equinor

Energy Perspectives 2019

Long-term macro and market outlook

Welcome to Equinor's Energy Perspectives 2019

I am frequently asked about my view on how the global energy system will develop, and even more frequently about where I think oil, gas, electricity and CO_2 prices will move over the short and long term. In Equinor we try to base our views on as many sources of information as possible, focusing on the potential effects of changes in market fundamentals and developments in technology, policy, resource availability and consumer behaviour.

The future of energy is uncertain. And the question of how to respond does not have one single answer. Uncertainties call for the use of scenarios, describing how policy, technology and market conditions can move developments in very different directions, both desired and undesired. That is what Equinor's Energy Perspectives 2019 aims to describe.

It seems certain that demand for goods, services and activities that require energy in their production or consumption will continue to increase, driven by population growth and improved living standards. The challenge energy companies and the global society is faced with through the Paris Agreement (article 4.1) is formidable and unparalleled in human history: To sufficiently rapidly transform the global energy system "on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty."

Equinor's vision is to shape the future of energy. We are developing toward a broad energy company, producing oil and gas with lower emissions while building a strong position within new energy solutions. Our strategy is: Always safe, High value and Low carbon. To succeed, we must have a robust approach to the opportunities and challenges that come our way. The analysis in this report is important input to our strategic priorities, but does not reflect our views and strategy. We want the global energy mix to transform in a sustainable direction, and we want to take part in the shaping of such a future.

With this 9th edition of Energy Perspectives our analysts again provide important insight. The only certainty is the uncertainty of the future, and we do not claim to hold the truth. We welcome engagement and debate. I hope the report will be as useful to your work as it is to mine.

Eldar Sætre
President and CEO

Executive summary

In what direction will global energy markets develop towards 2050? This is a crucially important question, not only for energy companies. The answer to this question will give profound signals on the chances of securing a sustainable development, as defined e.g. by the 17 Sustainable Development Goals. Recent signals show that possible combinations of important drivers such as economic and demand growth, energy efficiency, climate policy cooperation, technology development and geopolitics could result in very different development paths for global energy markets over the next decades. This 9th edition of Energy Perspectives aims to provide the reader with a helicopter perspective on possible macroeconomic and global energy market developments towards 2050, analysing relevant trends, energy sources, sectors and regions across three very different scenarios, called *Reform, Renewal and Rivalry.*

The scenarios are stories of the future that illustrate the very large future outcome space for energy markets. Two of the scenarios, *Reform and Rivalry*, illustrate where the world may move if current energy market, macroeconomic and geopolitical developments are not significantly changed. *Reform* represents a future driven by technology development and benign market forces, supported by gradually tightened energy and climate policies. *Rivalry* describes a future where the energy transition is slowed by lack of trust, significant geopolitical volatility and ineffective solutions to common challenges, like today. *Renewal,* on the other hand, shows where the energy markets need to go to contribute to a sustainable future. *Renewal* is driven by rapid and significant energy and climate policy tightening, global political cooperation, and fast technology change, delivering a path that keeps global energy-related carbon emissions consistent with the well below 2° target established in the Paris Agreement.

What is new in Energy Perspectives 2019? In addition to what follows from updated historical figures and revised assumptions on key input parameters such as economic growth and energy intensity, the description of *Renewal* is enriched with two sensitivities. The first one is centred around the direction in IPCC's 1.5° report, while the second one illustrates the effects of delaying policy action on climate to 2025. It is also illustrated how Renewal depends on a crucial combination of simultaneous changes in energy intensity, fuel mix and carbon capture, utilisation and storage (CCUS) developments. The potential impacts of hydrogen are quantified and visualised in an illustrative pathway to the *Renewal* framework. Finally, new perspectives are put forward for crude oil qualities, driven by different levels of oil demand and different supply mix in the three scenarios.

The challenges of satisfying global energy demand in a sustainable manner are vast and multifaceted. Leaders of nations, businesses and civil society are trying to make choices today, facing unknown futures. Doing so requires an informed debate and dialogue across many scenarios. I hope that Energy Perspectives 2019 will contribute to these discussions of possible energy futures.

Eirik Wærness

Senior vice president and Chief economist

The energy world in 2050

2.0-2.2 x

Size of the global economy, compared to 2018

29-49%

Share of solar and wind in global electricity generation, up from 7% in 2018

3,200-4,800 Bcm

Global gas demand, compared to 3,900 bcm in 2018

10-36 Gt

Global energy-related CO_2 emissions, compared to 33.1 Gt in 2018

0.6-1.3 Billion

Electric vehicles on the road, equivalent to 30% - 90% of the total LDV fleet

52-118 mbd

Global oil demand, compared to 99 mbd in 2018

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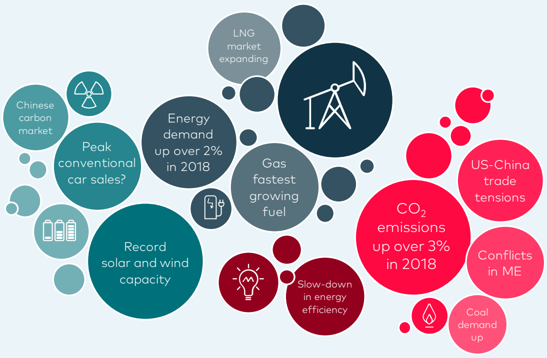
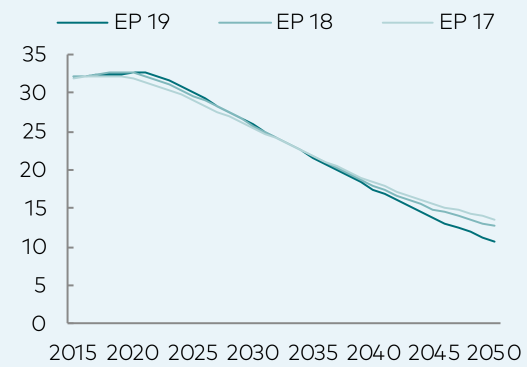
Recent signposts show diverging paths



Source: Equinor

Change in energy-related carbon emission trajectories in Renewal over time
Gt



Source: Equinor

UN Sustainable Development Goals

Source: UN

Context and uncertainties

The world can move in very different directions

This report presents three very different stories about the future. They are all possible development paths for the global economy and global energy markets. They all start at the same point of departure, but are based on very different assumptions on economic growth, technology development and energy and climate policies. Only one of the scenarios, *Renewal*, represents a sustainable path in terms of delivering on both economic growth and emission reductions. Unfortunately, this fact and the fact that this would be a desired outcome compared to the other scenarios, are not a guarantee that the world will develop according to the pathway described in *Renewal*. The challenges involved in delivering on *Renewal* are enormous, and the other alternatives presented in this report must therefore also be kept in mind and serve as a basis for robust strategies for companies, consumers and countries. In the following, some of the uncertainties associated with delivering on *Renewal* are described, while the descriptions of all the three scenarios; *Reform, Renewal* and *Rivalry*, are presented in the next chapter.

CO_2 emissions - Chasing a moving target

Global energy-related CO_2 emissions reached a historic high in 2018 and point to the challenge of satisfying growing energy demand and other important policy goals while reducing emissions. The more we use of the carbon budget – a finite amount of CO_2 that humans can emit on a net basis to stay on a sustainable path – the less we have left in the future. *Renewal* is based on a carbon budget to 2050 that is consistent with the goal of the Paris Agreement of limiting global warming to well below 2°. As time goes by without emissions starting to decline, the future path for CO_2 emission reductions in *Renewal* will become steeper, and the absolute CO_2 emission level in 2050 the world can allow itself will become lower. The world will continue to chase a moving target until it manages to stabilise and start reducing CO_2 emissions.

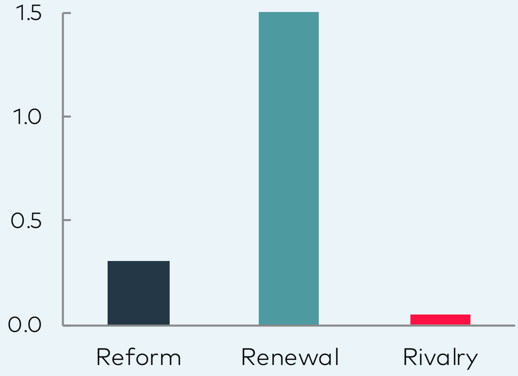
An energy transition or energy addition?

The world is changing and will become more electrified as many end-uses of energy increasingly switch to electricity, particularly in road transport. More of global electricity demand will be met from renewables, relying relatively less on coal for meeting growing demand. However, it is not yet clear whether the growth of renewables is causing a decline in the use of fossil fuels or just representing a new addition. So far, most signs point to the latter one. Despite record growth in solar and wind capacity installations, the world is still increasing its use of fossil fuels.

What are the uncertainties around reaching Renewal?

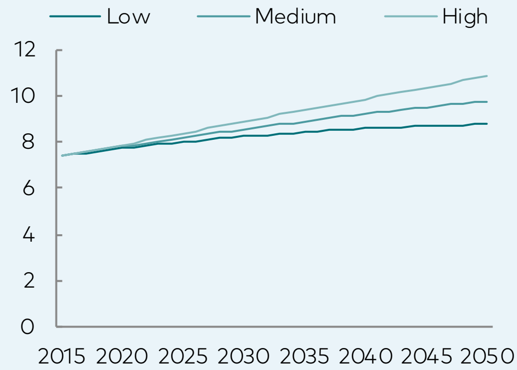
Renewal portrays one possible path that the energy system must move towards. By 2050, almost all use of coal must be eradicated, oil demand needs to be halved and gas demand also needs to be reduced by over 10%. Significant new CCUS capacity would be installed: the equivalent to over 1500 Sleipner CCS projects, which store 1 million tons of CO_2 underground per year. Already by 2030, annual additions of new solar and wind capacity need to double, and the production of batteries needs to increase more than 20-fold. Whether the world can achieve this, will to a large extent depend on the ability of political systems to regulate and reinforce market developments to change investments and consumer behaviour sufficiently fast. Also, speeding

Global CCUS capacity in 2050 by scenario
Gt



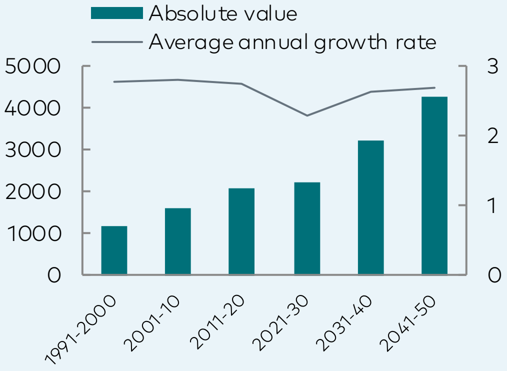
Source: Equinor

Population projections by fertility rate
Bn people



Source: United Nations

GDP development in Renewal
Bn USD (lhs), % (rhs)



Source: Equinor

up replacement of energy-related capital equipment will be necessary, as much of the capital stock, i.e., power stations, airplanes, ships, buildings and manufacturing plants, have long economic lives. Electricity markets are particularly exposed to the likelihood that regulation will grow over time. The increased penetration of zero marginal cost sources of electricity generation will depress wholesale prices and raise the need for market regulation to ensure the necessary investments in renewable capacity, back-up or storage capacity, demand side response mechanisms and the electricity grid.

CCUS is central in *Renewal*, but currently lacks a clear business case. Adding CCUS to electricity generation and industrial processes adds costs, but does not enhance efficiency or productivity. CCUS is special in that the only "source of revenue" is avoidance of a cost, namely the carbon price. And the paradox is that even if the carbon price were sufficiently high to make CCUS economic, the added cost of CCUS makes low or zero-carbon alternatives even more attractive. It is obvious that CCUS will have to rely on strong and generous policy support in a start-up phase, and the question is if it will ever be able to stand on its own feet.

What if a pillar of Renewal disappoints?

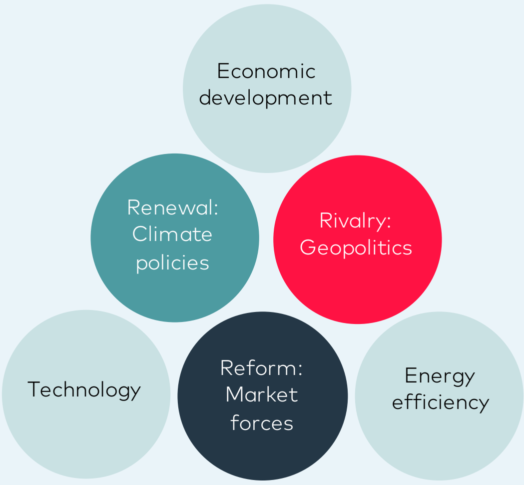
If one of the three pillars of *Renewal*, energy intensity improvements, energy mix changes and CCUS, does not deliver according to projections, another one needs to compensate to keep the scenario in line with the *Renewal* carbon budget. For example: if energy intensity develops as in *Reform*, CCUS will have to deliver 11 Gt of emission reductions in 2050 instead of 1.5 Gt. If the energy mix resembles that of *Reform*, CCUS will have to handle 8 Gt of CO_2 by 2050. These CCUS requirements arguably pose a significantly larger challenge than the assumptions in *Renewal*, which are themselves challenging compared to today's CCUS advancements.

Are there factors that can make Renewal more doable?

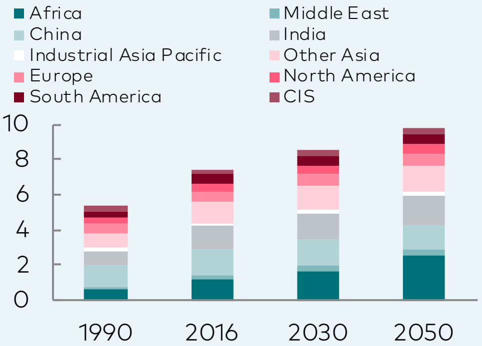
Having focused on the challenges of *Renewal*, it is fair to say that there are at least two factors that may make the journey easier in some dimensions. Most outlooks, including that of Energy Perspectives, take for granted that economic growth will continue at rates close to historical growth rates, and that the global population will continue to increase all the way to 2100 and possibly beyond. Economic growth could develop at more modest rates than projected, e.g. due to resource limitations or lower productivity development. This could on the one hand make it "easier" to satisfy energy demand, but it could challenge the ability to reduce poverty and also to lubricate the energy transition itself. The UN medium projection shows global population increasing from almost 8 bn today, to close to 10 bn in 2050. However, this projection faces some criticism in that it does not sufficiently consider the impact of women's education on fertility rates, and simply by adding this as a variable to the estimate, the population projection would peak at well below 9 bn, and well before 2050, reducing demand for energy.

In sum, delivering on all the sustainable development goals and in particular the energy and climate targets in the manner prescribed by *Renewal* is an enormous challenge. Also, the longer time it takes for targets to be supplemented by policy measures that work, the more difficult the task will be. Instead of waiting for full agreement on the optimal path for achieving different goals, it is time to get started.

The three scenarios and main drivers

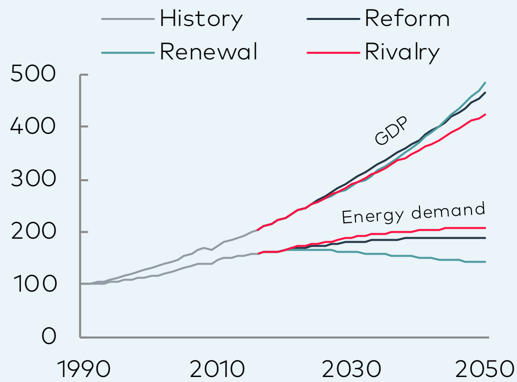


World population by region
Bn



CIS: Commonwealth of Independent States
Source: UN

World GDP and energy demand by scenario
Index, 1990=100



Source: IEA (history), Equinor (projections)

The three scenarios

Energy Perspectives contains three different scenarios, or stories of the future, that cover a wide outcome space for the global energy market. There are no specific probabilities attached to the scenarios, and although *Reform*, being the central scenario, may have a higher probability, the only certainty is that the real world will not develop exactly in line with any of the scenarios. The uncertainty is very large, and the scenarios are intended to illustrate a possible outcome space.

There are several similarities among the scenarios; all of them lead to a world where the economy is much larger by 2050, and in all scenarios the world uses energy more efficiently than today. Electricity demand grows considerably in all scenarios, driven by electrification of transport and other sectors of the economy. There is however only one variable that is fully consistent across the scenarios; they all build on the same population growth forecast from the UN, with the world population reaching almost 10 bn by 2050.

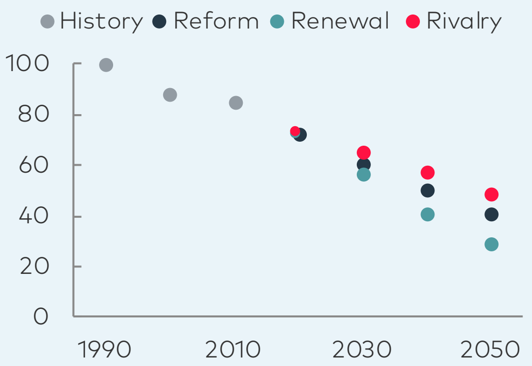
In a nutshell, *Reform* is driven by market forces and technology developments, *Renewal* by strong, coordinated climate policies, and *Rivalry* by a difficult geopolitical situation. That said, geopolitics, and the dynamics between variables, are key factors in all scenarios and partly determine which scenario the world moves towards. Several geopolitical variables are considered: the global order, conflict levels, political ideologies, trade and cooperation, demographics, migration and urbanisation. Energy is also an important part of the geopolitical picture, either through security of supply considerations or by the use of energy exports as leverage in foreign policy.

Reform: driven by market and technology

In *Reform*, the global order, or the rules, norms and institutions that govern relations between actors on the world stage, is characterised by the coexistence of competition and cooperation, rarely developing into sustained or large-scale conflicts. There will be episodic regional crises, but these remain largely contained and limited in time. The nature of instability may change as concepts such as hybrid and information warfare undermine traditional notions of war and peace. Conflicting models of global governance create some friction, but generally principles of market competition dominate. Global trade may experience periodic disruptions and disputes, but there are few or no irreversible breakdowns. Energy security remains an important concern as energy importing nations and regions continue to rely on oil and gas imports. Securing access to energy supplies, including nuclear and renewable energy, is a key political consideration.

