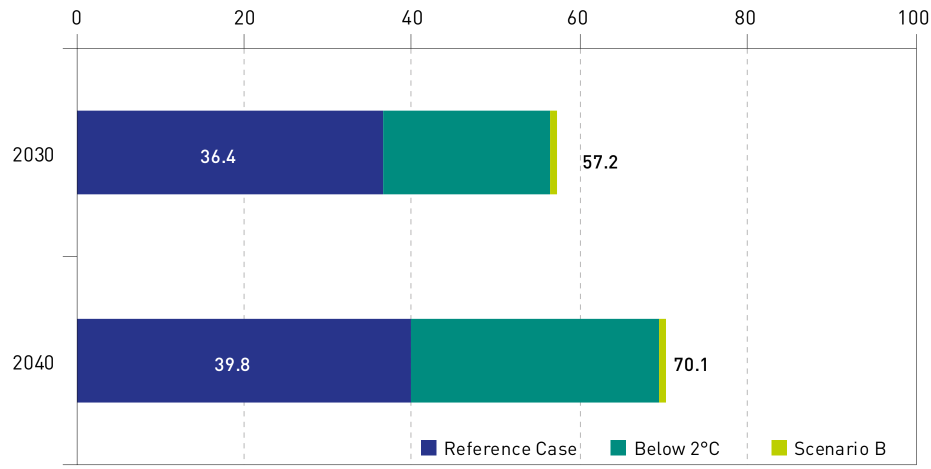
As a first step, the potential demand and locations for electricity trade were estimated, followed by the potential estimation of expected electricity demand, supply and the transmission potential for selected regions. After identifying the potential target countries and setting constraints on production, the possibilities for physically bringing supply to meet demand were also investigated. The technical capacity already in use was determined, which also allowed for an estimation of transmission through existing infrastructure. Finally, new transmission lines were approximated considering both underwater and overhead lines.

In addition to electricity exports, hydrogen produced in the energy-exporting developing countries is assumed to be exported too. In terms of hydrogen exports, demand was calculated, having estimated the potential supply, conversion and transportation costs of hydrogen. Finally, all policies in Scenario A – below 2°C are included in Scenario B.

It should be noted that the below 2°C Scenario sees lower electricity demand compared to the Reference Case, yet electricity would account for almost 36% of final demand in 2040 compared with 30% in the Reference Case. In Scenario B, electricity demand (including hydrogen use) would expand slightly given the increasing exports from energy exporting developing countries. However, global electricity would again be lower in this scenario compared with the Reference Case due to stringent climate change measures and policies.

In addition, a significant transition in the power generation sector is expected under Scenario A– below 2°C with renewable energy sources (as well as nuclear) accounting for about 56% of the electricity mix in 2030 and 69% in 2040. This equates to an increase of about 28 and 41 pp from 2018 levels, respectively. Under Scenario B, the share of renewables in global power generation increases further, but only slightly (Figure 9.5). In regards to CCS, and irrespective of the scenario considered, this technology is expected to play a significant role at a global level after 2030.

Figure 9.5
Share of renewables in global power generation



Source: OPEC.

9.3.2 Economic diversification in non-energy sectors (Scenario C)

Under Scenario C, potential growth in other sectors of the energy-exporting developing countries is assessed. These economies are assumed to be in a position to capture market share in expanding sectors, therefore substituting a share of export revenue losses. However, they are assumed to meet investment requirements without receiving international support.

In regard to the selected sectors, these were identified by examining the potential supply and current state of sectors, as well as the present structure of the energy-exporting developing countries' economies. Moreover, the already announced and implemented diversification policies in these economies were also taken into account. Increased investment into education (for appropriate skills) is assumed in these sectors, along with financing through government revenue and decreasing existing tax burdens.

Sensitivity Ca allows for international support, assuming that assistance is given to the energy-exporting developing countries through FDI and open trade. Both foreign and domestic investments lead to increased labour productivity, due to training, innovation and management expertise. In this case, all policies in Scenario C remain unchanged, with the additional introduction of foreign investment inflows into the selected sectors.

In Scenario C (and Sensitivity Ca), the contributions of selected sectors to the energy-exporting developing countries' GDP are expected to have an upward trend, along with exports related to products made available by the selected sectors. Table 9.3 shows that even in the Reference Case, the share of the extraction industry in the energy-exporting developing countries is expected to fall from more than 14% in 2018 to 12.6% in 2030 and 11.8% in 2040. The diversification measures in Scenario C, combined with the fall in demand for oil under Scenario A – below 2°C, mean that the share of the extraction industry in GDP could fall further; to 9.5% in 2030 and 7.5% in 2040.

Table 9.3
GDP by sector in selected energy-exporting developing countries *% share*

	Reference Case			Scenario C		
	2018	2030	2040	2018	2030	2040
Agriculture	6.9	7.6	8.0	6.9	7.9	8.4
Extraction	14.4	12.6	11.8	14.1	9.5	7.5
Manufacturing	15.8	17.0	17.5	16.0	16.8	18.2
Utilities	1.5	1.6	1.7	1.4	2.0	2.0
Construction	6.1	5.7	5.5	6.2	5.8	5.8
Services	55.4	55.5	55.6	55.4	58.0	58.2

Source: OPEC.

In addition, the diversification efforts lead to an increase in the shares of the manufacturing and services sectors. The share of manufacturing grows slowly at first (as it is affected by the measures considered under Scenario A – below 2°C), but increases to more than 18% of GDP by 2040. The share of services in GDP grows faster than in the Reference Case, reaching more than 58% in 2040. Although it remains modest in size, there is also an increased contribution to GDP from utilities.