Despite the need to deal with the climate challenge, *Reform* continues to have clear regional divergences in the adoption of low-carbon policies. EU together with China have emerged as the global climate leaders, while the US has stepped down and its climate ambitions gravitate along with shifting political leadership. The Nationally Determined Contributions (NDCs) pledged by nations around the world after the 21st Conference of the Parties (COP21) in Paris in 2015, provide the dominant policy guidance *Reform* builds on. The current NDCs are insufficient to put the world on a sustainable path and instead steer towards emission levels pointing to a global warming of around 3.0 to 3.2° according to the UN's 2018 Emission Gap Report. At the COP24 in Katowice in 2018 the nations were able to agree on most aspects needed for the Paris "rulebook" on how to

Energy intensity by scenario
Index, 1990=100



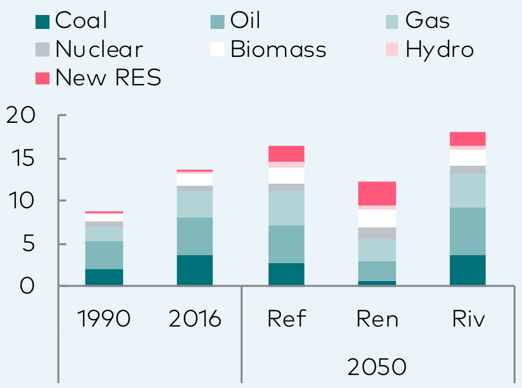
Source: IEA (history), Equinor (projections)

Rating the consistency of nations' efforts and policies with the Paris Agreement

4°C+ WORLD CRITICALLY INSUFFICIENT	< 4°C WORLD HIGHLY INSUFFICIENT	< 3°C WORLD INSUFFICIENT	< 2°C WORLD 2°C COMPATIBLE	< 1.5°C WORLD 1.5°C PARIS AGREEMENT COMPATIBLE	<< 1.5°C WORLD ROLE MODEL
RUSSIAN FEDERATION	ARGENTINA	AUSTRALIA	BHUTAN	MOROCCO	
SAUDI ARABIA	CANADA	BRAZIL	COSTARICA	THE GAMBIA	
TURKEY	CHILE	EU	ETHIOPIA		
USA	CHINA	KAZAKHSTAN	INDIA		
UKRAINE	INDONESIA	MEXICO	PHILIPPINES		
	JAPAN	NEW ZEALAND			
	SINGAPORE	NORWAY			
	SOUTH AFRICA	PERU			
	SOUTH KOREA	SWITZERLAND			
	UAE				

Source: Climate Action Tracker

Global TPED by fuel and scenario
Btoe



Source: IEA (history), Equinor (projections)

measure, report and verify emission reduction efforts. However, the nations did not manage to decide on the framework for how they can cooperate with one another when implementing their NDCs, which was deferred to COP25 that will take place in Chile in December 2019. The next major deadline on the COP agenda is in 2020, when countries must show that they have met their previous targets and affirm their new raised climate ambitions.

In *Reform*, climate and policy targets are acknowledged and considered, but they are not necessarily achieved. If no specific policies exist to achieve the targets, or if it is viewed that reaching them would come at an unacceptable economic cost, they are not assumed to be met. One example is the EU target to reduce CO_2 emissions by 80 to 95% by 2050 compared to 1990 levels. Based on the current policy momentum and market and technology developments, EU emissions are projected to be reduced by 60%, falling well short of the target. Another example of a target that is not achieved in *Reform* is the Indian renewable capacity target of 175 GW installed by 2022, as the current pace of capacity additions is not sufficient to reach it.

Reform places high emphasis on market and technology driven developments. End-user energy prices provide important signals for how the market operates, and energy and technology costs shape long-term investment decisions. End-user energy prices are assumed to gradually increase over time, as most regions introduce CO_2 prices, and energy subsidies are gradually phased out. The EU Emissions Trading Scheme is already well-established and in China the national carbon trading scheme is expected to be implemented by 2020. In the US, a bipartisan proposal for a new carbon tax is gaining some traction. Technology improvements continue at a fast pace, but no "leap-frogging" technology break-throughs are assumed, and different technologies coexist over time. Policies can support new technologies at an early stage, but only technologies that become competitive, or clearly show the potential to become competitive, are sustained. The energy transition speeds up, but is largely confined to electricity generation and road transport.

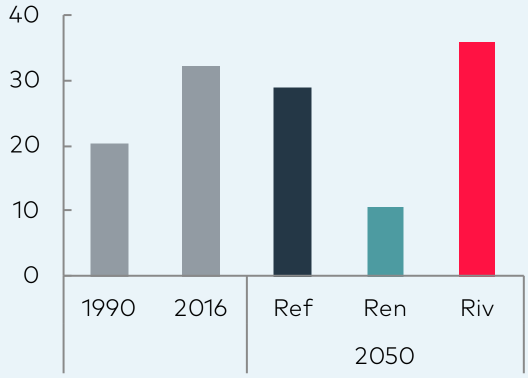
Electricity demand grows at a much faster pace than overall energy demand, and by 2050, global electricity demand is projected to be 80% higher than today. Electricity use grows in all sectors and the share of electricity in total final energy consumption (TFC) increases at a rate that is higher than historically. The share of fossil fuels in total primary energy demand (TPED) declines gradually, from 81% in 2016 to around 67% in 2050. Coal experiences the largest drop in share, followed by oil. Gas, on the other hand, increases its share slightly. All low-carbon energy sources increase their role in the energy mix, with new renewable sources (new RES) gaining the most. The changing energy mix has a clear impact on global energy-related CO_2 emissions, as they peak in the 2020s and end up around 10% lower by 2050, however far from sufficient to achieve climate targets.

Renewal: well below 2°

Renewal is a back-cast that is designed to be consistent with the Paris Agreement and limit global warming to well below 2°. The carbon budget of cumulative energy-related CO_2 emissions between 2017 and 2050 is set at just over 770 Gt. This is in line with the Sustainable Development Scenario in IEA's World Energy Outlook 2018 and would, according to IEA, limit global warming to about 1.7-1.8°. What

Annual net energy-related CO_2 emissions by scenario

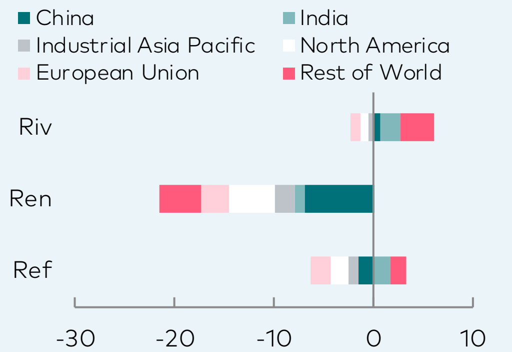
Gt



Source: IEA (history), Equinor (projections)

Change in CO_2 emissions by region and scenario, 2016-50

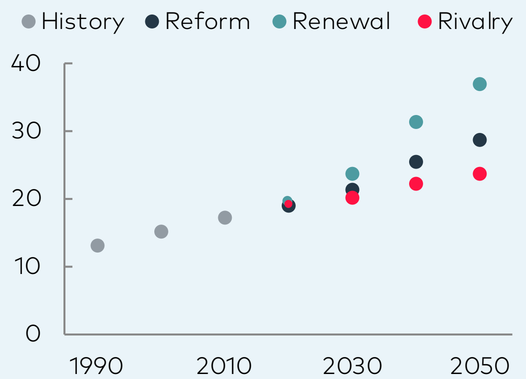
Gt



Source: IEA (history), Equinor (projections)

Electricity share of TFC by scenario

%



Source: IEA (history), Equinor (projections)

happens after 2050 will ultimately determine total cumulative emissions and to hit the target, emissions will have to go to zero around 2070. *Renewal* is consistent with this in the sense that if emission reductions continue at the same pace past 2050, emissions will reach zero a few years before 2070. The Intergovernmental Panel on Climate Change (IPCC) 1.5° report released in October 2018 contains a large number of emission trajectories consistent with limiting global warming to 1.5° rather than 2°. Energy Perspectives 2019 has also established a 1.5° sensitivity to *Renewal*, to visualise what this could imply for the global energy system (text box in The global energy market chapter). In addition, there is an additional sensitivity that assumes that CO_2 emissions follow the same trajectory as in *Reform* until 2025, to illustrate what must happen if necessary climate policy action is delayed (in the Greenhouse gas emissions chapter).

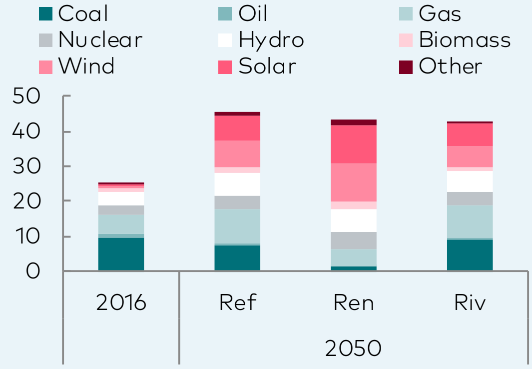
There are many combinations of energy demand, fuel mix and CCUS levels that can achieve the same carbon budget, and *Renewal* presents only one such combination. There are generally three main pathways towards deep long-term decarbonisation of the energy systems: namely electrification, hydrogen and CCUS. In practice it is likely that all three measures would have to be combined to reach the target together with energy efficiency improvements. *Renewal* has a strong focus on energy efficiency and electrification and is relatively cautious on CCUS. By 2050 it is assumed that global installed CCUS capacity will reach 1.5 Gt, which is very high compared to what is installed today, but low compared to some other low-carbon scenarios. Carbon offsets such as sinks and capturing CO_2 from the air has not been counted into the carbon budget, but could potentially play an important role, especially in the second part of the century. Hydrogen has not been explicitly incorporated in the Energy Perspectives scenario results due to the complexity of its impacts on TPED and TFC, but a hydrogen pathway has been developed to illustrate the potential role of hydrogen in the context of *Renewal* (in the Greenhouse gas emissions chapter).

How does the world work together to achieve the massive energy transition that is necessary in *Renewal*? The scenario relies on the assumption that a benign geopolitical environment supports a faster transition and greater global cooperation on climate change. The global order would be shaped by a greater convergence of global norms, institutions, values and principles. The prevailing global ideology is globalist, progressive and inclusive. International trade is boosted through global free trade regimes and more integrated regional infrastructure networks that create greater trade synergies and inter-connectedness. Global technology transfer is high, which enables a significant and rapid advancement in energy efficiency and clean energy. Energy security concerns are generally lower in *Renewal* as fuel import dependency declines, in combination with a generally high level of trust. The energy transition however also brings new challenges which are discussed in the text box "Geopolitics of Renewal".

Climate policies are implemented efficiently, and all regions are assumed to implement carbon prices at significantly higher levels than in *Reform*. Strong policy intervention is needed in energy markets to force the necessary investments in low-carbon technologies. This applies to renewables in the power sector, decarbonisation of the building sector, electrification of transport,

Global electricity generation by fuel and scenario

Thousand TWh



Source: IEA (history), Equinor (projections)

Capturing CO_2 from the air to make fertiliser

Source: Climework

Potential carbon sinks and negative emissions

Measure	Function
Tree planting	Absorb CO_2 from the atmosphere
Land management	Increase organic carbon content of soil
Bio energy with CCS (BECCS)	Capture CO_2 emissions from combustion of bioenergy
Direct air capture and carbon storage (DACCS)	Capture CO_2 from the air to store or use
Enhanced weathering	Draw in CO_2 through silicate or carbon minerals dissolved in rainwater
Ocean fertilisation	Stimulate growth of algae and plankton

Source: Equinor, various sources

realisation of efficiency gains in industry and CCUS within power generation and industry. A global approach is necessary, and all regions must partake in this collective effort.

Renewal may look very challenging, but the energy transition does not only rely on avoiding climate change as motivation. The push for renewables originates from a wide range of factors, such as energy security, fighting local pollution, building new industries and gaining a competitive advantage, creating local jobs and stimulating the economy. These considerations play a more self-reinforcing role in *Renewal* than in *Reform*. There may also be alternative paths to *Renewal* other than a geopolitically benign environment. It is not unthinkable that on a global level it may become necessary with coercion and sanctions to force non-compliant countries and regions to enact measures to reduce emissions. The political environment may become more volatile in line with large shifts in public opinion and pressure from young voters. Another possibility is that catastrophic climate events trigger abrupt and sudden changes driving the same type of change as in *Renewal*.

In *Renewal*, global TPED decreases due to energy efficiency improvements that are higher than economic growth rates. Electricity demand on the other hand increases by over 70% and the share of electricity in TFC doubles by 2050. The energy mix goes through a fundamental change as the share of fossil fuels falls below 50%, pushing global energy-related CO_2 emissions down by over 60% compared to today's levels.

Rivalry: pace of change slows down

In *Rivalry*, the geopolitical uncertainty and volatility that is currently present in the world is assumed to persist and, in some dimensions, also escalate. There is a resurgence in competition for the balance of power between the major powers. The use of force by nation states increases as conflict prevention mechanisms are increasingly less effective. Discriminatory, isolationist, mercantilist and nationalistic political ideologies gain momentum. International trade suffers from growing protectionism, and discriminatory and exclusionary bilateral agreements are favoured over open and inclusionary multilateral agreements. Less trade and cooperation hurt economic growth, and inequality grows as the negative consequences of urbanisation and migration are inadequately dealt with. There is a breakdown in the global consensus on tackling man-made climate change, leading to growing regional divergence in the adoption of green policies. Other energy policy objectives take higher priority, for example improving energy security by limiting the need for imports and developing domestic sources of energy.

Despite having the lowest economic growth, *Rivalry* has the highest energy demand growth. This is linked to less environmental regulation, slower or no phase-out of fuel subsidies and lower investments in energy efficiency. This in turn reduces energy intensity improvements, which, despite being faster than historical rates, are significantly slower than in the other two scenarios. Implementation of new technology is also slower, leading to smaller cost reductions, less efficiency gains, lower ability to integrate variable renewables in the power system and less electrification of transport.

Fuel demand for non-energy purposes
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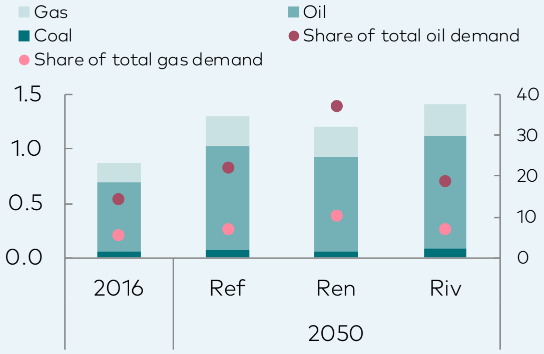
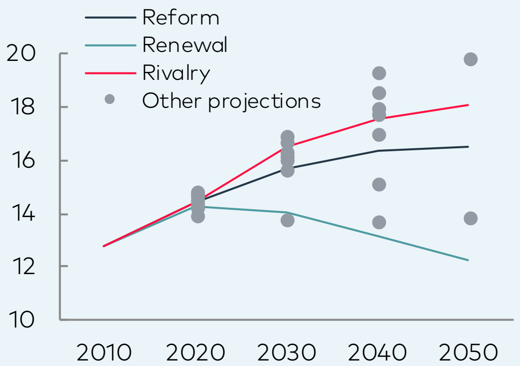


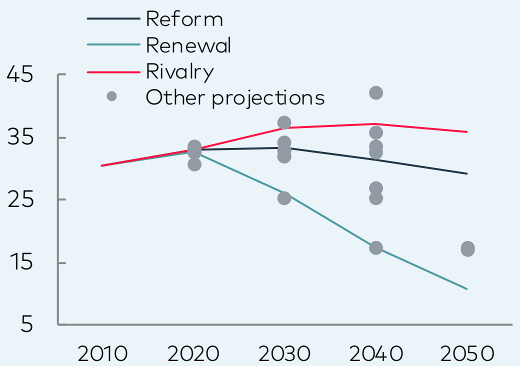
Source: IEA (history), Equinor (projections)

TPED comparison EP versus other projections
Btoe



Source: Equinor, IEA WEO 2018, Exxon Outlook 2018, BP Outlook 2019, Shell Sky 2018, DNV GL ETO 2018

Global energy-related CO_2 emissions comparison EP versus other projections
Gt



Source: Equinor, IEA WEO 2018, Exxon Outlook 2018, BP Outlook 2019, Shell Sky 2018, DNV GL ETO 2018

Due to high focus on energy security, domestic sources of energy are favoured. Coal does better in *Rivalry* compared to *Reform*, although it is difficult to see a large-scale revival of coal due to local pollution concerns and the growing competitiveness of renewables. Renewables therefore continue to grow at a fast pace in *Rivalry* as well, as they remain an attractive source of energy in most regions, and renewables are considered to be a domestic energy source that contributes to lower energy import dependency. However, less supportive regulation, more restrictions on trade and technology exchange and lower economic growth slow down capacity deployment compared to *Reform*. Gas loses out to coal in many regions due to higher cost and less focus on its environmental benefits. LNG demand is hurt by security of supply concerns, protectionism and less global trade, as well as its relatively high cost. Oil consumption is up relative to *Reform* due to less electrification in the transport sector, but also somewhat in other sectors due to lower energy efficiency, less regulation and continued fuel price subsidies.

The rate of electrification is lowest in *Rivalry*, but electricity demand growth is similar to *Renewal* as TPED is substantially higher. The energy mix experiences the smallest change in this scenario, and by 2050 fossil fuels still account for over 75% of TPED. CO_2 emissions continue to grow moderately until 2040, before declining slowly.

Benchmarking

The scenarios in this report are designed to capture the wide outcome space that exists for the future energy markets, reflecting the large uncertainty about the long-term energy future. There are numerous ways to design energy scenarios by combining different sets of assumptions. Even if two projections on the surface have similar assumptions, there may still be important differences that lead to diverging outcomes. Benchmarking with other projections is an important analytical exercise and usually attracts a lot of interest from observers.

The Energy Perspectives scenarios provide a wide outcome range compared to other projections. *Rivalry* is more conservative about long-term TPED compared to some of the other high demand projections. Similarly, *Reform* is at the lower end of demand projections compared to other central or reference outlooks. As expected, *Renewal* is fairly aligned with other scenarios in line with Paris goals, and well below the reference or central scenarios. The Energy Perspectives scenarios are optimistic on electricity demand, the share of electricity in TFC, and on the deployment of solar and wind electricity. Consequently, a more conservative outlook on energy demand, combined with high expectations for solar and wind electricity, leads to paths for CO_2 emissions that are lower than comparable projections. Most scenarios that are consistent with climate targets have significantly higher projections of CCUS than *Renewal*, a necessary measure to compensate for less aggressive assumptions on energy efficiency and lower use of coal and other fossil fuels.

Geopolitics of Renewal

IRENA, with the support of the governments of Germany, Norway and the UAE, established a Global Commission in January 2018 to explore the geopolitical implications of the energy transition, and issued a report summarising the Commission's findings in January 2019.

Increasing penetration of renewables in the energy mix is expected to transform geopolitics, as these energy sources are available in most countries of the world, are impossible to exhaust and hard to disrupt. Additional key characteristics are that renewables can be deployed at any scale, can be used in decentralised forms, and have zero short-run marginal costs. Most of these qualities of renewable energy contradict the characteristics of fossil fuels.

The geopolitical arena is expected to experience a repositioning of states. The extent of such repositioning will broadly depend on two factors: the exposure of the individual states to fossil fuel trade flow changes, and the level of ambitions and preconditions these individual states have to become leaders in renewable energy technology. Current fossil fuel exporters are likely to observe a decline in their global reach and influence, and will feel pressure to diversify their economies away from the petroleum industry. The level of such exposure and level of resilience or preparedness vary widely from producer to producer. A rapid shift from fossil fuels could also create financial risks relevant for the global economy and could contribute to political instability in less prepared economies.

For nation states, the future way to exercise global influence will be through the provision of new renewable energy technologies or the supply of relevant materials, metals and minerals. In a parallel development, current fossil fuel importers will have better possibilities to achieve energy independence and greater energy security. Trade flows will change, some maritime trade routes will become less important and new trade patterns will be linked to electricity and renewable energy related goods and technology. The nature of geopolitical tensions will also change from conflicts related to oil, gas, water and food to issues dominated by cybersecurity, technology and minerals.

A more decentralised supply of renewable energy will lead to a diffusion of geopolitical power, improved access to energy and the emergence of new energy market players, like citizens, cities and corporations.

This generally more constructive geopolitical framework underpins the success in a *Renewal* world in reaching global climate goals.

When black swans soar

"Black swans" are unforeseen events, typically with extreme consequences but low probability, that challenge conventional assumptions about future developments. Also known as "wild cards", "game changers" or "paradigm shifts", such events are by their very nature regarded as highly unlikely, but as one projects further out into the future, they could move closer to the realm of possibility. In Energy Perspectives 2018 we identified three black swans (nuclear fusion, blue death and the colonisation of Mars), this year we bring three new to the readers' attention that span the realms of geopolitics, climate, and technology.

New sources of resource extraction

Deep-sea mining is not new, but as advancements continue to be made in submersible technologies, and the seabed emerges as a hub for valuable resources, this could fundamentally alter the strategic importance of the maritime domain. For centuries, the maritime domain has traditionally acquired importance as a trade and transit corridor and as an area of contest for fishing rights, and in recent years for offshore oil and gas exploration. However, deep-sea mining could raise the stakes for traditional flashpoints, while creating new stages of geopolitical rivalry. Also related to frontier exploration, the advancements in rocket technologies (and a concomitant decline in cost) could also make the lunar surface and nearby asteroids targets for mining commodities such as rare earths and Helium-3, which could emerge as a catalyst for nuclear fusion.

Revolutions in transport

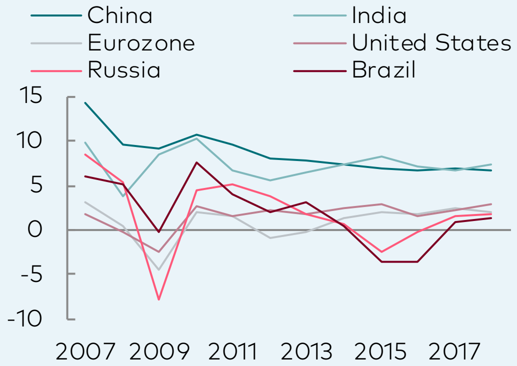
The revival of commercial supersonic air travel, the development of hypersonic air travel and magnetic hyper-loop capsules could fundamentally redefine how societies perceive concepts of distance and time. For instance, new forms of high-speed mass transit would alter how one defines urbanisation and the city/suburb divide. Further advancements in online communication and virtual reality could even reduce and eliminate some of the need for physical travel.

Climate engineering

As the damaging effects of climate change become more evident, it is possible that nation-states, corporations or even high-net worth individuals could unilaterally deploy solar geo-engineering technologies to reverse the damaging effects of climate change (such as the deployment of Stratospheric Aerosol Injection – or SAI). The uncertain cascade effects of such technologies could result in the creation of new and unpredictable geopolitical risks and conflict hotspots. Moreover, the anarchic and self-interested use of these technologies may also undermine global governance and reduce the overall effectiveness of broader climate change initiatives.

GDP growth 2007-2018 by region

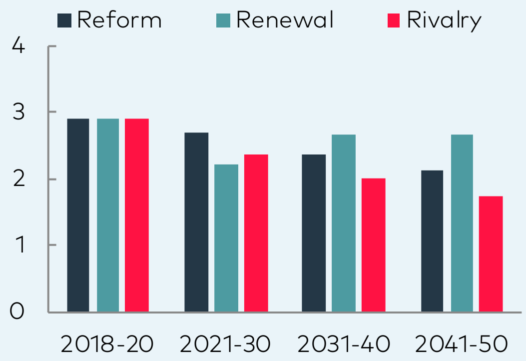
Real annual % change at market exchange rates



Source: IMF

Global GDP growth by scenario

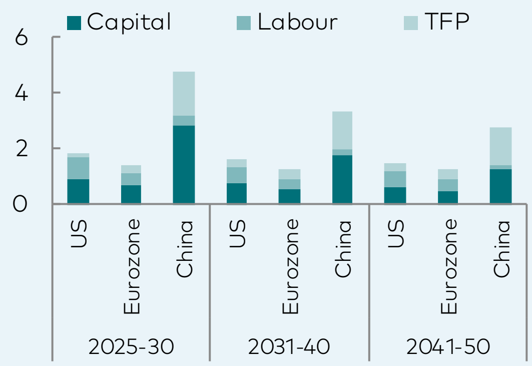
Real annual % change at market exchange rates



Source: Equinor

GDP growth by source in Reform

Real annual % change at market exchange rates



Source: Equinor

The global economy

Current situation

The global economic expansion experienced up to 2018 has weakened, with muted inflationary pressures, continued trade tensions and high level of public and private debt. Most leading economic sentiment indicators are sluggish, and China is experiencing the slowest growth since 1990. The US economy displays robust growth propelled by a tight labour market, relatively loose monetary policy and abundant fiscal stimulus. Despite a recovery on the back of the services sector, the Eurozone economy has turned gloomy as Italy fell back into recession and Germany came close to technical recession driven by weak manufacturing. Deteriorating contribution from net trade and Brexit uncertainty damage European business activity. Japan's growth remains weak and volatile, sustained by robust government spending, which offsets weaker trade and the impact of the consumption tax hike.

Despite the trade conflicts which worsen China's export earnings, its economy shows some resilience, helped by more accommodative monetary and fiscal policies and gradual reforms of state-owned enterprises. India's growth has temporarily improved as a result of industrial performance, pre-election fiscal stimulus and easing liquidity pressures among non-banking financial companies. Russia is experiencing weaker consumption and investment due to rising inflation, and Brazil's economic recovery continues at an uneven pace, with slow progress of the pension reform, high taxation and infrastructure bottlenecks hurting its competitiveness. As of now, the global economy looks to grow by 2.8% in 2019, which is lower than last year. Trade protectionism, tighter financial conditions, geo-political tensions and Brexit are the main downside risks. The upside risk of a cyclical rebound remains modest. Hence, risks to near-term growth tilt to the downside.

Assessing economic growth across different time horizons

The projection of economic activity is broadly speaking divided into two time horizons: the short and medium term until 2025 and the long term after 2025. The short- and medium-term analysis focuses on changes on the demand side of economies, i.e., private consumption, investments, government consumption, net exports and inventories. These projections are inspired by the countries' and regions' current situation and existing forecasts, and do not deviate much in the three scenarios.

When forecasting long-term GDP growth, we aim to take a longer-term view of global economic prospects that look beyond the short-term ups and downs of the economic and geopolitical cycle. The long-term analysis shifts focus to changes on the supply side of economies, which are determined by developments in the input factors of capital, labour and Total Factor Productivity (TFP). The capital component incorporates more than the accumulation and efficiency of capital, it also refers to available natural resources in the country. The labour component includes considerations about both population growth and the quality of the labour force. Finally, the TFP component comprises assessments about globalisation, market regulation and reform, and technological progress, which are diffused through international trade and investment. The long-term projections address the production potential of economies in the three scenarios, also assuming a degree of global convergence, as developing countries are projected to grow at faster rates than advanced economies.

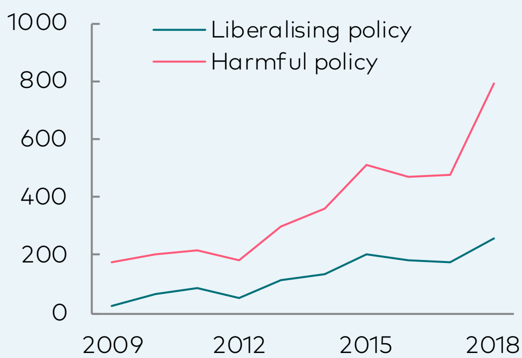
Trade protectionism reading its head

Trade protectionism is a policy of protecting domestic industries against foreign competition by means of tariffs, subsidies, import quotas, or other restrictions on the imports from foreign competitors. Protectionist policies have been implemented by many countries despite most mainstream economists agreeing that the world economy benefits from free trade. Free trade theory argues that by specialising in production instead of producing everything, each nation would profit from free trade that requires relatively fewer factor inputs. Hence, free trade maximises trading partners' comparative advantage, increases economic efficiency, and reduces consumer prices.

Protectionists argue that higher tariffs are a source of government revenue. They can protect new industries, diversify the economy and prevent job loss. Protectionists also say that free trade does not work in a global setting, where capital is mobile, and trade partners 'fight dirty' by, for example, subsidising production to gain unfair advantage to attract more jobs. There is however reason to believe that protectionism leads to retaliation and higher consumer prices, which results in lower demand causing job losses in other industries, besides encouraging inefficient firms to stay in business. New jobs created through protectionist measures are rarely taken by the people who lost the old ones without proper training. Overall, all players are better off as a result of free trade that enhances productivity and consumer choice.

Nevertheless, this debate conceals the fact that some groups in society end up worse off without support to prepare them for new kinds of jobs. The issue of inequality has to be solved by separate policies, where neither open trade nor protectionism have much to offer in terms of long-term solutions.

G20 trade policy intervention by type
Number of interventions



Source: Global Trade Alerts

Outlook to 2025

In 2019-20, global economic growth is expected to be stable at 2.8% per year on average. As such, a global economic recession is not foreseen, but the world's vulnerability relative to a significant event to send growth rates to negative territory has increased. Tighter financial conditions, policy uncertainty, market volatility and the risk of geopolitical events are all hurting business sentiment and investment. Policy makers need to address these concerns and combat diminishing labour-force growth rates and sluggish gains in productivity in order to mitigate vulnerability to shocks. The growth forecasts for the three scenarios start to deviate from year 2021 and are discussed below.

In *Reform*, the global economy is not able to further accelerate and grows at an average rate of 2.8% per year during 2021-25 due to a mild cyclical economic downturn in the US, higher debt, and weaker employment growth. However, healthy population growth, robust energy production and capital investments contribute to expansion. In the Eurozone, Brexit and increasing protectionism/EU-scepticism hamper European integration ambitions. Some labour and product market reforms, coupled with investments in research and development (R&D) filter through, as the area's economic performance reaches 1.5% per year on average. Japan's robust R&D development and more open labour policy lift productivity. However, trade frictions and public debt levels slow growth to 0.7% on an annual average over the period. China deepens reforms to accelerate its transformation from industrial to service and consumption driven growth, with solid labour market conditions, robust technology development and an orderly soft landing of the housing market. The anti-pollution campaign, state-owned enterprise reforms, and trade frictions lead to a moderate GDP growth deceleration to 5.3% per year on average. The combination of population dividend, infrastructure development and structural reforms drive India's growth to a robust 6.7% per year on average over the period. Brazil's large resource base and favourable demographics balance short- and medium-term structural policy challenges and result in an average expansion of 2.6% per year. In Russia, unfavourable demographics, outmoded manufacturing capacity, overburdened infrastructure and tight credit curb growth to an average of 1.5% per year.

In *Renewal*, capital resources are reallocated towards greening the economy, reflected by prioritisation of long-term goals over higher short-term economic returns. Initially, the transformation of the energy system is costly and requires subsidies, whilst, later in the outlook period, economic growth surges as green investments yield higher return. Strong policy regulation materialises in the form of increased taxes on emissions, a gradual phase-out of coal-fired power generation capacity, and a curb in the amount of energy used. *Renewal* yields lower oil and gas demand than the other scenarios and lower commodity prices, and therefore represents a challenge to net petroleum exporters. Economic growth in *Renewal* is 2.5% on average per year, which is 0.3 p.p. lower than in *Reform*. Europe and leading Asian countries are first movers with cost-efficient new solutions. The rest of the world follows closely behind, as the political will for greening increases. The positive impacts on economic growth of the energy transition in *Renewal* come to the surface beyond 2025.

The economic development in *Rivalry* is highly cyclical and protectionist. *Rivalry* portrays a multipolar world where populist, nationalist,

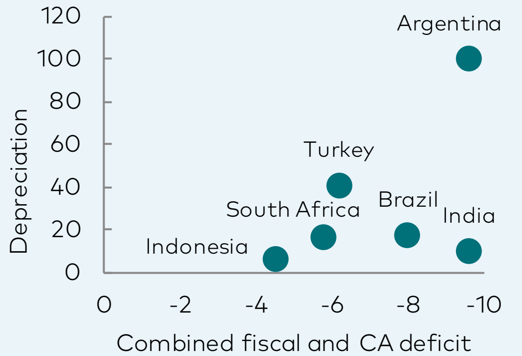
Emerging market vulnerabilities

Currently, several large emerging markets (EMs) struggle with economic imbalances at various levels. Local currencies lost value relative to USD during 2018, as a consequence of weakening investor confidence and increasing US interest rates. As a rule of thumb, depreciation is accompanied by increasing inflation and rising interest rates. In EM economies, especially those that are net energy importers, current account (CA) balances show a deficit. This deficit is driven by the energy price complex, a weakening local currency, and even weather or price issues impacting non-energy exports. Fiscal balances also tend to be in deficit, as governments spend more money than their public revenues stretch to. Fiscal deficits are to be mended by tax reforms, pension reforms and in general contractionary fiscal policies. Backing up trade and budget deficits and a weakening local currency does not come cheap, unless the economy is rich in foreign currency reserves. Most economies over the years have accumulated significant levels of public debt, with large portions borrowed in foreign currency. This makes debt increasingly difficult to service when local currencies weaken. Such imbalances make economic performance in EMs volatile and highly dependent on the countries' political climate and ability to implement necessary reforms.

The energy market implications of the EM challenges are multiple and far-reaching. To improve their CA balances, EMs prefer producing energy from domestically available energy resources instead of imports. Increasing their capacity for renewable electricity generation or domestic supply and use of coal, oil and gas are all useful tools in this regard. EMs also tend to incentivise foreign direct investment to boost their capital account, and explore energy end user price subsidies and regulation or energy export taxes as possible tools to narrow their budget deficits.

2018 currency depreciation and combined fiscal and CA deficit, selected EMs

% vs USD (vertical axis), % of GDP (horizontal axis)



Source: IHS, Thomson Reuters Datastream

inward-looking and short-term priorities direct policy making, where focus on the climate challenge takes the back seat and where disorder, conflict and power struggle apply at the expense of cooperation and trust. This is a feature in a world with escalated regional conflicts, sanctions and inefficient markets that dampen technology development. Political and economic resources are channelled to less productive purposes, such as security and defence spending. Further, *Rivalry* is characterised by a lack of trust between countries and focus on own interests, rather than solutions serving global interests. The economic growth in *Rivalry* is 2.6% on average per year, which is 0.2 p.p. lower than in *Reform*. Pockets of outright economic recessions are seen in different regions. Economic activity is markedly poor first and foremost in the Middle East and North Africa (MENA), considering the region's historical trend growth rate, where it grows on average by 2.7% per year. This assumes a continuation of the tumultuous geopolitical situation seen today in MENA, while other regions are slightly more sheltered. The US is about to abandon outdated regional alliances and costly commitments, as well as pursuing energy self-sufficiency. The growth in EU is also weakened as a consequence of internal lack of coordination and impact of protectionism, while China seeks to expand its geo-economic policies.

Outlook beyond 2025

The last couple of years have been characterised by significant uncertainty that have dominated the economic and geopolitical picture, such as the Brexit process, sanctions on Russia and the trade conflict between China and the US. High volatility in foreign exchange and interest rates has strongly influenced many emerging market economies. Nevertheless, it is of great importance to consider these shocks to the extent they point to deeper structural shifts, like a populist backlash against globalisation or automatisation, and the perceived impact of these trends in increasing income inequality and weakening social cohesion.

The UN projections show that the global population continues to increase, but at a decelerating rate. The world population is expected to reach 9.8 bn in 2050. Longer life expectancies and lower fertility contribute to an aging population and a decrease in the global workforce. A high labour market participation rate, improving educational systems, social welfare systems and labour market flexibility, are therefore all key elements for securing a competitive future workforce. Countries continue to draw on their capital base of resources, machinery, transport equipment, infrastructure and financial capital. As financial markets improve, capital efficiency increases in emerging economies. Digitalisation, automatisation and robotisation become important tools combining labour and capital to enhance productivity and to manage the aging issue.

Reform: a trend-based economy

Global growth in *Reform* is somewhat lower than the historical growth rate of 2.9% seen since 1990. This is primarily caused by demographic factors that result in unfavourable changes in the working-age population. In addition, the catch-up potential for emerging market economies decreases over time. In *Reform,* global economic growth and the world's energy and economic systems develop mostly in line with trends seen in previous decades. Traditional energy carriers continue to dominate, although some climate and environmental regulations are tightened and the share

The economic effects of an aging population

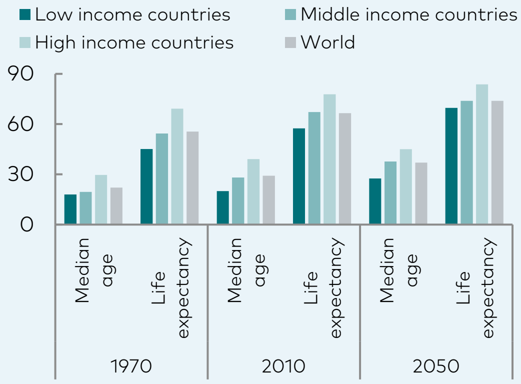
The world's aging population is expected to shape the future of economies. Global population continues to get older, a phenomenon known as demographic aging. Aging and population growth are mainly driven by two factors, longevity and fertility. The trends in increasing longevity and decreasing fertility rates are expected to continue, and reshape both the scale and age composition of the world's population.

The conventional wisdom is that aging leads to slower growth, because the old generation saves less, which translates into higher interest rates, lower investments, and lower labour productivity. Others think aging may actually increase economic growth, because people will adapt by saving more and working longer. Some consequences of aging are clearly unfavourable, such as imbalances in the pension budget due to an increase in the old-age dependency ratio.