It is important to also note that diversification efforts assumed in Scenario C could improve the trade balance of the energy-exporting developing countries, both through higher exports and lower imports of other products. In addition, the increase in non-energy trade will not cancel out all the effects of reduced energy exports. For instance, the loss of royalties from energy extraction will continue to put pressure on government budgets. This is discussed further in the socio-economic impacts section.

Finally, the additional foreign investments in Sensitivity Ca boost domestic economies in the energy-exporting developing countries, such as in construction. It leads to higher export volumes, but also an increase in imports, for example, machinery for construction. It therefore does not have a large additional impact on the trade balance.

9.3.3 Impacts on energy demand and the energy mix

As already stated, decelerating energy demand growth is expected at a global level in primary terms under a below 2°C-compatible pathway. In particular, the decelerated annual growth rate is estimated at about 0.4% over the period 2018–2040, with significant changes in the energy mix.

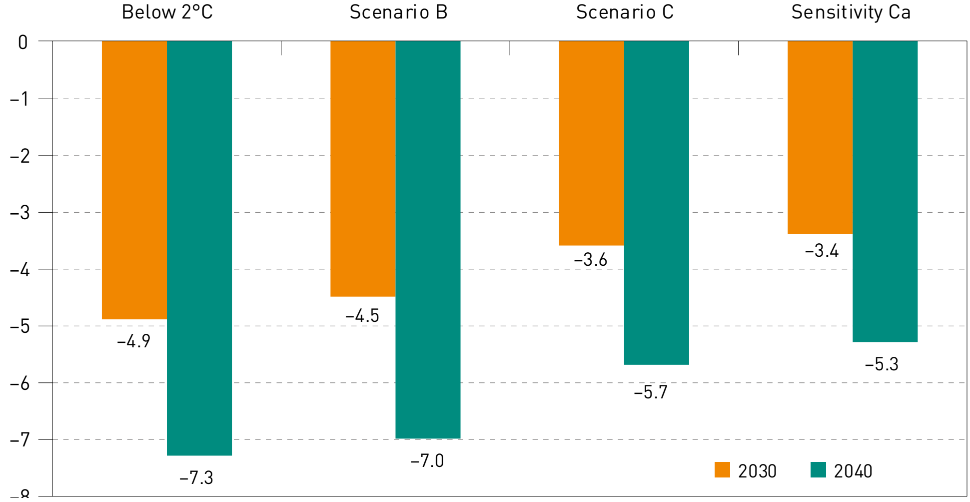
Given the reduction in the share of fossil fuels, energy-exporting developing countries are assumed to proceed with economic diversification within the energy sector or in the wider economy. Regardless of the scenario, global energy demand and the energy mix would not react significantly differently with the introduction of diversification in the energy sector of the energy-exporting developing countries (Scenario B) or in the wider economy (Scenario C). This is the result of countries having already proceeded with climate change actions and measures to reduce emissions at a level consistent with a below 2°C pathway. It is also the result of the assumption that diversification in energy-exporting developing countries is implemented on a gradual basis; while considering additional production options without introducing any reduction in oil production. It means the energy market is not affected by a shock owing to sudden energy supply changes.

9.3.4 Socio-economic impacts

Given that the implementation of stringent climate change actions and measures could have disproportionately adverse impacts on the economies of energy-exporting developing countries, there is a strong case for measures that could offset negative impacts. Economic diversification in these countries is one potential option.

Figure 9.6 shows the estimated percentage changes in GDP for selected energy-exporting developing countries under Scenarios B and C, as well as Sensitivity Ca. It is evident that GDP is expected to decrease under Scenario B by 4.5% in 2030 and 7% in 2040, compared with 4.9% and 7.3% under Scenario A – below 2°C. Under Scenario C, the negative implications on the energy-exporting developing countries' GDP are further reduced, as GDP reductions are 3.6% in 2030 and 5.7% in 2040. Economic diversification supported by increased FDI and labour productivity (Sensitivity Ca) could help alleviate, at a higher level, the potential adverse economic impacts. However, taken together these measures are still not sufficient to fully mitigate the adverse impacts of climate change actions and measures in line with a below 2°C pathway. Even in the best-case scenario, the losses in the economies of energy-exporting developing countries remain much higher than the global average reduction in GDP – these losses are estimated at 3.1% and 2.9% in 2040 under Scenario C and Sensitivity Ca, respectively.

Figure 9.6
Percentage change in selected energy-exporting developing countries' GDP compared to the Reference Case



Source: OPEC.

Economic diversification could also reduce the negative effects on employment for energy-exporting developing countries resulting from global stringent climate change actions. Diversification within the energy sector could create new jobs in the electricity sector, whereas a focus on investment in education and training in Scenario C could create high-value jobs in the education sector.

Moreover, an increase in manufacturing exports (or fewer imports) could create manufacturing jobs in specific export industries. The development of new domestic industries, for example, through tourism, is more likely to create jobs in services sectors, such as retail. The exact choice of sectors, however, will depend on the specific advantages of each country.

It should be finally noted that emission reductions under these cases would be similar to those achieved in the below 2°C Scenario, but energy-exporting developing countries' losses would also be less than in below 2°C Scenario.

9.4 Economic diversification in OPEC Member Countries

In terms of OPEC Member Countries specifically, most of the known proven crude oil reserves, almost 80% of the global total, are contained in OPEC Member Countries. Based on the latest available data, about 42% of the world's crude oil production originates from OPEC economies. Natural gas fields have been exploited too; with OPEC Member Countries currently accounting for 35.8% of global proven natural gas reserves, and for more than 16% of the global marketed production of natural gas.