Aging is expected to induce behavioural adaptations in savings and labour force participation, but will these adjustments be large enough to reverse the negative effects of demographic change? Capital per worker and labour productivity can be affected via two main channels. A longer life span can induce higher savings, as active workers consume less and save more for the retirement period. At the same time individuals would choose to work longer if retirement age is not regulated. The first effect leads to higher labour productivity and increased capital accumulation. The second effect can weaken saving incentives. Therefore, to understand the size and direction of the demographic effects it is important to determine whether aging is driven by an increase in longevity or by a decrease in fertility. In our long-term GDP-projections the composition of the population follows UN convention and is uniform across all scenarios.

Demographic trends by income groups

Years



Source: UN

of renewables in the energy mix increases significantly. Increasing carbon levels in the atmosphere lead to a slight negative climate impact on economic growth from the mid-2030s onwards. The global economy grows on average by 2.3% per year between 2026 and 2050, as financial and fiscal reforms and investments in digital infrastructure enhance capital efficiency. Growth over the entire projection period is 2.5% per year on average.

Renewal: a sustainable economy

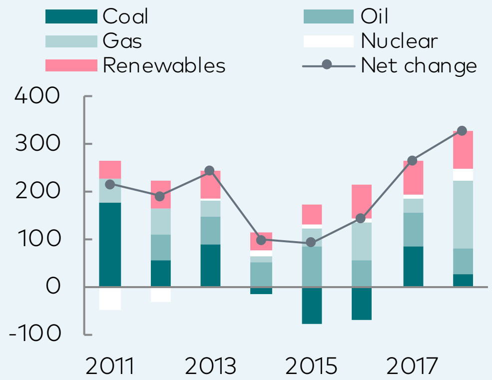
The transition towards more investment in renewables gradually delivers higher economic growth than marginal investments in traditional energy systems. Subsidy schemes on both fossil fuels and renewable value chains are removed, and gradually green investments achieve the highest return on capital. Policy makers work to promote the green shift and the global price on carbon emissions rises to help fund new low-carbon solutions. The green shift is interlinked with a rapid digitalisation and automatisation of the energy industry, which in turn contributes to efficiency gains in the global economy. Economies of scale and technological progress apply to the industry and spread by global arrangements and joint ambition in areas important for international green growth. The transformation of energy systems implies a transition away from heavy industry towards lighter industry and a more service-based economy. This requires a shift towards a more labour-intensive economy and creates more local jobs, which are welcomed by governments. Current fossil fuel exporting regions in particular experience challenges that must be addressed by diversification of their economies. In *Renewal*, the world avoids negative climate impact on growth, and the level of geopolitical conflict is low. The positive effects offset the negative effects represented by the impact of moderated consumption. After a period of undershooting with lower economic return due to the cost of scrapping some of the existing fossil infrastructure, the economy overshoots relative to *Reform* and economic growth picks up. In compound annual growth rate (CAGR) terms, world GDP growth for the period 2026-50 in *Renewal* is 2.6%, while the whole projection period delivers a similar average growth rate at 2.6%.

Rivalry: a volatile economy

In *Rivalry*, the benefits of globalisation are reduced due to less trade and less transfer of technology and learning between regions. This, again, results in less optimisation of productivity and yield, caused by reduced focus on comparative advantages. Weaker institutions and increased geopolitical tension drive growth in military expenses. From the late 2020s the negative climate impacts are increasing in scale. Global warming and negative environmental consequences, including local pollution, gradually escalate. This particularly hurts the economic activity in less developed economies and countries close to the Equator. Throughout the forecasting period, the Americas enjoy thriving inter-regional trade counteracting increased protectionism in the region and enabling relative prosperity. Europe is unable to compete efficiently on the global scene and drifts into stagnation and protectionism. In CAGR terms, world GDP growth for the period 2026-50 in *Rivalry* is 2.0%, while the whole period to 2050 delivers a slightly higher 2.2% average growth.

The global energy market

Change in global TPED by fuel
Mtoe



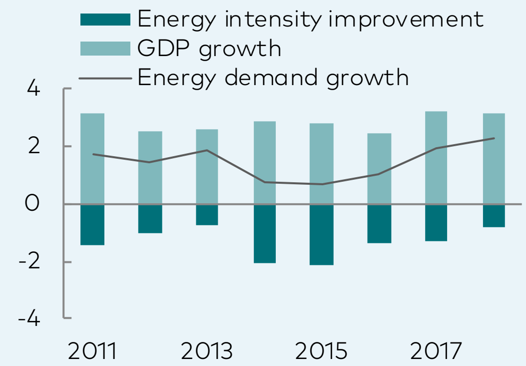
Source: IEA

Current situation

Global energy demand experienced another strong year in 2018, growing at 2.3%, which is the fastest pace since 2010, when the global economy was recovering from the financial crisis. The US and China alone accounted for about two-thirds of the growth. After three years of decline, US energy demand rebounded on the back of strong economic growth and weather-related demand, caused by a cold winter and a hot summer. India was the third largest source of new demand, while mature economies such as the EU and Japan experienced flat demand. Gas positioned itself as the fastest growing fossil fuel and accounted for the largest increase in absolute terms of all fuels. In 2018, global gas demand rose by about 170 bcm, a remarkable 4.6% increase from 2017, led by growth in China and the US. Renewable energy, including all renewable electricity generation and bioenergy, grew by 4% and was the second largest source of incremental energy demand. Oil demand grew at 1.3 mbd in 2018, slightly slower than in 2017, but still a healthy rise. Coal demand increased for the second year in a row, but demand is still below the peak in 2013. Nuclear electricity production grew for a sixth consecutive year due to new reactors being commissioned in China, as well as the restart of four reactors in Japan.

The energy intensity of the economy, or how much energy is used per unit of economic output, is a key metric to put energy demand growth into context. The improvement in energy efficiency was significantly lower in 2018 than some years earlier – the energy intensity of the global economy only improved by 0.8%. The development over the last years has been particularly weak in the US and China, where economic growth has been relatively energy intensive.

Global energy intensity development
%



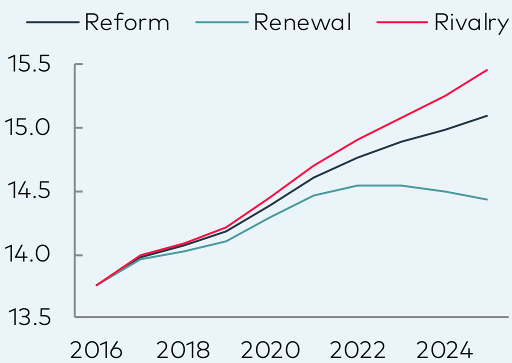
Source: IEA, Equinor

Outlook to 2025

Energy demand developments are assumed to start diverging quite rapidly after 2020. Demand growth in *Rivalry* is in line with recent trends, while *Reform* and especially *Renewal* mark a slowdown in global energy demand growth and improvement in energy intensity. In *Renewal*, demand growth slows down to 0.2% and energy intensity improvements are twice as fast as in *Rivalry*. The development per fuel also starts developing very differently between the scenarios towards 2025, particularly for coal and oil. In *Renewal*, coal demand goes into decline immediately, while oil demand peaks in the early 2020s. In *Reform*, coal demand flattens out and starts to decline in the early 2020s, while oil demand continues to grow past 2025. In *Rivalry*, both coal and oil use rise past 2025.

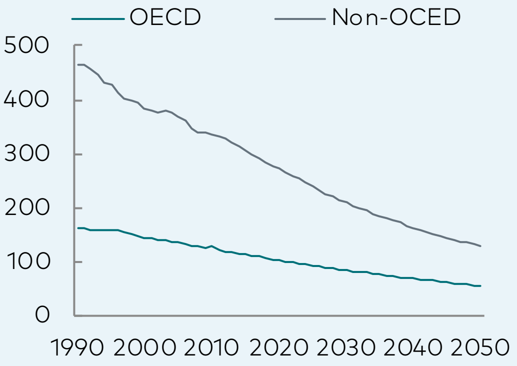
It may be prudent to ask how fast energy markets can change, given the inherent inertia and vastness of the energy system. Investments typically have long lead times and projects may take many years to be completed. There are however indications that this paradigm is being challenged with the onset of solar and wind electricity generation and shale oil and gas production. In these sectors, investment decisions can be made faster, new solar plants can be built in less than a year, and shale drilling has very short lead times. There are also examples of how the outlook for a whole commodity can change fundamentally in a relative short period of time. Up until 2013, coal was the fastest growing fossil fuel. Most projections showed that global coal demand would continue to grow for the next 15-20 years. Now many projections show that Chinese and global coal demand may have peaked and will never move above the levels seen in 2013.

Global TPED by scenario, 2016-25
Btoe



Source: IEA (history), Equinor (projections)

Energy intensity development in Reform
Toe/million USD (Real 2010 USD)



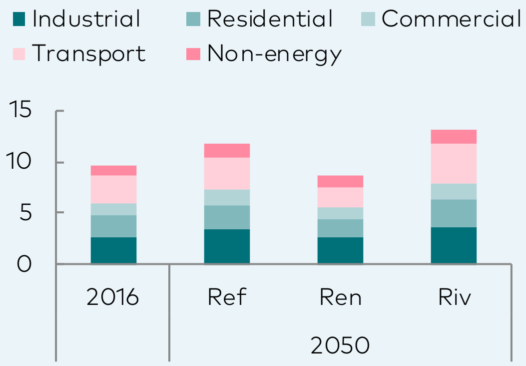
Source: IEA (history), Equinor (projections)

Sources of energy efficiency improvements

Area of the economy	Measures
Buildings	Retrofit insulation, new windows, heat pumps, LED lighting, modern appliances, smart meters
Consumers	Reduced consumption of goods and services, recycling and reuse, public transport
Industry	New equipment, automation, waste reduction, electrification
Transport	Fuel efficiency, electrification, optimised logistics
Power/ heating	Co-generation, decommissioning of old thermal plants, shift to renewables

Source: Equinor, various sources

TFC by sector and scenario
Btoe



Source: IEA (history), Equinor (projections)

Outlook beyond 2025

Reform: steady demand growth

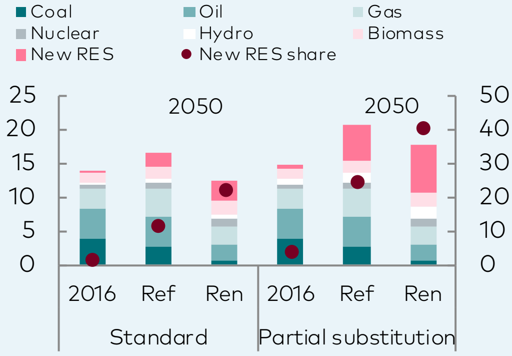
Energy demand grows at a steady pace towards the mid-2040s when demand plateaus and in 2050 stands at a level 20% higher than in 2016. Demand growth is slower compared to current and historical trends, as energy intensity improvements, helped by policy, technology and market development, pick up to a speed that is about twice the historical average since 1990. Measured over the whole projection period, energy demand on average grows by 0.5%. North America, EU and Industrial Asia Pacific experience declining demand, while all other regions increase energy use. The fastest growing regions are Southeast Asia, India and Africa. In absolute terms, India sees the largest growth, followed by China. Despite very different starting points, all regions, both developed and developing, have impressive improvements in energy intensity. Developed countries have less energy intensive economies and a different economic structure with lighter industries, larger public sectors and larger service sectors. Developing countries have an energy intensity that is almost three times as high as developed countries. This improves considerably towards 2050, as their economies evolve, and energy intensity declines towards the same level as that experienced today in developed countries. At the same time, however, developed regions' energy intensity is cut in half.

There are a number of ways to measure energy use. TPED is the sum of all sources of energy, either used directly by end users as fuel or via electricity. It also includes energy that is used to transform energy into different forms as well as efficiency losses in electricity and district heat generation. Another way to look at energy demand is to measure TFC. TFC measures how much energy is used directly by end users, comprising either fuels for direct burn or electricity and heat. The growth in TFC between 2016 and 2050 is 23% in *Reform*, compared to the 20% growth in TPED. This indicates that the amount of energy available to provide energy services, or useful energy, grows slightly more than what TPED developments indicate. Another important observation is that direct use of fuels grows at a much slower pace than the use of electricity. Electricity is much more efficient than the direct burn of fuels and provides much more useful energy. These topics are discussed further in the electricity chapter. The largest demand sector today is the industrial sector and it remains the largest over the projection period. The non-energy sector, which uses energy as a raw material or feedstock (mainly) for petrochemical products, grows over twice as fast as the other sectors.

Reform also contains large changes in the fuel mix with a declining fossil fuel share and a growing renewable share. Fossil fuel share declines to 67% of TPED, from 82% in 2016. Oil remains the largest source of energy, with a share of 26% in 2050, down from 32% in 2016. Total oil demand grows towards 2030, driven by increasing demand from transport and petrochemicals. Due to electrification, transport demand for oil starts going into decline just before 2030 and leads to a peak in oil demand. Coal demand gradually declines throughout the period and drops from 27% of the mix to 17%. Gas is the best performing fossil fuel, growing steadily, but moderately, towards 2040 and ending up at 24% of TPED by 2050, with demand increasing in all sectors. New renewables grow from 2% of TPED in 2016 to 12% by 2050.

TPED standard and partial substitution, by scenario

Btoe (lhs), new RES % share of TPED (rhs)

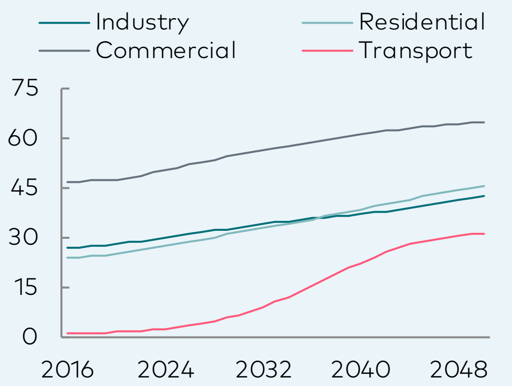


Source: IEA (history), Equinor (projections)

There are however alternative ways to calculate the contributions of renewable electricity to the energy mix. Energy Perspectives is based on IEA's method of accounting for TPED. IEA converts hydro, wind and solar electricity into energy terms based on the energy content of the electricity and does not assume any inefficiencies or losses in the conversion process. Before, IEA used a partial substitution method. This gave electricity a primary energy value equal to the amount of fuel required to generate the electricity in a thermal power station. Applying this method, new renewables increase their share from 1.7% in 2016 to 4.2%, hydro increases its share from 2.5% to 6.3%, and fossil fuels now account for only 76% of the mix. The change in 2050 would be even larger, with new renewables accounting for 25% of TPED and fossil fuels only 54%. There are pros and cons of both approaches, but the partial substitution method arguably provides a better measurement of the contribution of renewable electricity to the energy mix. The key point is that whichever accounting method is used, the results in terms of TFC remain unchanged, and so will the amount of fossil fuel supply required globally.

Share of electricity in TFC by sector in Renewal

% shares



Source: IEA (history), Equinor (projections)

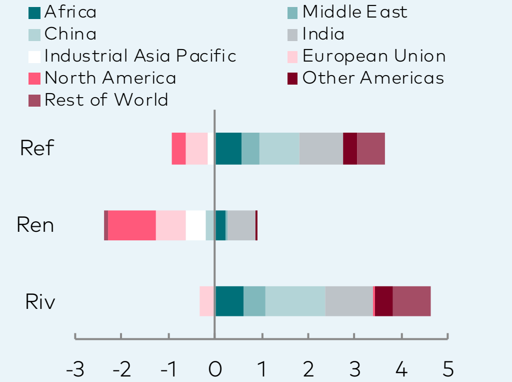
Renewal: imminent peak in demand

In *Renewal*, the necessary CO_2 emission reductions in the energy sector are, amongst other factors, achieved through energy efficiency improvements that are three times higher than the historical trend. By 2050, TPED is almost 10% lower than in 2016, in spite of the global economy being 2.4 times larger. Energy demand peaks already in 2022, and measured from the peak, demand declines on average by 0.6% every single year. To put this into perspective, the statistics going back to 1960 show that global energy demand has only dropped three times before and never for more than two or three years in a row. The changes required in *Renewal* are unprecedented and rely on a series of positive and impactful factors coming forcefully together to allow the economy to grow while energy demand declines, both policy, technology, and consumer behaviour.

All developing regions, except China, experience some energy demand growth in *Renewal*. The combined annual growth rate for these regions will be 0.5%, less than half of that in *Reform*. China, already being the largest energy user in the world, has an enormous potential for energy efficiency improvements, and demand declines by an average of 0.2%. Energy demand must drop at a much faster pace in developed regions, with an average decline of 1.4% per year. However, all regions need to undertake rapid energy efficiency improvements as their economies grow.

Change in TPED by region and scenario, 2016-50

Btoe

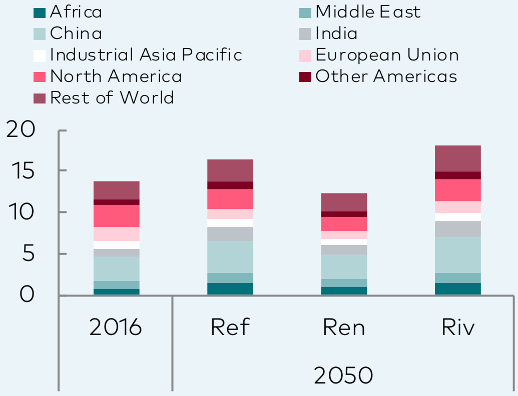


Source: IEA (history), Equinor (projections)

TFC follows a similar path to TPED, but the average number masks the diverging developments between fuels for direct use and electricity. Electricity demand grows by 1.8% per year, which is very close to the growth rates from *Reform*, while direct burn of fuels declines by 1.1% per year. All sectors reduce energy demand except non-energy. Energy used as feedstock in the non-energy sector does not by itself lead to CO_2 emissions as it is not burned. Whether a final product, such as plastics, is ultimately incinerated rather than recycled or placed in a landfill, is not accounted for in the energy-related CO_2 emissions. Other sectors such as transport, industry, residential, commercial and the public sector will need to reduce energy demand through various efficiency measures, including reducing energy use for lighting, heating and cooling, improving building insulation and switching to more efficient and modern

TPED by region and scenario

Btoe



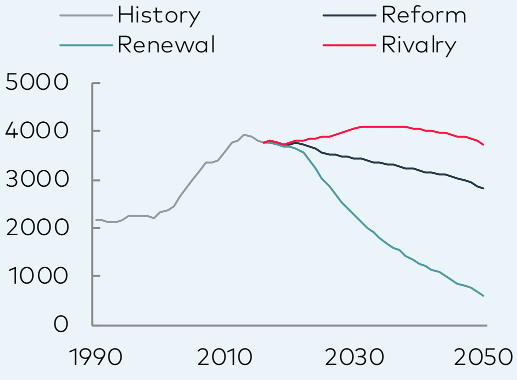
Source: IEA (history), Equinor (projections)

India's energy demand is the fastest growing in all scenarios

Source: Arihant Daga/Unsplash

Global coal demand by scenario

Mtoe



Source: IEA (history), Equinor (projections)

industrial processes. Electrification is a key measure to achieve this, and the rate of electrification of TFC in all sectors grows much faster than in *Reform*. In industry, the share of electricity in TFC grows to over 40% by 2050, and in the residential sector it moves above 45%.

The changes in the energy mix in *Renewal* are substantial. The share of fossil fuels declines to 46% of TPED and new renewables increase their share to over 22% in 2050. Using the partial substitution method gives a share of fossil fuels of only 27% in 2050, while new renewables would surpass fossil fuels with a share of 35%. Coal demand is almost eradicated by 2050, first in developed countries and later in developing regions. Gas benefits from the phase out of coal, and gas use increases by almost 20% towards the mid-2030s. Eventually, as coal is phased out and renewables continue to grow, the demand for gas peaks and starts falling. Oil demand peaks in the early 2020s due to swift electrification of road transport, and by 2050 total oil demand drops to 52 mbd, just a little over half of today's levels. The clear winner in *Renewal* is solar and wind electricity, where the strong regulatory support continues, and the high deployment leads to continued rapid cost and technology improvements.

Rivalry: no peak in demand

In the *Rivalry* scenario, energy demand continues to grow throughout the whole projection period with an annual growth rate of 0.8%, as there is less focus on climate and energy efficiency policies, and technology development is slower than in the other scenarios. Energy intensity improves roughly in line with the historical improvements since 2010, but faster than historical trends going back to 1990. All regions experience higher demand growth in *Rivalry* compared to the two other scenarios. Energy use in developed regions only declines slightly towards 2050, while developing regions experience significant growth as total demand goes up by over half by 2050. TFC grows at a slightly faster rate than TPED. Electricity accounts for a growing share of TFC, but to a lesser extent than in the two other scenarios. Specifically, the electrification of transport develops much more slowly. In *Rivalry*, the share of electricity in transport approaches 9% by 2050, while in *Reform* and *Renewal* the comparable figures are 17% and 31%, respectively.

The energy mix changes much more slowly in *Rivalry*. The share of fossil fuels declines to 73% of the mix. New renewables expand quickly, ending up at 2050 levels which are six times as high as in 2016. Despite the impressive growth, new renewables make a limited dent in the global energy mix, accounting for about 8% by 2050. Considering the partial substitution method, fossil fuels and new renewables would account for 62% and 18%, respectively. In *Rivalry*, global coal demand continues to expand towards the early 2030s, as all regions use more coal compared to *Reform*, and demand grows past the previous peak of 2013. After 2030, coal demand gradually declines and the share of coal in the energy mix ends up at just over one-fifth by 2050. Gas demand develops very similarly in *Rivalry* and *Reform* on a global level, even though there are important differences on a regional level. Gas surplus regions use more gas, while gas importing regions use less, as there is less appetite to be dependent on LNG and pipeline imports. Global oil demand does not peak in *Rivalry* and continues to grow by 1.0-1.5 mbd per year until 2030 before growth slows down.

The 1.5° ambition: a tall order

Replacing 2° with 1.5° as the targeted cap on global warming, and consequently as the yardstick for climate change mitigation efforts, was first proposed by the Alliance of Small Island States ahead of the climate conference in Copenhagen in 2009. The proposal was dismissed as unrealistic. But the idea that 2° might not be stringent enough was sown, and at the Paris meeting in 2015 the lower target of well below 2° and pursuing efforts to limit the temperature increase to 1.5° was endorsed by 106 countries. The pros and cons of aiming for 1.5° were, however, unclear due to a lack of research on how much would be gained and how much extra effort that half degree would take, and the IPCC was instructed to initiate research and put together a report for release in 2018.

This report, released last October, has become a focal point for climate policy discussions. Those arguing for the more ambitious target have emphasised its warnings of severe impacts on ecosystems, biodiversity, sea levels and general living conditions in exposed areas linked to temperature increases in the 1.5-2° interval. More mainstream observers have highlighted the huge challenges of achieving the target as illustrated by its four "illustrative model pathways". Net CO_2 emissions decline by 91-97% between 2010 and 2050 in these pathways and hit zero during the 2050s.

The 1.5° ambition calls for more of the same measures that are on the table for the 2° and "well below 2°" targets. The world must rapidly become more energy efficient and reduce its use of fossil fuels, especially coal. An obvious way forward is to increase electricity use at the expense of other fuel use even faster than in a 2° consistent future, decarbonise power generation to the extent technically possible, and step up efforts to extend the borderlines for the technically possible. Not-in-my-backyard attitudes to the deployment of wind turbines and solar panels must be set aside. Countries that have dismissed nuclear may need to reconsider. Hydrogen from electrolysis or from fossil fuels with CCUS may become indispensable. Natural carbon sink enhancement and radical changes in land use policies must be fast-tracked. The 1.5° ambition will also require a hard look at options outside the mainstream policy range, such as enforced lifestyle changes, including travelling and dietary habits. At the end of the day, global economic growth, as traditionally measured, which continues relatively unaffected in most 2° scenarios, may also need to come down.

The key variable is *net* emissions, meaning that positive gross emissions after the 2050s are allowed, provided that these emissions are captured and utilised or stored, or compensated for by "negative" emissions. "Overshoot" in the early years is also possible, provided that excessive emissions now are compensated for by negative emissions later. Only one of the four model pathways in the 1.5° report does not rely on vast amounts of CCUS before 2050 and negative emissions after 2050.

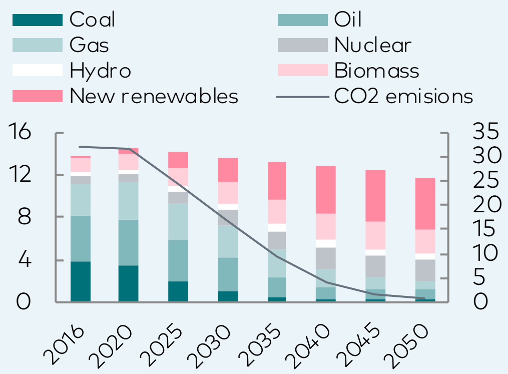
Achieving a 1.5° compatible emission level by 2050 with the energy demand and fuel mix developments we assume for *Renewal* would have required CCUS and negative emission technologies to remove almost 10 Gt CO_2 per year by then. To gain an understanding of what it might take to meet the 1.5° ambition *without* resorting to more CCUS than we assume for *Renewal*, we have developed a sensitivity for a 410 Gt CO_2 budget. 410 Gt represents the energy-related share of the 570 Gt budget mentioned in the 1.5° report as giving a 66% probability of attaining the target, over the 2019-2100 period. The 2019-50 budget is assumed to be the same, since emissions must be close to net zero by 2050.

In this sensitivity, global TPED declines by 20% between 2019 and 2050 with coal use dropping by 93%, oil use by 77% and gas use by 79%. Nuclear and hydro are up by 152% and 77%, respectively, and new renewables output increases by 20% per year or 725% over the whole period. The energy intensity of the world economy declines by 3.1% per year. Global energy-related CO_2 emissions are 0.7 Gt by 2050, down by 98% compared to their level by 2020. The emission decline rate increases from slightly above 5% per year in the early 2020s to 15-16% per year between 2035 and 2050.

Might this be doable, in the face of a growing world population, a host of other development goals and unavoidable system rigidities? History provides no clues, since an energy transition like this has no historical precedence. A very strong and universally shared political will would of course be needed. What else – technology breakthroughs, economic transfers, forced behavioural changes and other factors – might be needed, remains open to question.

World TPED and energy related CO_2 emissions in 1.5° sensitivity

Btoe (lhs), Gt (rhs)



Source: IEA (history), Equinor

The link between energy consumption and human development

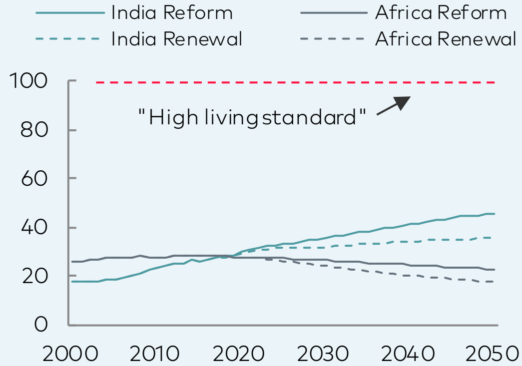
It is generally accepted that there is a strong link between energy consumption and the Human Development Index (HDI). HDI was developed by the UN to create a measure of development of a country as an alternative to only using economic growth. The main indicators that form the HDI are life expectancy, education and income. Correlations between HDI and energy use per capita show that increasing energy use up to a level of at least 100 Gigajoules (GJ) per capita per year is consistent with improved human development. The divergence between energy use per capita in different countries and regions around the world is enormous. In North America, use is above 300 GJ per capita, in Europe around 150 GJ and in India and Africa it is around 30 GJ. It is estimated that as much as 80% of the global population use less than 100 GJ per capita. In most outlooks this is not set to improve much for the developing regions. In fact, African per capita energy demand declines towards 2050 in all Energy Perspectives scenarios due to population growth outpacing energy demand growth. India's per capita use increases, but even by 2050, it is only one-third to half of the "necessary" 100 GJ.

There are however some drawbacks with this simple correlation. Firstly, it measures the total energy use of the economy, while if it is the living standard of the poorest individual we are interested in, this is arguably closer linked to the energy use related to that person's household, i.e. in the residential sector. Secondly, with more and more of the modern goods that define a high living standard being run on electricity, it may be more appropriate to look at electricity demand in the residential sector as a measure of how living standards are developing. Today, an average household in the EU uses about 4000 kWh per year, while households in India and Africa only use about one-fourth of that. The outlook shows that electricity demand per household in India and Africa will substantially increase. In *Renewal* by 2050, African household electricity use triples and in India it quadruples.

This increasing electricity demand in Indian and African households paints a very different picture from looking at energy use per capita. It shows that there is a significant convergence in electricity demand between the EU and India and Africa. In fact, Indian household electricity use may surpass that of the EU by 2050 in *Renewal*. It is important to keep in mind the relative size of the households, in EU the average household size is 2-2.5 people, while in India and Africa it is on average above 4.5. In any case this is a remarkable development. At these levels, Indian and African households should have enough electricity to run the modern gadgets and appliances that Western consumers take for granted. It also shows that it is possible to improve the living standard despite modest gains in, or even decreasing, levels of energy use per capita.

Energy demand per capita

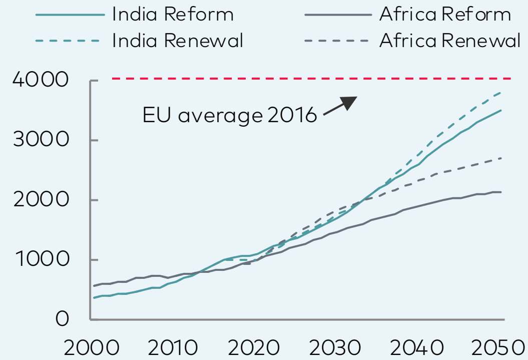
GJ



Source: IEA (history), Equinor (projections)

Electricity demand per household

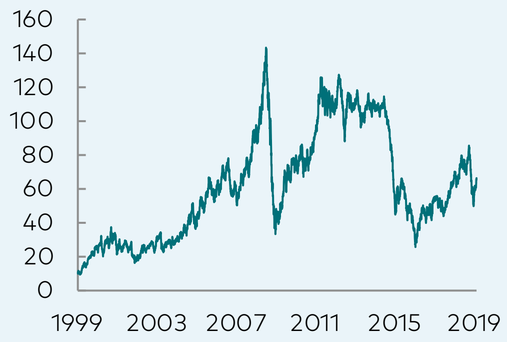
kWh



Source: IEA (history), Equinor (projections)

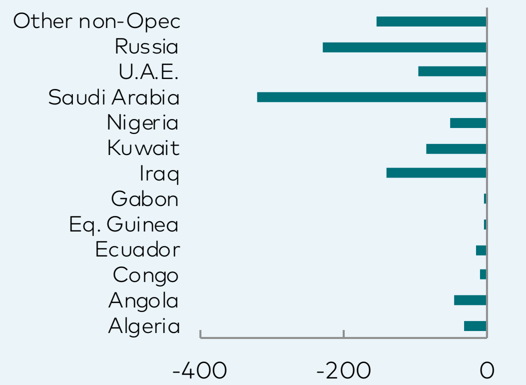
The global oil market

Oil price Dated Brent
USD/bbl



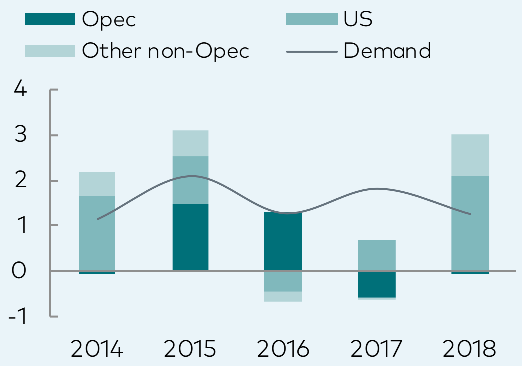
Source: Platts

Opec+ supply cuts to be implemented by 1H 2019
kbd



Source: Bloomberg

Annual change in global oil balance
mbd



Source: IEA

Current situation

Imagine a global commodity market where a large group of suppliers are acting as an alliance, managing the price of the commodity through its combined supply. Now imagine that demand for this commodity increases rapidly, while at the same time the alliance fails to increase their capacity. Finally, imagine then what happens when the price becomes so high for such a long period of time that it allows for new competitors to enter the market place with price-competitive and flexible supply.

It is in the aftermath of these realities that the oil market currently finds itself. Despite multiple attempts by the supplier alliance to remedy the situation, the oil market has been chronically oversupplied since the beginning of 2014.

In the spring of 2019, Opec and contributing non-Opec countries (Opec+) are in a coordinated supply cut arrangement, the second one in three years. It is expected that there will be more Opec management needed in the years to come. After commercial storage levels dropped below the five-year average in the spring of 2018, Saudi Arabia and Russia opened the taps to ease the quick tightening following from the strong declines in output from Venezuela and to cover for lost Iranian exports, as the US reimposed nuclear sanctions. The market sentiment went bullish during the third quarter of 2018 and drove prices high. The anticipated tightness in the crude market never surfaced, much due to the US issuing import waivers to several of Iran's crude customers, but also because of signs of slowing global economic growth and an emerging trade war between US and China.

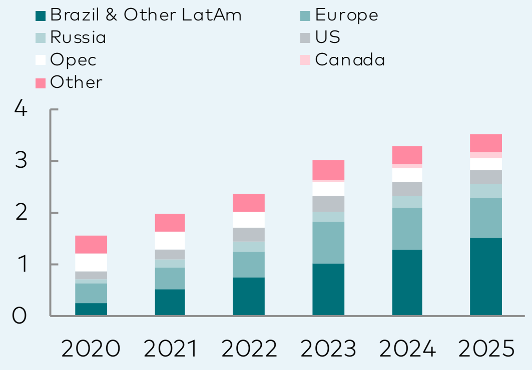
The US shale oil producers emerged competitive from the 2015-17 period of low prices and are delivering strong volume growth. Other non-Opec producers are still delivering on projects approved pre-2014 and will continue to do so up until 2022. Net non-Opec supply growth is expected around 1.9 mbd for 2019, where 1.3 mbd of this is US shale and 0.5 mbd US NGLs. Global oil demand grew by 1.3 mbd in 2018 and is expected to grow by around 1.5 mbd in 2019, meaning Opec+ needs to maintain its agreement to manage the market. The global crude quality mix has become lighter as heavy oil from Venezuela and Iran has been significantly reduced. Opec cuts have predominantly been in heavy crudes, and simultaneously light tight oil production in the US has increased.

Outlook to 2025

As the impetus of the high prices up until 2014 is still significant, the impact of low investment levels in recent years is yet to be felt on supply. In *Reform*, US tight oil supply grows by an average of 0.5 mbd per year from now to 2025, reaching more than 10 mbd. To this, 0.2 mbd annual growth of NGLs can be added. Net non-Opec oil supply excluding US shale is expected to grow by an average of 0.35 mbd annually up until 2025.

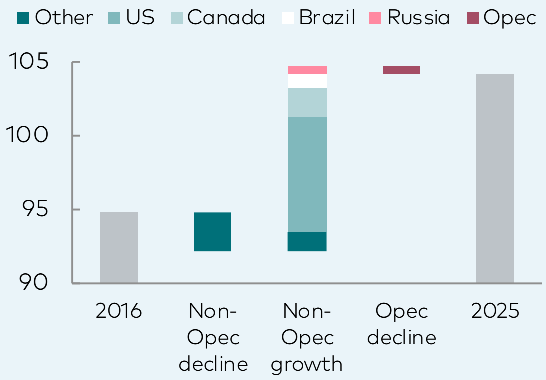
The growth will come from several sources, including Brazil, Canada and the North Sea, offsetting declines in Latin America and West Africa. Shale oil activity outside the US is primarily centered in the Vaca Muerta shale play in Argentina.

Supply from projects sanctioned, but not in production, by February 2019
mbd



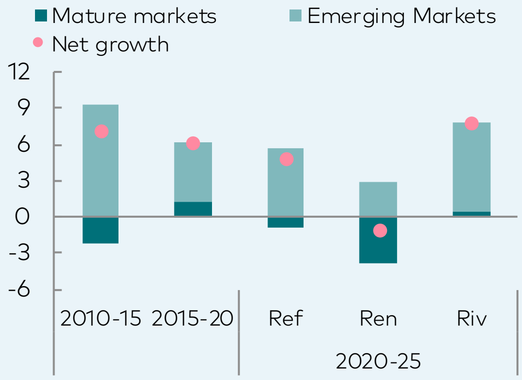
Source: Wood Mackenzie, Equinor

Change in oil supply in Reform, 2016-25
mbd



Source: IEA (history), Equinor (projections)

Global oil demand growth by scenario
mbd



Source: IEA (history), Equinor (projections)

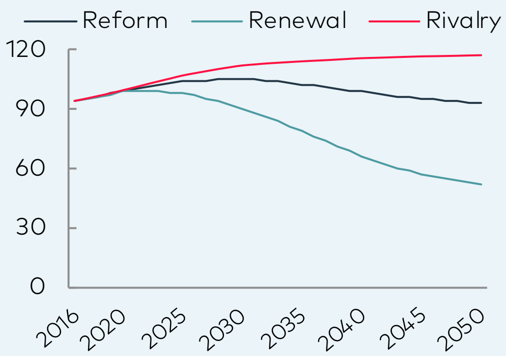
Faced with growth in new supply, Opec+ will have the difficult task of carefully balancing the market in a price range that does not encourage rapid shale supply growth, but ensures high enough oil revenues to balance Opec countries' budgets. While Libya, Nigeria and Iraq are well on their way in recovering from significant supply disruptions, the situation in Venezuela is still deteriorating and there is still an ongoing strife between Saudi Arabia and Iran.