Subsequently, OPEC economies are all heavily dependent on natural resources. For instance, in all OPEC economies, except the UAE, oil is the main export commodity (Table 9.4). The share of oil in the value of total exports hovered around 73% and 54%, in 2010 and 2018, respectively. Oil currently accounts on average for above 20% of the GDP value in OPEC Member Countries as a group, albeit with significant discrepancies among OPEC economies. For example, oil accounts for more than 40% of the value of GDP in Equatorial Guinea, Republic of the Congo and Kuwait; while it accounts for less than 15% of the value of GDP in Ecuador, Nigeria and IR Iran.

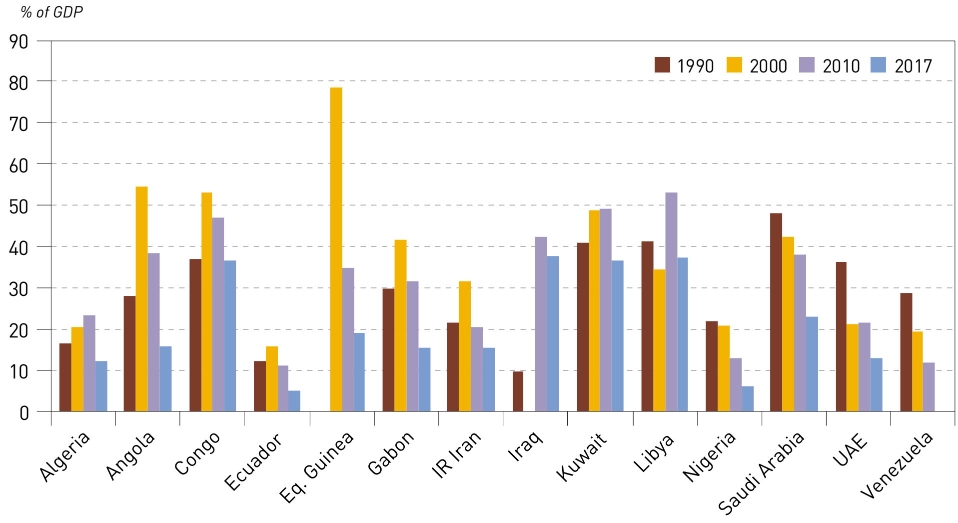
Table 9.4
Petroleum exports from OPEC Member Countries, 2010 and 2018

Value of petroleum exports	*$ billion*		*% GDP*		*% total exports*	
	2010	**2018**	**2010**	**2018**	**2010**	**2018**
Algeria	38.2	26.1	23.7	14.6	61.7	59.1
Angola	49.4	36.3	58.9	36.6	97.6	89.1
Congo	8.4	4.5	69.9	43.8	98.4	45.2
Ecuador	9.7	9.9	13.9	9.5	49.9	40.4
Equatorial Guinea	9.3	5.4	56.9	49.3	92.8	97.5
Gabon	6.2	4.2	43.1	24.5	89.3	64.8
IR Iran	72.2	60.2	14.8	14.4	60.8	56.0
Iraq	51.6	68.2	37.2	32.1	98.3	71.6
Kuwait	61.8	58.4	53.5	41.2	92.0	81.2
Libya	47.3	17.1	62.4	34.5	96.6	69.1
Nigeria	67.0	54.5	18.5	13.1	83.2	86.5
Saudi Arabia	214.9	194.4	40.8	24.8	85.6	66.0
UAE	74.6	74.9	25.8	18.1	35.0	19.3
Venezuela	62.3	34.7	21.2	35.2	93.2	99.1
OPEC	772.8	648.7	29.2	22.0	73.1	53.6

Source: OPEC.

Moreover, OPEC exports of crude oil and petroleum products have grown over the last few decades, so that OPEC currently exports about 29 mb/d, but as a percentage of the global total the level has dropped. In 1990, crude oil and petroleum product exports of OPEC Member Countries constituted more than 44% of the global total, whereas in 2018 the figure was about 38%. Oil rents also correspond to an average of about 21% of OPEC economies' GDP; with export revenues from oil being estimated at a level of almost $650 billion in 2018 (Figure 9.7).

Figure 9.7
Oil rents



Source: World Bank.

As a result, OPEC economies have a relatively homogenous export portfolio, being reliant on exports from a single commodity, whose market structure and geopolitics incorporate a high-level of uncertainty. The contribution of manufacturing sectors has been rather low in all OPEC economies, other than Algeria, whose share in GDP has also seen a declining trend over time. The agricultural sector has a relatively small and declining share in OPEC economies' GDP; whereas, the value added of services appears to have an increasing GDP share.

In addition, the dependence of OPEC economies on the rest of the world for a significant number of products and services is reflected in the increasing trend of total imports to meet domestic demand. The evolution of trade flows also indicates the challenges created by the perceived vulnerabilities inherent in natural resource based economies. OPEC economies need therefore to be sufficiently diversified to address economic challenges created by their dependence on natural resources.

In terms of FDI, it should be further noted that in 2017 OPEC economies received 1.2% of the global total, while investments made by OPEC economies abroad accounted for 2.4% of global FDI. Moreover, the share of FDI inflows for OPEC Member Countries has been declining in recent years, as in 2010 this region received 4.5% of global investments. On the contrary, FDI outflows originating from OPEC economies were 1.6% of the global total in 2010. Respectfully, the share of foreign inflows in OPEC economies' GDP was at the level of only 0.5% in 2017, having fallen since 2010 when it was more than 2%. On the other hand, the share of outflows was estimated at 1.2% in 2017 compared with 0.8% a decade before.

Therefore, inward flows of FDI have been trending downward ever since 2010. There was also a downturn in outward FDI flows, but in recent years the net result is that outward flows have been higher than inward flows. The decline in FDI flows into developing countries is a worldwide trend that has taken shape as developed countries repatriate production operations, partially because of changing sentiments about global trade and production, and partially because of technological changes and increased competitiveness. In the case of OPEC economies, in particular, the decline in inflows of FDI is also due to the fact that investment in natural resource sectors has faltered in recent years.

Another important feature of OPEC Member Countries is the age of their population. The annual growth rate of OPEC economies' population has remained higher than 2% over the last decades. Population increased by approximately 2.2% p.a. between 2010 and 2017, compared with a 2.8% increase of OPEC economies' labour force. In addition, young citizens under the age of 30 represented about 60% of their total population in 2017.

However, it should be stressed that with a fast growing population over the past decades, combined with insufficient diversification, OPEC economies' GDP per capita has stagnated. In fact, OPEC economies' GDP per capita has seen a declining trend over the last few years. The income available per capita in 2017 is eight pp lower that what it was in 2010, partly because the overall population has increased from almost 424 million in 2010 to 496 million in 2017. At the same time, the rate of unemployment remains higher than the world average. Therefore, new sources of rents are required to sustain prosperity in countries with expanding populations.

In regard to the economic diversification aspects, the figures related to the four indexes have already been described for OPEC Member Countries and other major economies worldwide. For instance, the *Herfindahl Index* decreased for OPEC economies over time. In general, OPEC Member Counties seem to show diversification trends similar to other energy-exporting countries, yet progress lags behind. They underperform other natural resource based economies, with their GDP and exports being more concentrated and less diversified.

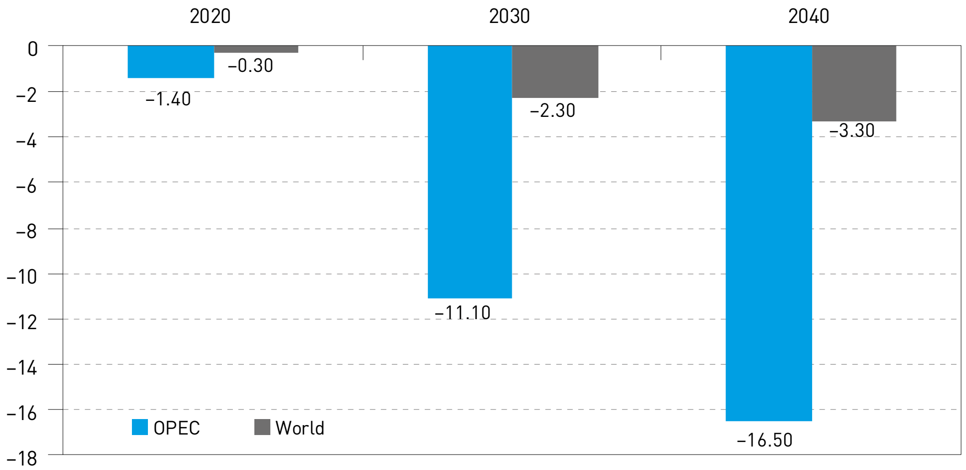
The diversification and complexity of OPEC economies' structure remains low, yet economic diversification is at the centre of multi-year development plans in OPEC Member Countries. OPEC countries' strategy has been focused on the diversification of the national economy and increased investment in not only energy, but also advanced manufacturing industries, tourism, transportation and innovation. Some countries are seeking to become knowledge-based economies, while some are already benefitting from the diversification of their economies by becoming manufacturing and logistics hubs, developing economic cities and creating industrial clusters. Some countries also have ambitious targets for economic diversification, in regards to lowering the share of the energy sector in total economic activity, while increasing the contributions of other sectors, including services.

OPEC Member Countries' development plans may differ in substance, but they all emphasize new economic activities and the private sector as engines of sustainable growth and development in the future of these economies. In this context, economic diversification is not only the cornerstone of their strategy and a key goal pursued by the leadership, but is also conceived as a vehicle for the achievement of their sustainable development. Thus, OPEC Member Countries pursue diversification measures and engage in activities that could enable increased exports, stimulating their economies to diversify.

However, stringent mitigation pathways and the implementation of associated policies could adversely affect OPEC economies. More specifically, the reduction of OPEC Member Countries' GDP is large under Scenario A compared with the overall effect of the global economy. As illustrated in Figures 9.8 and 9.9, the reduction of OPEC Member Countries' GDP could be 11.1% in 2030 compared with a less than 2.5% decrease in global GDP. In 2040, the respective GDP reductions are at a level of 16.5% and 3.3%.

It is, therefore, evident that OPEC Member Countries could face large adverse impacts arising from the implementation of enhanced climate action that is consistent with a below 2°C pathway. Considering Scenario B and Scenario C, as well as Sensitivity Ca, Figures 9.8 and 9.9 indicate that GDP impacts in OPEC Member Countries are estimated to be negative through the projection period. However, the magnitude of the negative impact differs substantially between scenarios, showing the possible mitigating effect of targeted economic diversification policies.

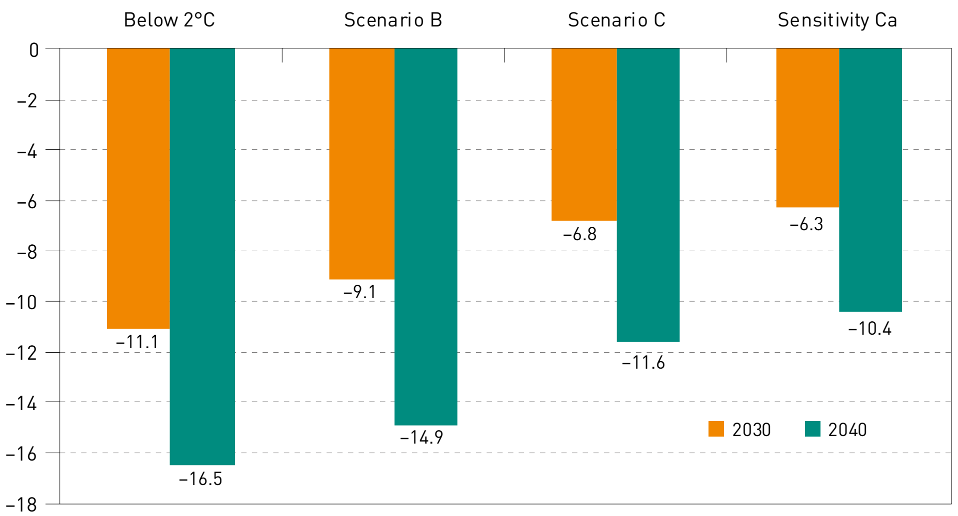
Figure 9.8
Impact on GDP in below 2°C scenario*



* *% difference from Reference Case*

Source: OPEC.