In *Reform*, the average annual oil demand growth from 2018 to 2025 is expected to be 1.0 mbd, resulting in total oil demand of 104 mbd in 2025, leaving no room for growth in Opec supply. The main driver is high economic growth in emerging markets. The transport sector is still by far the largest contributor, representing almost two thirds of the growth. Increasing wealth brings with it a higher demand for more goods made of petrochemicals, and the non-energy sector represents a quarter of the total oil demand growth up until 2025. The mature economies have seen an uptick in oil demand on the back of low oil prices from 2015 to 2019. This development is expected to turn to structural decline as energy intensity improves, the pace of economic growth slows, and the population grows older. North America is a bit of an exception, where petrochemical demand has been strong in recent years and will continue to grow from levels around 3.3 mbd in 2018 to 4.2 mbd in 2025, with significant new ethane cracker capacity coming on stream, incentivised by easy and cheap access to ethane from US tight oil and gas supply. This results in a 2% increase in North American oil demand between now and 2025.

With respect to the demand for individual oil products, the International Maritime Organization (IMO) lowering of the cap on sulphur in bunker fuels used in international waters will reshape the fuel oil market. Refinery upgrades and desulphurisation capacity expansions are underway, and exhaust gas scrubbers are being installed in vessels to allow the continued use of high sulphur fuel oil (HSFO). Most likely, there will still be a surplus of HSFO which could end up in the power generation sector. Thus, in *all* scenarios, the decline in fuel oil used within the power and heat segment up to 2025 slows down temporarily. Gasoil demand increases further, as vessels switch from fuel oil to gasoil to be compliant with the regulations. The implementation of IMO regulations will change the dynamics between light and heavy grade crude oils, but this could be offset by the change in the crude slate currently happening in the market.

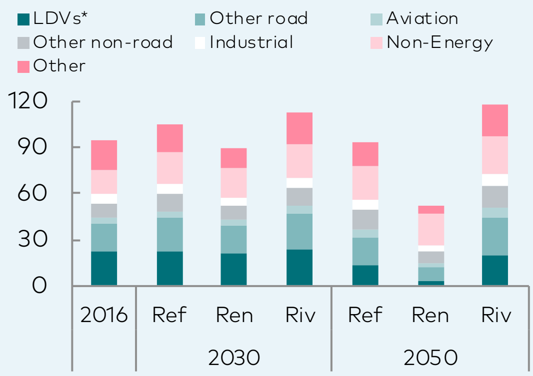
In *Renewal,* oil demand peaks in the early 2020s and declines to 98 mbd in 2025. Oil demand in all sectors is lower than in *Reform* in 2025, with the transport sector taking the lion's share of the difference. Lower demand puts downward pressure on prices which affects tight oil supply, increases decline rates of conventional reserves and in isolation puts more strain on Opec member countries' economies. Oil demand in *Rivalry* is based on assumptions of less electrification of the transport, industry and residential sectors, and lower growth of new renewables in the power generation sectors, which results in total oil demand of 107 mbd by 2025, 3 mbd higher than in *Reform*. Particularly the slower electrification of the road transport segment leads to higher oil demand. In *Rivalry*, Opec supply suffers from political unrest and disruptions, while increased prices boost non-Opec production.

Global oil demand by scenario
mbd



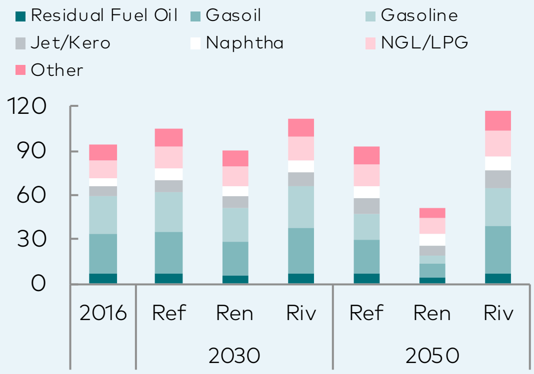
Source: IEA (history), Equinor (projections)

Global oil demand by sector and scenario
mbd



*LDVs: Light Duty Vehicles
Source: IEA (history), Equinor (projections)

Oil product demand by scenario
mbd



Source: IEA (history), Equinor (projections)

Outlook beyond 2025

Reform: demand peaks in 2030

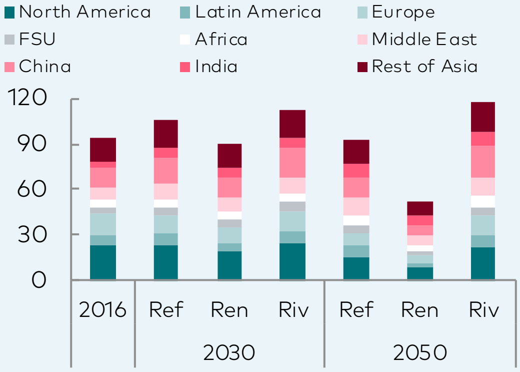
Oil demand grows robustly through the early 2020s, levels out in the second half of the decade and peaks at 105 mbd around 2030 before declining to 93 mbd by 2050. Electrification, particularly in transport, and efficiency gains in all sectors offset the effect of continued growth in the petrochemical industry, aviation and shipping. In emerging economies, economic growth remains strong enough to sustain continued oil demand growth for the next two decades before stagnating from 2040. Emerging economies' demand growth, excluding China, averages 1% per year between 2025 and 2050. Chinese oil demand growth peaks together with global oil demand around 2030, before declining by 0.6% on average per year towards 2050. In mature economies, the downward pressure on oil due to electrification and efficiency gains is not outweighed by economic expansion, resulting in declining demand from 2025. Growth in global aviation and shipping demand continues after 2025, particularly in emerging markets, and partially compensates for the decline in road transportation, resulting in a total oil demand in the transport sector of 49 mbd in 2050, down from 55 mbd today.

The growth in use of polymers in new applications seen over the last years continues. In *Reform*, polymers have contributed to revolutionising the design of car body exteriors, resulting in improved fuel efficiency, improving dent resistance, lower production costs and more innovative concepts. Polymers are also entering the construction industry where plastic composite materials can replace wood and to a smaller degree steel. A continuation of the plastic and other polymers revolution means that the industry will face a mounting pollution problem and further threats to marine life caused by the disposal of plastic bags, bottles and other packaging material. Recycling is the obvious solution, but recycling of plastics is expensive and currently at a low level. Overall annual growth in oil demand in the non-energy segment is 0.8% from 2025 to 2050, mainly driven by increasing demand for goods in emerging economies.

Electrification and access to new renewables reduce the share of oil in other sectors. Residential and commercial oil use decline in most regions. However, in some emerging economies like India and Africa, LPG replaces biomass in cooking and heating. Industrial oil demand increases in some of the emerging economies like India and Africa as their economies develop, while levelling out and going into decline in China and the mature economies where manufacturing stagnates. Power generation oil use starts declining at a faster pace after a short period of support due to the impact of the IMO regulation in the early 2020s, providing cheap fuel oil.

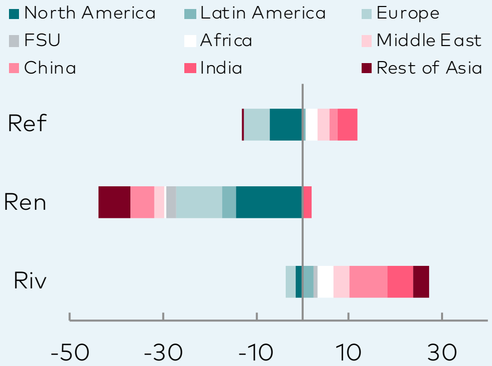
In emerging economies, the share of gasoline in oil demand remains relatively high despite expectations of increased electrification of the road transport sector. However, electrification will become clearly evident in the mature economies, where the share of gasoline in total oil demand declines from 27% in 2025 to 15% in 2050. Gasoil/diesel shows a slower decline as it is also used outside the transport sector. Growth in the non-energy and residential sectors result in LPG and naphtha increasing their share of the total global oil demand from 17% in 2025 to 23% in 2050. Also, the share of jet/kerosene goes up, driven by growth in aviation demand. The contribution of other products remains broadly stable. New refinery capacity is needed to replace aging refineries, and new refineries are brought on stream in

Oil demand by region and scenario
mbd



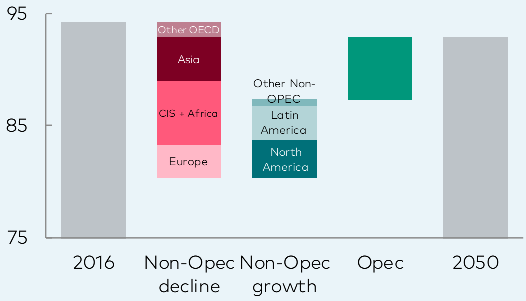
Source: IEA (history), Equinor (projections)

Change in oil demand by region and scenario, 2016-50
mbd



Source: IEA (history), Equinor (projections)

Change in oil supply in Reform, 2016-50
mbd



Source: IEA (history), Equinor (projections)

growth regions, like Asia. The change from gasoline production to distillates towards 2050 directionally favours investments in hydrocrackers, as they represent higher yields of jet/kerosene and gasoil/diesel. Growth in LPG supply fits with growing demand for lighter products, while investments in new complex refinery processes, like catalytic reformers, alkylation and catalytic crackers geared towards gasoline production, lose momentum.

Significant investments are needed going forward to replace decline from existing conventional non-Opec supply and to cover future global oil demand. However, a market in post-peak-demand will likely see more cautiousness from investors, exacerbating the risk of undersupply and driving price volatility. Conventional non-Opec supply peaks in the mid-2020s, preceding the peak in demand, while the high growth period in tight oil supply, in the US and elsewhere, comes to an end in the early 2030s. Supply from new offshore fields in Brazil and other Latin American countries continues to grow into the 2030s, but not enough to compensate for decline in other regions. Opec production grows steadily over the full period, reaching more than 47 mbd in 2050, including 10 mbd of NGLs. Global crude quality will gravitate towards medium quality after the decline of shale post 2030. This could pose challenges to refining capacity if the upgraded refineries are not well prepared.

Renewal: demand in steady decline

All sectors use less oil in *Renewal* compared to *Reform*, leading to a global oil demand around 52 mbd in 2050. Through continued policy push, particularly prior to 2025, and faster battery technology development, the electrification in the transport sector speeds up relative to *Reform*. Road transport demand is further depressed by energy efficiency improvements, improved logistics and changes in consumer behaviour, with many more using public transport. *Renewal* also sees conscious policies to reduce the use of cars and develop efficient transport solutions in large cities. The consequence is a massive 73% reduction in oil demand for road transport from 2025 to 2050, to a level around one third of that in *Reform*. In aviation, oil demand is declining, due to energy efficiency and biofuels and eventually electricity eating into the fuel mix along with, ultimately, changed consumer behaviour. Biofuels, gas and electricity are becoming more important in maritime transport, at the expense of oil, growing its combined share from almost nothing in 2025 to more than 30% in the maritime transport energy mix by 2050. Demand for petrochemical products expands in *Renewal*, driven mainly by the energy efficiency gains of switching from metals to lighter materials. However, plastics do raise other environmental issues which also receive even more attention in *Renewal* than in *Reform*, dampening this growth. In other sectors quicker improvements in efficiency and faster electrification are the main drivers for lower oil demand. *Renewal* lacks the support from a growing LPG demand in the household and commercial sectors in Africa and India seen in *Reform*, due to faster development of electricity grids and the use of new renewables like solar panels and wind turbines in combination with batteries.

In 2050, the share of gasoline in total oil demand in *Renewal* is less than half of that in *Reform*. The share of gasoil in products demand is also declining, while the share of jet/kerosene and residual fuel oil stays similar to that in *Reform*. LPG and naphtha, on the other hand, increase their share in this scenario. Lower total demand for refined

Oil supply change in Renewal and Rivalry versus Reform beyond 2030

Region	Renewal	Rivalry
North America	↓	↑
Latin America	↓	↑
Europe	→	→
CIS	↓	↑
Asia	→	↑
Opec	↓	↑
Rest of World	↓	↑

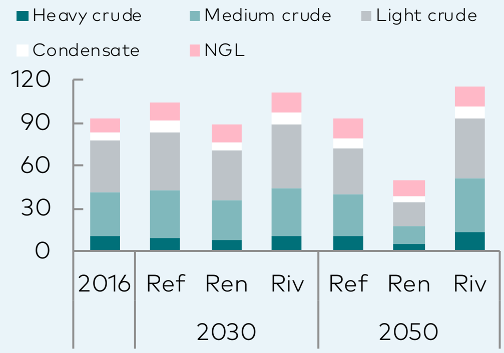
Source: Equinor

Plastic waste exhibition at MAAT in Lisbon

Source: Martijn Baudoin/Unsplash

Crude oil quality mix by scenario

mbd



Source: Equinor

products reduces the need for refinery capacity by 45% in 2050, accelerating the shutdown of older refineries.

On the supply side, the main change compared to *Reform* comes from the reduction in non-Opec volumes, especially the US, Brazil and Russia. Lower prices accelerate decline rates and limit investments in new supply capacity. Opec supply is stable towards the end of the 2020s due to its low-cost position, before the effect of declining demand in *Renewal* starts to have significant impact on these volumes. The changes in supply investments affect the quality of the new barrels, where heavy and light crudes decline while NGLs grow. This means the quality mix becomes lighter and extra investments in upgrading refining capacity would be very limited. Although less complex refineries are more predominant, due to the higher share of LPG and naphtha instead of gasoline and distillates, more fractionation for light barrels will be needed as well as further growth of the petchem plants. Transport and "other" products will be produced from medium grades processed in complex refineries that are built during the 2020s, while light ends will be mainly supplied by upstream barrels.

Rivalry: oil demand continues to grow

While lower and volatile economic growth limits demand growth in *Rivalry*, oil demand is still at 118 mbd in 2050, considerably higher in this scenario than in *Reform*. Despite lower economic growth, all major sectors have higher oil demand in 2050 than in *Reform* due to less improvements in energy efficiency and slower electrification. Lower efficiency gains and less electrification of road transport add almost 14 mbd of road oil demand by 2050 compared to *Reform*.

Higher geopolitical volatility in *Rivalry* hits Middle East and North Africa the hardest, leading to periods of supply disruptions and limited capacity growth from Opec producers. Increased non-Opec supply is required to compensate and meet the higher oil demand. Higher growth in tight oil supply in the US, Argentina, China and Russia is driven by higher oil prices. Price levels and higher focus on exploration increase Brazilian oil supply and other offshore Latin America, while reduced environmental pressure supports growth in Canadian oil sands. The supply development in this scenario involves new barrels accross the spectrum of qualities, and as in *Reform* significant new refinery capacity with similar complexity as today is needed to replace aging refineries in the main demand centres. Investments in both new complex refineries and petrochemical plants are required to cater for the diversified demand of products and the quality mix of the new production. Countries' concerns about self-sufficiency in final products imply a risk of overcapacity and less efficient trade flow patterns.

Petrochemicals and plastics: the dual challenge

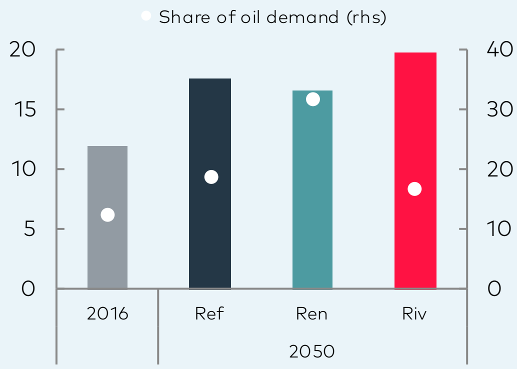
Products derived from petrochemicals are major contributors to improved standards of living and have become an indispensable part of our society today. Plastics, rubber and synthetic fibres have revolutionised our lives and have made consumer products cheaper, lighter, stronger and safer. The world's growing dependency on petrochemicals is evident in the increasing oil demand from this sector. Oil demand from the petrochemical sector has grown steadily over the past few decades and currently accounts for 12 mbd (13%) of global oil demand. It is expected that this trend will continue and that petrochemicals will play an increasingly important role in long-term oil demand. Contrary to the outlook for most other sectors, oil demand from petrochemicals grows in all three scenarios.

Demand for petrochemicals is largely driven by the global consumption of plastics and polymers. Consumption has increased by almost thirtyfold since 1960. More than half of the global consumer packaging is plastic based, and the advantage of plastics is that they are more malleable, lighter, cost effective and less energy intensive to produce compared to alternative materials such as paper, natural fabrics, aluminium, steel and cement. The downside to the use of plastics is that it generates an enormous amount of waste. The world has yet to find an effective solution for managing this unsustainable development – another area where the lack of regulation and political framework to address negative external effects is obvious. The challenge is growing by the day, as an increasing amount of plastic waste finds its way into the environment at an alarmingly fast pace. An approximate 10% of all plastics produced are estimated to have been recycled, a similar amount has been incinerated, and about 60% has ended up in landfills, the environment and in the ocean. About 20% is still in use.

The growing concerns regarding the environmental sustainability of plastics have spurred several initiatives from governments, consumers and consumer goods companies. China has banned imports of plastic waste; the EU recently agreed on a plan to ban single-use plastics such as disposable cutlery, plates and straws; and several African countries have already banned the use of plastic bags. Several large corporations, both in the chemical and consumer goods industries, are changing their strategies and policies to become more environmentally sustainable. For example, in early 2019 nearly 30 major global companies formed the 'Alliance to End Plastic Waste'. These efforts will certainly have an impact on the oil demand from the petrochemical sector, but forecasting future demand is complex. It depends on a variety of factors such as recycling technologies, levels of government involvement, the global economy, rising population and consumer behaviour. There is no shortage of initiatives, and certainly more will follow. If these efforts accelerate faster than anticipated, there is a potential downside risk to the oil demand from the petrochemical sector. If the level of recycling improves from an estimated 15% today to 30% by 2050, there is a potential downside in demand of 3 mbd in *Reform*, and if recycling levels reach 50% and demand for plastic packaging remains unchanged, the downside to demand could be more than 8 mbd.

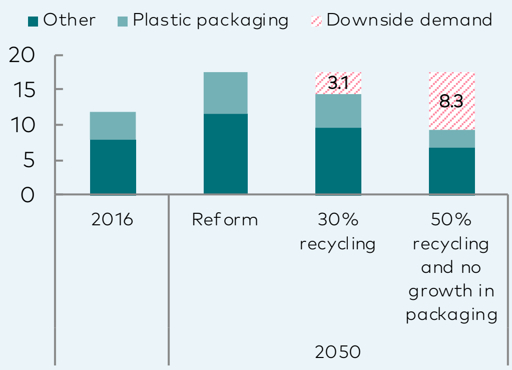
Despite wide agreement globally that the issue of plastic waste needs to be addressed and solved, there are many factors pointing to continued growth in plastics consumption going forward. Urbanisation, improved standards of living and higher median income are strong forces that will drive demand for consumer goods in developing countries such as China and India. This, combined with the lack of viable alternatives, will make the goal of reducing plastics consumption extremely challenging to reach. Only a comprehensive global framework where all aspects of the economy contribute to a more sustainable future will position the world to succeed in placing plastics production and consumption on a more sustainable footing.