Figure 9.9
Percentage change in OPEC economies' GDP compared to the Reference Case



Source: OPEC.

Scenario B reduces the negative GDP impact by about two percentage points by 2030 and by about 1.5 percentage points by 2040. Going further, the non-economy sectors (Scenario C) could provide a further reduction, namely an additional 2.3 pp by 2030 and 3.3 pp by 2040. Implementing the measures contained in both scenarios and assuming foreign support (Sensitivity Ca) could lead to a substantial reduction of GDP losses. The 16.5% loss of GDP due to the impacts of Scenario A could be reduced by 6 pp by 2040.

In regard to employment impacts, the time profile of the job losses in OPEC economies is similar to that for GDP, with a gradually increasing reduction of losses over time. The reductions in employment under Scenario A occur in most economic sectors, not only in the energy sector.

It is notable that employment does not increase by much in Scenario B compared to Scenario A. The reason for this is that the types of activities being promoted in Scenario B are not typically labour-intensive and therefore do not lead to much additional job creation. Scenario C offers better outcomes, because the sectors targeted in this scenario are more labour-intensive. In this scenario, there is some recovery in employment across the OPEC Member Countries' economies, both in the targeted sectors and more widely from indirect effects. Sensitivity Ca has the largest positive effects (compared to Scenario A) because the inflow of FDI allows additional jobs to be created in investment-intensive sectors, such as construction. Nevertheless, it should be emphasized that the employment effects remain negative in all cases and even in the sensitivity the loss of employment is substantial.

9.5 Conclusion

For OPEC Member Countries and other energy-exporting developing countries that rely on revenues from natural resources, the imperative need to reorient their economies is growing, owing mainly to an emerging stringent regulatory framework on climate change action and the associated adverse impacts of response measures. Achieving diversification is considered vital for the long-term economic sustainability of their economies.

The notion of economic diversification has conventionally described a strategy to transform the economy from using a single resource, or a relatively narrower set of income sources, into one based on multiple sources of income or a considerably broader variety of new and emerging economic sectors. Such a diversification pathway or strategy may be driven by various motivations, with the key objective being to boost economic performance along with sustainable growth.

Analysis shows that there is no one-size-fits-all policy prescription for economic diversification efforts. There exists no universal guidance for countries to proceed with a sustainable pathway of successful economic diversification and growth. Yet, the diversification of exports is perceived as essential for economic prosperity.

Natural resource based economies could achieve economic diversification depending, for instance, on their ability to move into advanced technological areas. Innovation in products and services is a complex process that requires coordinated policies, enhanced capabilities and knowledge. Yet, countries could pursue different mechanisms for diversification, based on underlying factors, national circumstances and priorities. Some of these factors include the level of dependence on natural resources, institutional arrangements, and the involvement of government in creating pathways for diversification and growth, and economic determinants that enhance the ease of doing business and advancing competitiveness.

In light of what has been described, policymakers could pursue policies and action that extend existing capabilities into industries of higher added value and complexity. Extending the value chain within the energy sector could also generate different types of jobs, including in the service sector, such as logistics and trading, and supporting services, such as accounting, finance and human resource management. These could also surge sectoral growth, as well as labour and capital mobility, resulting in higher productivity levels that could translate to increased diversification.

Concurrently, the quality of institutions, access to finance, promotion of investments, high-quality human capital, physical infrastructure, and collaborative approaches are critical determinants of cultivating a vibrant economic environment and a successful diversification process. Having a multitude of different resources, natural resource based economies could also use their comparative advantage and diversify production and exports within the natural resources sector. OPEC Member Countries and other energy-exporting developing countries considered in this analysis hold a comparative advantage in oil and gas production. They could therefore tailor their economies to the natural resources sector and approach their own diversification in the context of the value chain of energy products driven by technological advancement.

However, it should be stressed that energy-exporting developing countries, including OPEC Member Countries, are heterogeneous and their economies could diversify in different ways with some being more adaptable and competitive than they were some years ago.

The scenario analysis indicates economic diversification within the energy sector or supported by increased (foreign) investment and labour productivity in other economic sectors could help alleviate the potential adverse economic impacts of response measures. However, such efforts would not be sufficient to fully mitigate the adverse impacts of a stringent regulatory framework consistent with a below 2°C pathway.

To this end, policies and measures implemented to enhance UNFCCC Parties' contributions to tackle climate change create challenges for energy-exporting developing countries, owing to actions related to the energy transition. Energy-exporting developing countries could consider diversifying to thrive, including within the energy sector, yet benefits generated by economic diversification would not compensate them for the adverse impacts from which their economies would suffer.

Governments could play a key role in regard to the extent of the mentioned adverse impacts. The role of international cooperation should also be highlighted, as it could contribute to the identification and sharing of best practices and experiences of countries that have successfully diversified their economies. Non-domestic barriers could also be identified, such as trade barriers, along with ways in which the international community could facilitate increased foreign investment and support in the form of technology transfer and financial support.

Annex A
Abbreviations

A/C	Air conditioning
ADB	Asian Development Bank
AFVs	Alternative Fuel Vehicles
AI	Artificial Intelligence
ANWR	Alaskan National Wildlife Refuge
b/d	Barrels per day
BEV	Battery electric vehicles
boe	Barrels of oil equivalent
BoJ	Bank of Japan
bt	Billion tonnes
CAAC	Civil Aviation Administration of China
CAFE	Corporate Average Fuel Economy
CCGT	Closed-cycle gas turbine
CCP	Combined cycle power
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CGD	City Gas Distribution
CHP	Combined heat and power
CNG	Compressed natural gas
CNMC	Comisión Nacional de Mercados y la Competencia
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO_2	Carbon dioxide
COP	Coefficient of Performance
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COTC	Crude Oil to Chemicals Complex
CPC	Caspian Pipeline Consortium
CPP	Clean Power Plan
CSP	Concentrated solar power
CTLs	Coal-to-liquids
dwt	Dead weight ton
E&P	Exploration and production
ECAs	Emission Control Areas
ECB	Energy Information Administration (US)
ECI	Economic Complexity Index
EEDI	Energy Efficiency Design Index
EIA	Energy Information Administration (US)
EISA	Energy Independence and Security Act (US)
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency (US)
ESPO	Eastern Siberia-Pacific Ocean
ETM	End of tax manoeuvre
ETS	Emissions trading system
EU	European Union
EVs	Electric vehicles
FCC	Fluid catalytic cracking
FCVs	Fuel cell vehicles
FDI	Foreign direct investment
Fed	US Federal Reserve
FHCs	Fluorinated hydrocarbons

A

FIDs	Final investment decisions
FPSO	Floating production, storage and offloading
GDP	Gross Domestic Product
GFEI	Global Fuel Economy Initiative
GHG	Greenhouse gas
GMBM	Global market-based measure
Gt	Gigatonnes
GTLs	Gas-to-liquids
GW	Gigawatt
HEV	Hybrid electric vehicle
HHI	Herfindahl-Hirschman Index
HSFO	High sulphur fuel oil
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
ICCT	International Council on Clean Transportation
IMO	International Maritime Organization
IMF	International Monetary Fund
ITC	Investment tax credit
IT	Information technology
kn	Knot
km/h	Kilometre per hour
kWh	Kilowatt hour
LCOE	Levelized cost of energy
LNG	Liquefied natural gas
LOOP	Louisiana Offshore Oil Port
LPG	Liquefied petroleum gas
LSFO	Low sulphur fuel oil
MATS	Mercury and Air Toxics Standards
mb/d	Million barrels a day
mboe/d	Million barrels of oil equivalent a day
MEPC	Marine Environment Protection Committee
MGO	Marine gasoil
MJ	Megajoule
MMBTU	Million British Thermal Unit
mpg	Miles per gallon
mt	Million tonnes
MTBE	Methyl tertiary butyl ether
mtpa	Metric tonnes per annum
MW	Megawatt
MY	Model years
NAFTA	North American Free Trade Agreement
NDCs	Nationally determined contributions
NDRC	National Development and Reform Commission
NECPs	National Climate and Energy Plans
NGLs	Natural gas liquids

NGVs	Natural gas vehicles
NHTSA	National Highway Traffic and Safety Administration
NMOG	Non-methane organic gas
NO_x	Nitrogen oxide
NPRA	National Petroleum Reserve in Alaska
OECD	Organisation for Economic Co-operation and Development
ORC	Organic Rankine Cycle
p.a.	Per annum
Pemex	Petróleos Mexicanos
PHEV	Plug-in hybrid electric vehicles
pp	Percentage point
PPP	Purchasing power parity
PTL	Power-to-liquid
PV	Photovoltaic
R&D	Research & Development
REN	Renewable Energy Policy Network
RFS	Renewable Fuel Standard
RINs	Renewable Identification Numbers
rpm	Revolutions per minute
SAF	Sustainable alternative fuels
SAFE	Safer Affordable Fuel-Efficient
SDG	Sustainable Development Goals
SMRs	Small modular reactors
SO_2	Sulphur dioxide
SO_x	Sulphur oxide
SPR	Strategic Petroleum Reserve
STI	Science, technology and innovation
SUVs	Sports utility vehicles
TAN	Total Acid Number
TAPS	Trans-Alaska Pipeline System
tb/d	Thousand barrels a day
ULS	Ultra-low sulphur
UN	United Nations
UNFCCC	United Nations Framework Convention of Climate Change
VGO	Vacuum gasoil
VLCCs	Very large crude carriers
VMT	Vehicle miles travelled
WCS	Western Canadian Select
WCSB	Western Canadian Select Basin
Wh/kg	Watt hour per kilogramme
WHR	Waste Heat Recovery
WLTP	World Harmonised Light Vehicle Test Procedure
y-o-y	Year-on-year
ZLEV	Zero- and low-emission vehicles

Annex B
OPEC World Energy: definitions of regions

OECD

OECD Americas
Canada
Chile
Guam
Mexico
Puerto Rico
United States of America
United States Virgin Islands

OECD Europe
Austria
Belgium
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Latvia
Lithuania
Luxembourg
Netherlands
Norway
Poland
Portugal
Slovakia
Slovenia
Spain
Sweden
Switzerland
Turkey
United Kingdom

OECD Asia Oceania
Australia
Japan
New Zealand
OECD Asia Oceania, Other
Republic of Korea