Petrochemical oil demand by scenario
mbd (lhs), % (rhs)



Source: IEA (history), Equinor (projections)

Petrochemical oil demand sensitivities in Reform
mbd



Source: IEA (history), Equinor (projections)

The global gas market

Current situation

The global gas market continued growing through 2018. According to IEA's first estimate, global natural gas demand rose by 4.6% to 3,928 Bcm last year. This reflects an average 2.0% annual growth over the last five years. There's a steady flow of investments in the gas sector, evidenced by sanctioning of several new LNG projects in 2018, as there's an outlook for a tighter global gas market in the early 2020s.

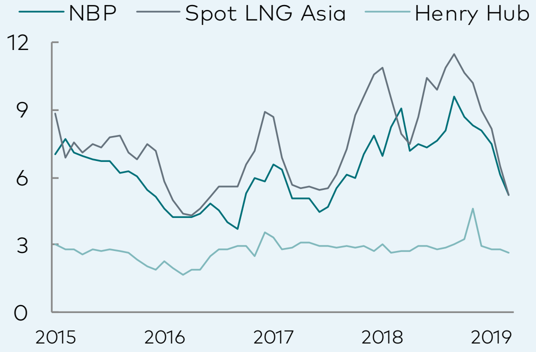
Over the last three years, European gas demand has increased by more than 70 Bcm, reaching 530 Bcm in 2018, with the increase taking place primarily in power generation. Gas prices were relatively high through 2018, backed by strong demand in the Pacific basin and inter-fuel competition in the power sector due to rising coal and CO_2 prices. Germany's nuclear reactors will be closed by 2022 and the country recently launched a plan for decommissioning coal-fired generation capacity by 2038. On the supply side, European indigenous production is in decline. The Groningen field's production permit will be reduced from the current 19.4 to 12 Bcm over the next three to four years, and full closure is envisaged by 2025. Norwegian pipeline supply delivered about 114 Bcm in 2018, a small decline from 2017, while Russian gas supplies to Europe (including Turkey) again reached record levels, for the third year in a row, accounting for 202 Bcm. Consequently, Gazprom's market share rose to 37% in 2018, up from 34% in 2017. LNG imports to Europe stood at 68 Bcm in 2018, up 8% from 2017.

Backed by market confidence in production growth, North American storage inventories entered the 2018 withdrawal season at a 17% deficit relative to the five-year average. While an unexpected cold spell in early November saw the Henry Hub spot price spike, the price surge was moderate and short-lived as the cold weather passed. The North American gas market continued to expand in 2018, to a total of over 980 Bcm, led by low prices driving demand from the electricity and petrochemicals sectors, as well as export demand. This year, US LNG export facilities will add 40 Bcm per year (Bcma) of capacity from five different projects, bringing the total export capacity to around 85 Bcma, with capacity expected to further grow to 90 Bcma in 2020.

The global LNG market shows signs of a new investment cycle. Sanctions of new projects picked up in 2018, totalling 25.8 Bcma of capacity. By May 2019, 34 Bcma of capacity has been sanctioned. LNG Canada and Golden Pass LNG took their final investment decision (FID) without long-term sales and purchase agreements in place; a clear indication of strategic positioning by the large players.

Chinese sourcing of LNG prior to the heating season softened the LNG spot market through the winter of 2018/19 compared to the previous winter season. Even though constraints on LNG import infrastructure in China will curb demand growth in 2019, demand is still likely to be 15 Bcm higher than in 2018. The restart of nuclear units in Japan and South Korea will dampen growth in LNG demand this year. India is installing around 24 Bcma of import capacity in 2018 and 2019, however the country is unlikely to utilise a large share of this capacity, as the pipelines connecting to local markets are not fully in place. Some other countries will continue to increase LNG import and thus absorb part of the new LNG, including Pakistan and Bangladesh looking to solve their increasing energy supply deficit.

Regional gas prices
USD/MMBtu

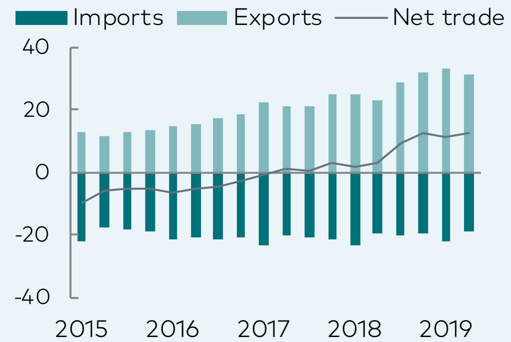


Source: ICIS Heren, NYMEX, Platts

Germany will phase out nuclear by 2022 and decommission coal-fired generation capacity by 2038

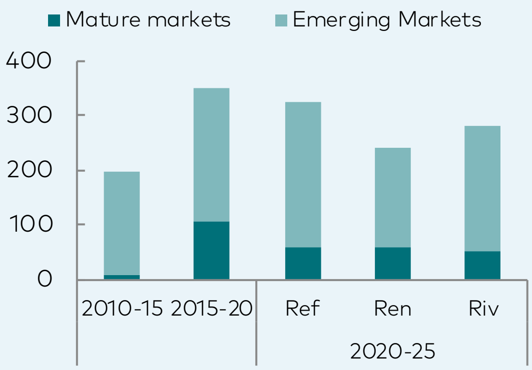
Source: Reuters/Arnd Wiegmann

US quarterly natural gas trade
Bcm



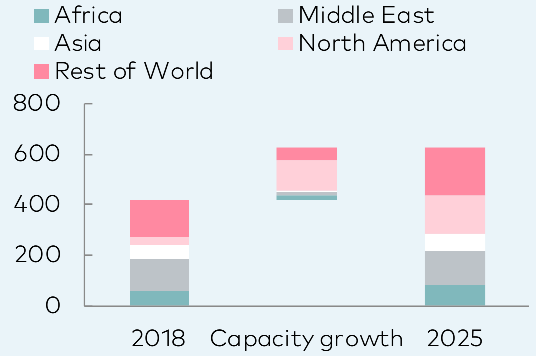
Source: EIA

Global gas demand growth by scenario
Bcm



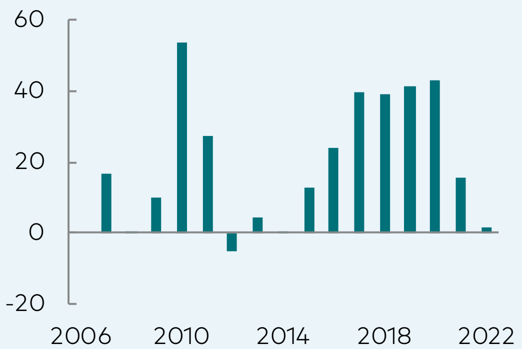
Source: IEA (history), Equinor (projections)

LNG capacity by region
Bcm



Source: Equinor

Change in global LNG capacity, year-on-year
Bcm



Source: IHS (history), Equinor (projections)

Outlook to 2025

The period until 2025 will be dominated by the supply side positioning to meet underlying demand growth, which is strong in all the scenarios in this period. The developments are therefore expected to be quite similar across scenarios. During the 2020s, global gas demand growth absorbs additional LNG supply and the gas price is expected to start its recovery to levels allowing for adequate returns on investments in new supply.

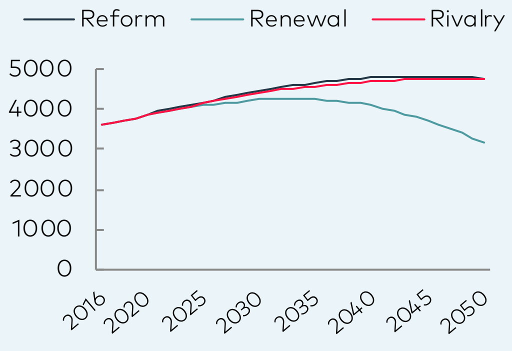
Some 100 Bcma LNG capacity is under construction globally, with 55 Bcma expected to reach the market by the end of 2020. While some of this originates from Australia and Russia, the majority comes from US LNG projects. New FIDs during this and next year continue to add supply by the mid-2020s, including four new trains in Qatar, with a combined capacity of 40 Bcma. This is a brownfield project where the feed gas is liquids-rich, boosting competitiveness. Other projects that are likely to be developed in this period are also brownfield projects in the US, Australia, Mozambique and Papua New Guinea.

Despite stable demand, Europe's import dependency is increasing. While gas supply from the Norwegian Continental Shelf continues to be close to record levels, domestic supply in Denmark, the Netherlands and the UK continue to drop despite new recent discoveries on the UK Continental Shelf. North African exports to Europe are expected to gradually decline towards 2025 from the current level around 40 Bcma, driven by stronger local demand and lower gas output. Supply from the Caspian region adds diversification from around 2020, while the continued strength in Russian supply supports a market balance together with increased LNG imports. Europe's spare LNG regasification capacity can potentially provide an outlet in periods of surplus LNG volumes, and support in balancing the global LNG market.

The Asian market continues to grow after 2020, led by strong Chinese demand towards 2030, as the country's energy policy aims for a natural gas share in TPED of 15% by 2030, up from 7-8% in 2018. In the same period, the share of coal is expected to fall from around two-thirds to less than 50% in 2030. Other countries like Bangladesh, India, Indonesia, Pakistan and Thailand represent a considerable demand for LNG to make up for declining domestic supply and/or growing energy demand. The combined future demand of these countries has the potential to exceed that of China, though their political ability to realise such plans are more limited than China's. Infrastructure constraints, lack of funding and sensitivity to price represent dampening factors to LNG import growth, while soft medium-term prices incentivise demand and tighten the global LNG balance.

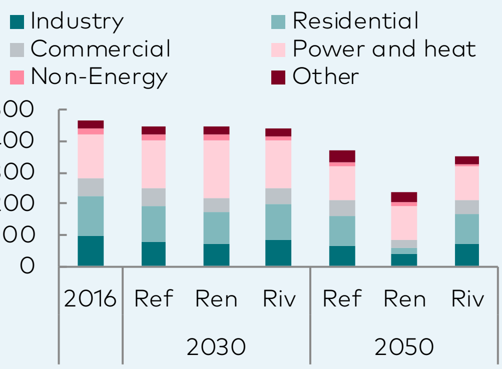
North American gas supply is currently at an all-time high and expected to reach over 1,170 Bcma by 2025. This means that downward price pressure remains but ensures that demand continues to grow on the back of cheap resource availability. The influx of affordable associated gas coming from oil-directed drilling activity is also driving supply growth. Associated gas supply averaged 218 Bcm in 2018 and is expected to continue growing through 2025, as new transport capacity is built in oil-rich plays such as the Permian. Appalachia sees volumes increase as supply fills a current surplus in pipeline capacity and grows into new capacity now under construction. As the North American supply outlook is so strong, the

Global gas demand by scenario
Bcm



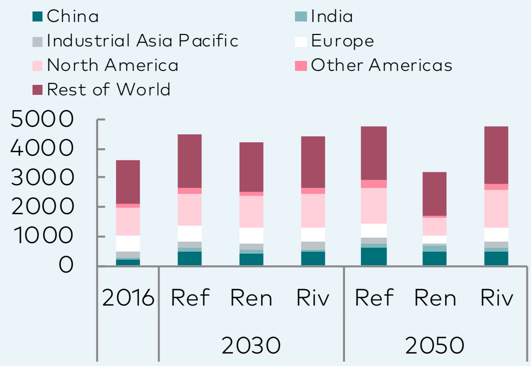
Source: IEA (history), Equinor (projections)

EU gas demand by sector and scenario
Bcm



Source: IEA (history), Equinor (projections)

Global gas demand by region and scenario
Bcm



Source: IEA (history), Equinor (projections)

challenge for the market is to balance flows with incremental demand from industrial use, gas-fired electricity generation and LNG and pipeline exports.

Gas demand in Latin America is growing, based on economic growth and increased electricity sector demand. The continent is rich in gas resources, though price regulations have failed to provide investment incentives, leading to LNG import dependency. Both Brazil and Argentina are implementing energy policy frameworks to attract investment in supply-side and downstream infrastructure. Indigenous supply will reach about 180 Bcm in 2025, curbing the region's LNG import needs significantly. The potential for market integration within the Southern Cone (defined by Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay) should reinforce efficient gas exchange between neighbouring markets, exploiting seasonal variations in demand and flexibility in supply.

Outlook beyond 2025

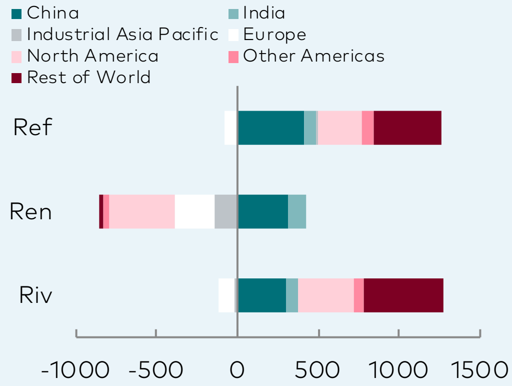
Reform: global demand continues to grow

Long-term gas demand increases by 33% from 2016 to almost 4,800 Bcm in 2050. This corresponds to an annual growth rate of 0.8% over the total period and some 0.5% from 2025 to 2050. Although North American demand keeps growing based on low-cost resource availability, Asia remains the main growth engine for global gas demand; and despite a peaking of European gas demand by around 2030, net imports continue to grow. As the share of LNG in global gas supply increases towards 20%, a gradual harmonisation of global gas price formation is unfolding. Even if we will not necessarily see a global LNG price, the increasing share of uncontracted spot-based LNG contributes to such a development.

European gas import dependency increases significantly from the current level of 55% to almost 80% by 2040 and onwards, calling upon significant volumes of LNG and pipeline imports. The pipeline import capacity from Russia, North Africa and Middle East is significant, but comes with various caveats. Overdependency on Russian piped gas is a politically stated concern, although European utilities together with Russia actively develop new supply routes to ensure long-term gas flows to the continent. Domestic gas needs in export countries such as Algeria limit the North African export potential. US LNG offers supply diversification, but at the same time anchors European gas prices roughly at par with more expensive import regions in Asia. Demand side management is Brussels' tool to balance concerns about import dependency. Strategic responses to curb demand in the heating and cooling sectors are high on the agenda and address close to half of EU's gas demand. However, the lead time is extensive as building refurbishment, energy system replacements and newbuilds take time.

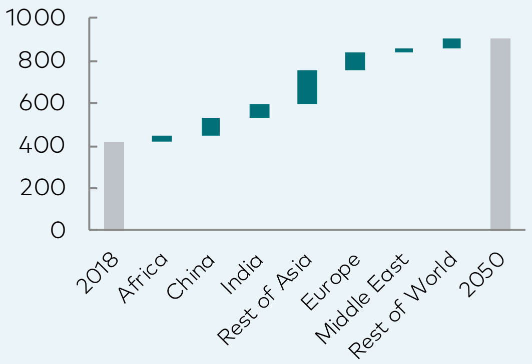
Asia's long-term gas demand grows significantly, and large-scale imports are required to satisfy sustainable economic growth and fuel diversification. Russian and Central Asian pipeline export capacities are expanding, reaching some 95 Bcma by 2025 and could be further expanded if policies and negotiations succeed. Still, Asia's gas supply continues to rely on LNG market growth. Suppliers within the Pacific basin benefit from higher realised netbacks due to lower transport costs, whereas Atlantic basin suppliers benefit from flexibility to optimise between Europe and Asia. Regardless of location, project developers need adequate price signals to make new FIDs and

Change in gas demand by region and scenario, 2016-50
Bcm



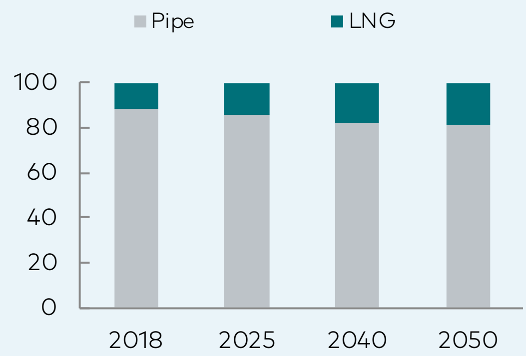
Source: IEA (history), Equinor (projections)

Global LNG demand growth in Reform by region, 2018-50
Bcm



Source: Equinor

LNG share of global gas market in Reform
%



Source: Equinor

commit the necessary capital. Unless the market over time allows for expectation for full cost coverage, new LNG capacity will not be developed. The low-price environment as of the recent past has pushed costs down and called upon simplified concept developments. The continuation of this trend is required to strengthen gas' competitiveness.

North American natural gas supply grows by 10% between 2025 and 2050. Continued growth of both domestic and global demand incentivises new production, which reaches its peak in the mid-2030s. Mexico's consolidated infrastructure is required to allow for US pipeline exports to the Mexican industry and electricity sectors. North American development of cleaner energy sources results in a balanced penetration of renewables, giving gas the opportunity to capture a share of the market.

Renewal: global demand peaks, then declines

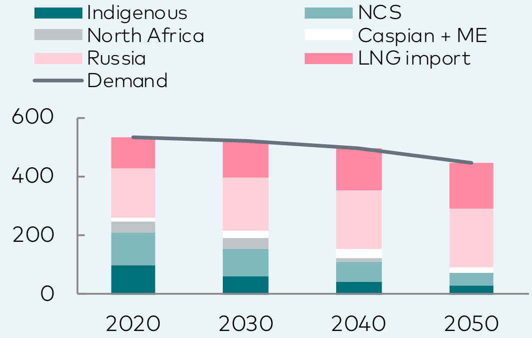
In order to reach global climate targets, the role of natural gas is critical to ensure sustainable growth and replace coal, in particular in growing Asian economies. As global demand peaks at around 4,300 Bcm in 2035, the consequent decline materially impacts the global supply picture. *Reform* calls upon more LNG supply from the early 2020s and onwards. This is much less the case in *Renewal,* with the total market dropping to below 3,200 Bcm in 2050, down 12% from 2016 levels. The risk of surplus LNG capacity in *Renewal* is therefore higher than in *Reform*. Mature markets increasingly adopt new low-carbon technologies driven by energy policies and global climate targets. As scale increases and costs are reduced, renewable energy sources provide a cost- and climate-efficient supply alternative to traditional fossil energy sources. To sustain its long-term position in the energy mix, natural gas needs to gradually meet the challenge of becoming green in absolute terms, not only being greener than alternative fossil fuels.