NON-OECD COUNTRIES

Latin America
Anguilla
Antigua and Barbuda
Argentina
Aruba
Bahamas
Barbados
Belize
Bermuda
Bolivia (Plurinational State of)
Brazil
British Virgin Islands
Cayman Islands
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
El Salvador
French Guiana
Grenada
Guadaloupe
Guatemala
Guyana
Haiti
Honduras
Jamaica
Martinique
Montserrat
Netherlands Antilles
Nicaragua
Panama
Paraguay
Peru
St. Kitts and Nevis
St. Lucia
St. Pierre et Miquelon
St. Vincent and the Grenadines
Suriname
Trinidad and Tobago
Turks and Caicos Islands
Uruguay

Middle East & Africa
Bahrain
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Cape Verde
Central African Republic
Chad
Comoros
Côte d'Ivoire
Democratic Republic of the Congo
Djibouti
Egypt
Eritrea
eSwatini
Ethiopia
Gambia
Ghana
Guinea
Guinea-Bissau
Jordan
Kenya
Lebanon
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mayotte
Morocco
Mozambique
Namibia
Niger
Oman
Qatar
Réunion
Rwanda
São Tomé and Principe
Senegal
Seychelles
Sierra Leone
Somalia
South Africa
South Sudan
Sudan
Syrian Arab Republic
Togo
Tunisia
Uganda
United Republic of Tanzania
Western Sahara
Yemen
Zambia
Zimbabwe

INDIA
India

CHINA
People's Republic of China

Other Asia
Afghanistan
American Samoa
Bangladesh
Bhutan
Brunei Darussalam
Cambodia
China, Hong Kong SAR
China, Macao SAR
Cook Islands
Democratic People's Republic of Korea
Fiji
French Polynesia
Indonesia
Kiribati
Lao People's Democratic Republic
Malaysia
Maldives
Micronesia (Federated States of)
Mongolia
Myanmar
Nauru
Nepal
New Caledonia
Niue
Pakistan
Papua New Guinea
Philippines
Samoa
Singapore
Solomon Islands
Sri Lanka
Thailand
Timor-Leste
Tonga
Vanuatu
Viet Nam

OPEC
Algeria
Angola
Republic of Congo
Ecuador
Equatorial Guinea
Gabon
IR Iran
Iraq
Kuwait
Libya
Nigeria
Saudi Arabia
United Arab Emirates
Venezuela

EURASIA

Russia
Russian Federation

Other Eurasia
Albania
Armenia
Azerbaijan
Belarus
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Georgia
Gibraltar
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Malta
Montenegro
Republic of Moldova
Romania
Serbia
Tajikistan
Republic of North Macedonia
Turkmenistan
Ukraine
Uzbekistan

Annex C
World Oil Refining Logistics and Demand: definitions of regions

US & CANADA

United States of America
Canada

LATIN AMERICA

Greater Caribbean

Anguilla
Antigua and Barbuda
Aruba
Bahamas
Barbados
Belize
Bermuda
British Virgin Islands
Cayman Islands
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
Ecuador
El Salvador
French Guiana
Grenada
Guadeloupe
Guatemala
Guyana
Haiti
Honduras
Jamaica
Martinique
Montserrat
Netherlands Antilles
Nicaragua
Panama
Puerto Rico
St. Kitts & Nevis
St. Lucia
St. Pierre et Miquelon
St. Vincent and The Grenadines
Suriname
Trinidad and Tobago
Turks And Caicos Islands
United States Virgin Islands
Venezuela, Bolivarian Republic of

Mexico

Mexico

Rest of South America

Argentina
Bolivia (Plurinational State of)
Brazil
Chile
Paraguay
Peru
Uruguay

AFRICA

North Africa/Eastern Mediterranean

Algeria
Egypt
Lebanon
Libya
Mediterranean, Other
Morocco
Syrian Arab Republic
Tunisia

West Africa

Angola
Benin
Cameroon
Republic of Congo
Côte d'Ivoire
Democratic Republic of Congo
Equatorial Guinea
Gabon
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
Senegal
Sierra Leone
Togo

East/South Africa

Botswana
Burkina Faso
Burundi

Cape Verde
Central African Republic
Chad
Comoros
Djibouti
Eritrea
eSwatini
Ethiopia
Gambia
Kenya
Lesotho
Madagascar
Malawi
Mauritius
Mayotte
Mozambique
Namibia
Réunion
Rwanda
São Tomé and Principe
Seychelles
Somalia
South Africa
South Sudan
Sudan

Uganda
United Republic of Tanzania
Western Sahara
Zambia
Zimbabwe

EUROPE

North Europe
Austria
Belgium
Denmark
Finland
Germany
Iceland
Ireland
Luxembourg
Netherlands
Norway
Sweden
Switzerland
United Kingdom

South Europe
Cyprus
France
Gibraltar
Greece
Italy
Malta
Portugal
Spain
Turkey

Eastern Europe
Albania
Belarus
Bosnia and Herzegovina
Bulgaria
Croatia
Czech Republic
Estonia
Hungary
Latvia
Lithuania
Montenegro
Poland
Republic of Moldova
Romania
Serbia
Slovakia
Slovenia
Republic of North Macedonia
Ukraine

RUSSIA & CASPIAN

Caspian Region
Armenia
Azerbaijan
Georgia
Kazakhstan
Kyrgyzstan
Tajikistan
Turkmenistan
Uzbekistan

Russia
Russian Federation

MIDDLE EAST

Bahrain
IR Iran
Iraq
Jordan
Kuwait
Oman
Qatar
Saudi Arabia
United Arab Emirates
Yemen

ASIA-PACIFIC

Pacific Industrialized
Australia
Japan
New Zealand

Pacific High Growth
Brunei Darussalam
Indonesia
Malaysia
Philippines
Republic of Korea
Singapore
Thailand

China
People's Republic of China

Rest of Asia
Afghanistan
American Samoa
Bangladesh
Bhutan
Cambodia
Cook Islands
Fiji
French Polynesia
Guam
India
Democratic People's Republic of Korea
Kiribati
Lao People's Democratic Republic
Maldives
Micronesia, Federated States of
Mongolia
Myanmar
Nauru
Nepal
New Caledonia
Niue
Pakistan
Papua New Guinea
Samoa
Solomon Islands
Sri Lanka
Timor-Leste
Tonga
Vanuatu
Viet Nam

Annex D
Major data sources

Advanced Resources International Inc.
Africa Energy Portal
Africa Progress Panel
African Union
Airbus
American Chemical Society (ACS)
American Petroleum Institute (API)
Argus
Asia-Pacific Economic Cooperation (APEC)
Asian Development Bank (ADB)
Baker Hughes, a GE company
Barclays Research
Bloomberg
Boeing
BP Statistical Review of World Energy
Brazil, Ministry of Mines and Energy
Brookings Institute
Bunkerworld
Cambridge Econometrics
Canada, National Energy Board
Canadian Association of Petroleum Producers
Canadian Energy Research Institute
Carbon Tracker Initiative
Center for Strategic and International Studies (CSIS)
Chile, Prensa Presidensia
China National Petroleum Corporation (CNPC)
Citigroup
Cleantechnica
Climate Action Tracker
Coaltrans Conferences
Consensus forecasts
Deloitte
Deutsche Bank
E&P Magazine
East African Community
The Economist
Economist Intelligence Unit online database
Energy Research Institute of the Russian Academy of Sciences (ERI RAS)
Energy Intelligence Group
Energy Sage
EnSys Energy & Systems, Inc
Equinor
Ernst & Young
Euractiv
EUREL
European Automotive Manufacturers Association
European Commission (EC)
European Council
European Environment Agency
European Parliament
Eurostat
Evaluate Energy
Financial Times
Forbes

A

Global Commission on the Economy and Climate
Global Wind Energy Council
Goldman Sachs
Green Climate Fund (GCF)
GSMA Intelligence
Harvard Business Review
Haver Analytics
HSBC
Hydrocarbon Processing
International Commodities Exchange
IEA Monthly Oil Data Service (MODS)
IEA Oil Market Report
IEA World Energy Outlook
IHS Markit
IMF, Direction of Trade Statistics
IMF, International Financial Statistics
IMF, Primary Commodity Prices
IMF, World Economic Outlook
India, Ministry of Finance
India, Ministry of Petroleum & Natural Gas
India, Ministry of Power
Indian Institute of Technology, Kanpur
Institute of Energy Economics, Japan (IEEJ)
Institut Français du Pétrole (IFP)
Interfax Global Energy
Intergovernmental Panel on Climate Change (IPCC)
International Air Transport Association (IATA)
International Association for Energy Economics (IAEE)
International Atomic Energy Agency (IAEA)
International Civil Aviation Organization (ICAO)
International Council on Clean Transportation (ICCT)
International Maritime Organization (IMO)
International Monetary Fund (IMF)
International Renewable Energy Agency (IRENA)
International Road Federation, World Road Statistics
International Union of Railways (UIC)
Japan, Ministry of Economy, Trade and Industry (METI)
Japan Automobile Manufacturers Association, Inc (JAMA)
Joint Aviation Authority (JAA)
Joint Organisations Data Initiative (JODI)
Journal of Petroleum Technology
Lazard
McKinsey Global Institute
National Development and Reform Commission (NDRC)
National Energy Administration of the People's Republic of China (NEA)
National Renewable Energy Laboratory
Natural Gas World Magazine
Nexant
New York Mercantile Exchange
Nuclear Energy Institute (NEI)
OECD Trade by Commodities
OECD/IEA, Energy Balances of non-OECD countries
OECD/IEA, Energy Balances of OECD countries
OECD/IEA, Energy Statistics of non-OECD countries

OECD/IEA, Energy Statistics of OECD countries
OECD/IEA, Quarterly Energy Prices & Taxes
OECD, International Trade by Commodities Statistics
OECD International Transport Forum, Key Transport Statistics
OECD, National Accounts of OECD Countries
OECD Economic Outlook
Oil & Gas Journal
OPEC Annual Statistical Bulletin (ASB)
OPEC Fund for International Development (OFID)
OPEC Monthly Oil Market Report (MOMR)
Orgalim
Oxford Economics
Oxford Institute for Energy Studies
Petrobras
Petroleum Economist
Petroleum Intelligence Weekly
Platts
Power Technology – Verdict Media
PricewaterhouseCoopers
REC Solar
Refinitiv
REN21 – Global Status Report 2017
Renewable Energy World
Reuters
Rystad Energy
Seatrade
Siemens AG
Society of Petroleum Engineers (SPE)
South China Morning Post
Sustainable Energy for All
The Economic Times
Trading Economics
Turner Mason and Company
UK.gov
UN Department of Economic and Social Affairs
UN Energy Statistics
UN Food and Agriculture Organization (FAO)
UN International Trade Statistics Yearbook
UN National Account Statistics
UN Conference on Trade and Development (UNCTAD)
UN Development Programme (UNDP)
UN Economic and Social Commission for Asia and the Pacific (UNESCAP)
UN Educational, Scientific and Cultural Organization (UNESCO)
UN Environment Programme (UNEP)
UN Framework Convention on Climate Change (UNFCCC)
UN International Labour Organisation (ILO)
UN Statistical Yearbook
US Bureau of Labor Statistics
US Department of Energy (DoE)
US Department of the Interior (DoI)
US Energy Information Administration (EIA)
US Environmental Protection Agency (EPA)
Wall Street Journal
Wood Mackenzie

World Bank
World Coal Association
World Coal Institute
World Economic Forum
World Energy Council
World Nuclear Association
World Resources Institute
World Trade Organization (WTO), International Trade Statistics
Xinhua

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