In Europe and North America, lower gas prices cannot counter the strengthening competition from energy efficiency and renewable energy. Still, decline in European domestic gas supply leaves the import dependency above 200 bcm in 2050. The Russian market share in Europe increases throughout the period due to its competitive position and low supply cost. North African gas supply weakens due to absent investment signals and funding towards the latter end of our analysis horizon. In Asia, particularly driven by India and China, gas demand is more resilient throughout 2030-50. The competitive position of gas versus coal combined with climate regulation play a significant role in reinforced coal phase-outs, supporting gas demand for a longer period.

However, the competitiveness of natural gas deteriorates as end users face increasing costs from emitting CO_2. CCUS and hydrogen production are means to address this issue and ensure a raison d'être for gas in a low-carbon context. However, the commercial scope of CCUS is limited to geographies close to supply. Resource owners and partners must develop strategies to utilise infrastructure and reservoirs to avoid stranded assets.

European gas balance in Reform

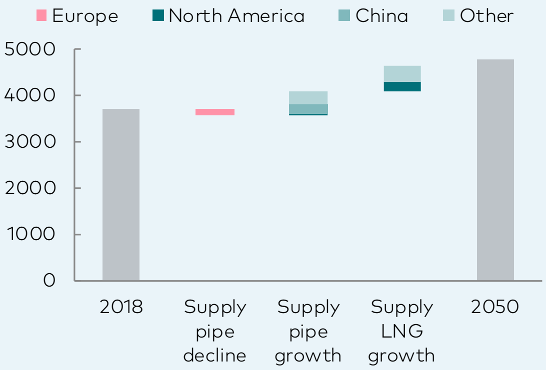
Bcm



NCS: Norwegian continental shelf
ME: Middle East
Source: Equinor

Change in gas supply in Reform, 2018-50

Bcm



Source: Equinor

Gas supply change in Renewal and Rivalry versus Reform beyond 2030

Region	Renewal	Rivalry
North America	↓	↑
Europe	→	→
China	→	→
India	→	→
Middle East	↓	↓
Africa	↓	→
CIS	↓	↑
Rest of Asia	↓	→

Source: Equinor

Rivalry: global demand impacted by geopolitical instability

In *Rivalry*, the prerequisites for integrating regional gas markets are at risk, as geopolitical and regional conflicts persist. Less focus on climate policies, slower phase-out of fossil fuel subsidies and less incentives for energy efficiency improvements counter the negative impact that the lower economic growth has on energy demand growth. Increased protectionism discourages new LNG investments and the preference for imported gas diminishes. Still, gas use increases in regions with abundant low-cost resources, such as North America and Russia; while on the other hand, demand declines, or grows at a slower pace compared to *Reform*, in import regions. Overall global demand in 2050 is more or less similar to *Reform*.

The Middle East contributes to limited gas demand growth and continuous geopolitical instability in the region impacts the plans for developing new projects, which implies less gas available for export. The geopolitical context hampers the financial capabilities and as such the potential for new investments.

In Asia, gas demand is about 160 Bcm lower in 2050, relative to the level in *Reform*. Concerns about energy security mute gas imports, hence no new gas import pipeline is developed beyond the Power of Siberia (38 Bcma capacity from Russia), currently under construction. This comes on top of the three existing pipelines from Central Asia (55 Bcma) and the pipeline from Myanmar (13 Bcma). LNG imports therefore remain at current levels.

For Europe, gas demand is marginally lower compared to *Reform*. Lower LNG availability calls on higher gas prices to satisfy growing import needs and to stimulate indigenous gas supplies. Some countries improve their relationships to and reliance on Russian gas.

Long-term supply challenges

Reform requires new supply chains to be built. The global LNG markets will be developed to supply both mature markets in Europe and growing emerging markets in Asia. Continued efficiency gains, cost reductions, project improvements, and tax credits should improve the competitive position of investment projects. *Renewal* reinforces these perspectives as prerequisites for new investment in order to maintain and defend the role of gas in a low-carbon context. *Rivalry* also calls for significant new investments, but suffers from a lack of trade and climate policy frameworks, in particular affecting affordability and demand in gas importing regions. Eventually, producers need firm price signals and credible gas market frameworks to defend new investments in a more competitive energy landscape.

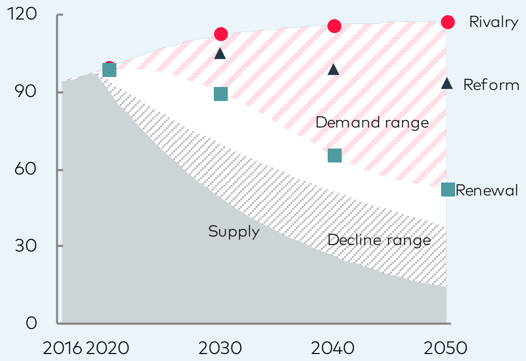
Globally, IEA estimates the technically recoverable and proven natural gas reserves at close to 800 trillion cubic metres (Tcm) and 220 Tcm respectively. These estimates are sufficient to comfortably meet the estimated accumulated demand in *Renewal*, *Reform* and *Rivalry*, ranging from 135 to 158 Tcm. The main gas supply areas will remain unchanged: North America (US), Russia and Middle East (Iran, Qatar), being low-cost sources of gas. It is anticipated that China will become one of the leading gas producers, though its supply will mainly serve domestic needs. European indigenous gas supply is expected to decline significantly from 2025-30.

Need for new oil and gas supply capacity

Supply from existing fields alone cannot satisfy the wide range of oil and gas demand scenario projections. New supply capacity will have to be brought onstream to cover the supply-demand gap. To test this hypothesis, as usual, we compare our long-term demand scenarios with two supply curves representing future supply from existing fields. In our analysis, existing supply will decline by 3-6% to reflect a mixed portfolio of conventional and unconventional supply of different maturity. A 3% decline rate would typically include investments in production enhancement (EOR), while a 6% decline would exclude most of those. The gap indicates how much oil and gas must be supplied to satisfy demand from brownfield developments, from greenfield project sanctions and from exploration.

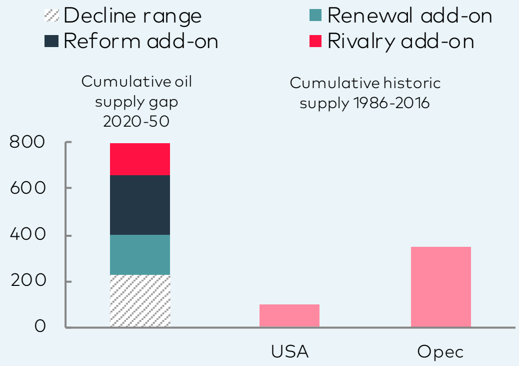
Global oil demand ranges from 52 mbd in *Renewal* to 118 mbd in *Rivalry* in 2050, while oil supply from existing fields in 2050 is estimated at 14-38 mbd. In *Renewal* in 2050, 14 to 38 mbd of oil must be made available for the market on top of the remaining, existing supply. This delta corresponds roughly to one to three times Saudi Arabia's, the US' or Russia's current oil supply. In *Rivalry*, the gap measures up to 80-105 mbd in 2050. The cumulative gap in the three scenarios is between half and two times Opec's historic production over 30 years.

Oil demand and supply from existing fields
mbd



Source: IEA (history), Equinor (projections)

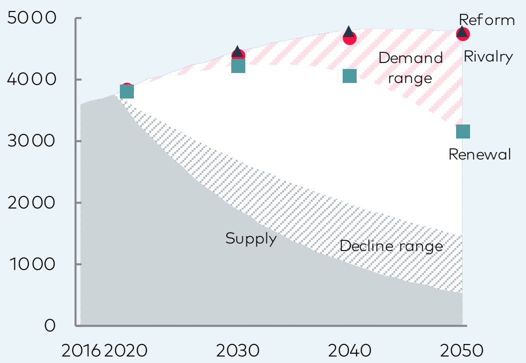
Cumulative oil supply gad and historic supply
Bn bbl



Source: BP (history), Equinor (projections)

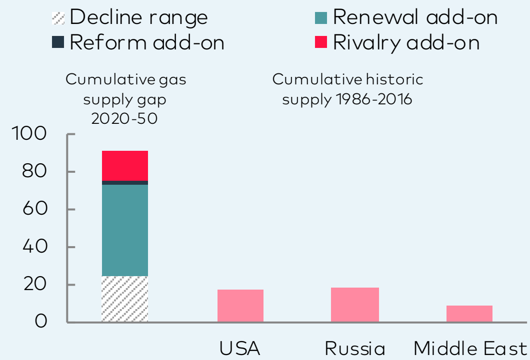
Global gas demand in the three scenarios is projected from 3,200 Bcm in *Renewal* to 4,800 Bcm in *Reform* in 2050. In *Renewal*, 1,700 to 2,600 Bcm new gas will have to reach markets in 2050, corresponding to 3 to 4.5 times current Russian annual production. In *Reform*, the highest demand projection, the range increases to 3,300 to 4,200 Bcm, respectively. The cumulative gap is somewhere between three and five times US or Russian production over 30 years.

Gas demand and supply from existing fields
Bcm



Source: IEA (history), Equinor (projections)

Cumulative gas supply and historic supply
Tcm



Source: BP (history), Equinor (projections)

A comparison of the cumulative gaps with global oil and gas reserves reported by BP, tells the story of potential abundance. Proven oil reserves are reported at 1,700 bn bbls and the reserves to production (R/P) ratio at 50 years, meaning two to ten times the cumulative gap for oil. Global proven gas reserves stand at 195 Tcm and the R/P ratio at 53 years. The relationship between proven reserves and the cumulative gap of gas is 2-4. This picture presents a challenge to high-cost, high-carbon intensity, low-quality remote reserves and discoveries in difficult regulatory and political environments, especially in *Renewal*. As we are moving across scenarios from *Rivalry* and *Reform* to *Renewal*, the room for new oil and gas investments is shrinking, investments are becoming increasingly short-cycled, producer prices are lower, and the competition for new quality reserves and discoveries is intensifying.

Renewable energy

Renewable energy means energy from sources that – unlike coal, oil, gas and uranium accumulations – replenish themselves. Waterfalls, wind and sunshine are prominent examples. Geothermal energy, i.e., heat extracted from the earth itself, is another. Biomass is also considered a renewable energy source. Renewable energy may be used for power generation or, in the cases of geothermal heat and biomass, directly by end users. Renewable energy is pursued for economic and supply security as well as environmental reasons. While renewable power plants may be costly to build, operation and maintenance costs are low, as there are no fuel expenses (with the exception of biomass). Renewable energy is typically local energy, exposed to seasonal and time of day changes and the weather, but less so to geopolitical turmoil. And most importantly in a climate constrained world, renewable energy emits no CO_2 when supplied or used, or – in the case of biomass – emits only as much CO_2 as it has previously absorbed from the atmosphere.

Wind and solar PV power: racing ahead

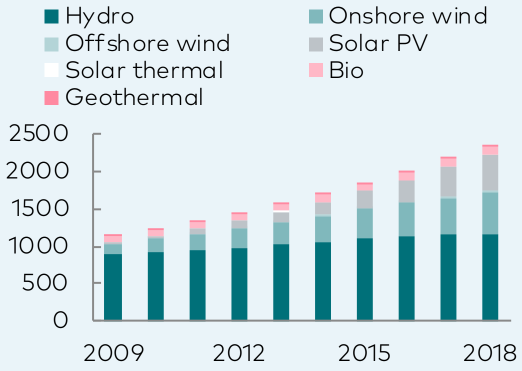
Installed solar and wind electricity generation capacity experienced another strong year in 2018, adding almost 150 GW and bringing total capacity to above 1000 GW. China further consolidated its position as the leading player in renewable electricity in 2018, accounting for almost half of all new capacity. Already in 2016/17, China's total installed wind and solar capacity surpassed that of the EU, making China's installed capacity the world's largest. The share of solar and wind in global electricity generation is increasing quickly. In 2018 it accounted for around 7%, up from less than 1% in 2007.

The prominence of new renewable power does however vary significantly both across and within regions. In EU the combined share of wind and solar power was up from 3% to 15% between 2007 and 2017. In Denmark, a star performer in new renewable energy terms, the wind and solar share of total net generation in 2018 averaged 55%. Green observers consider the experiences of Denmark and select other countries that have gone all in for new renewable electricity as proof that although there may be challenges along the way towards 80% or even higher power sector decarbonisation rates, most countries have a long way to go before these challenges become troublesome.

That may be true, although there are major differences in individual countries' ability to neutralise fluctuations in domestic generation by imports or exports that also need to be considered. Denmark, with access to Scandinavia's and continental Europe's national electricity systems, frequently imports or exports its way out of temporary deficit or surplus situations. Bigger and/or isolated countries do not necessarily have that option. Germany, which also has prioritised new renewable power, had by the end of 2018 only experienced a share of solar and wind above 30% in a few months and it is yet to be seen how they will manage when levels go as high as in Denmark.

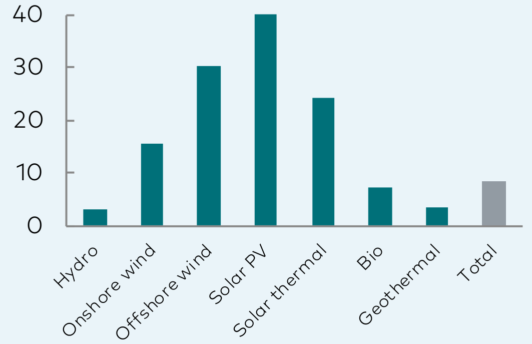
The question if there is an upper limit to the share of variable power in total electricity supply is very much a question of costs. If there is a will to pay the extra costs involved, the limit can usually be shifted upward. IEA suggests six phases for the integration of wind and solar power into the grid

Global renewable electricity generation capacity
GW



Source: IRENA

Global renewable electricity generation capacity growth rates, 2009-18
% CAGR



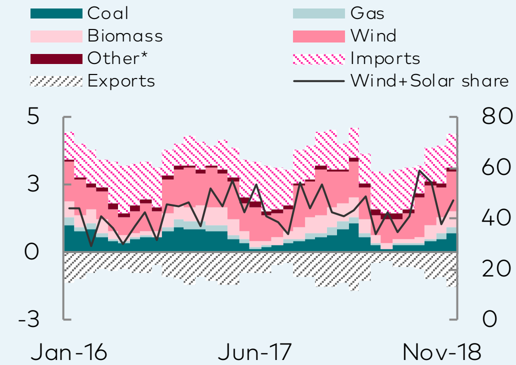
Source: IRENA

IEA's six phases of variable power integration

- **Phase 1: Under 3%.** No noticeable impact
- **Phase 2: Up to 15%.** Noticeable impact that can be managed quite easily by upgrading operational practice
- **Phase 3: Up to 25%.** Significant integration challenges requiring backup dispatchable power plants, transmission grid extensions, increased attention to demand side management
- **Phase 4: Up to 50%.** Additional technical challenges related to the stability of the power system
- **Phase 5: Up to 75%.** Structural surpluses of variable power calling for increased electrification of energy end use to absorb them
- **Phase 6: Up to 100%.** May require the conversion of electricity to chemical energy carriers to ensure inter-seasonal flexibility

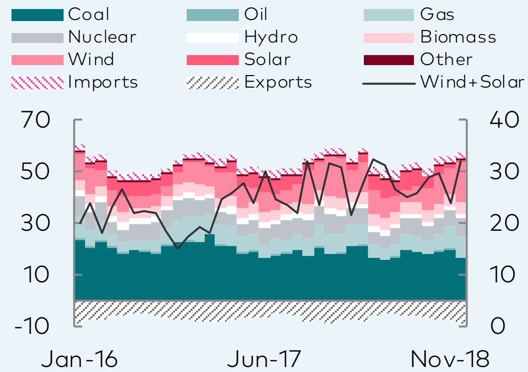
Source: IEA

Denmark's electricity generation and supply
TWh (lhs), % share of total supply (rhs)



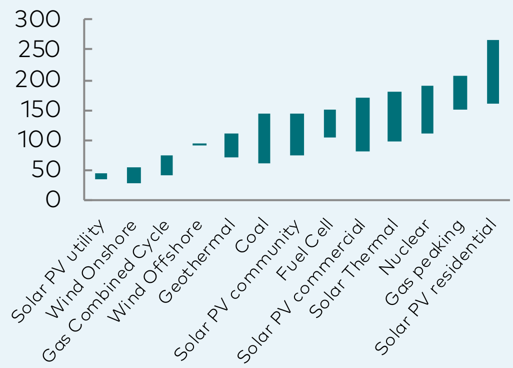
*Other: Oil, hydro, solar, other
Source: IEA

Germany's electricity generation and supply
TWh (lhs), % share of total supply (rhs)



Source: IEA

LCOE ranges in US, unsubsidised basis
USD/MWh



Source: Lazard

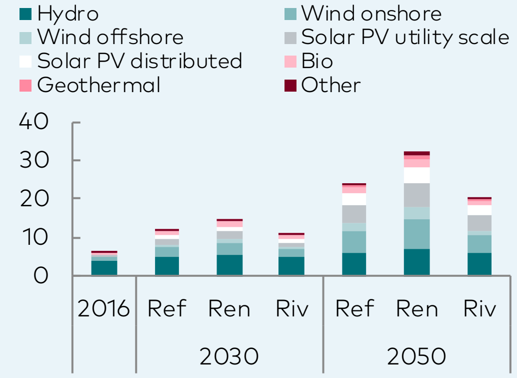
The power sector transition has been driven by policy – by favourable new renewable electricity pricing arrangements, tax breaks and other forms of direct subsidies. Economic support and promises to wind and solar PV generators of a shielded existence remain features of some countries' energy policies. However, we now see that governments are opting away from feed-in tariffs, which weigh on state budgets and disincentivise efficiency improvements, and are turning instead towards competitive auctions as a way of determining the electricity supply mix and identifying the most promising projects.

This development is driven by economies of scale, cut-throat competition and learning that have provided for continued new renewable electricity cost and price reductions. The "levelized cost of electricity" (LCOE) – a dominant if often misused indicator of power plant competitiveness – of new renewable electricity has declined to the point of positioning onshore wind and solar PV as the most attractive options on an unsubsidised basis in large parts of the world. Offshore wind is now widely expected to expand on an unsubsidised or lightly subsidised basis through the 2020s. Distributed – i.e., rooftop and microgrid – solar PV electricity is still more costly to generate than utility scale electricity, but it may still work against the retail price of grid power which needs to cover transmission, distribution and overhead costs in addition to generation costs.

The LCOE does as indicated not tell the full story of a power plant's attractiveness – it addresses only the costs of building and operating the plant, not the costs of linking it into the grid, not the value of the plant's output when it is able to produce and not its likely impact on prices. Growth in zero marginal cost electricity supply may depress prices below even very competitive LCOE ranges, calling for regulatory reform and new pricing mechanisms to secure necessary investments in electricity infrastructure, backup and storage. Despite all uncertainties, there are still strong indications that the economics of new renewable electricity are becoming increasingly robust, and wind and solar operators winning auctions by bidding below LCOE ranges clearly expect these trends to continue.

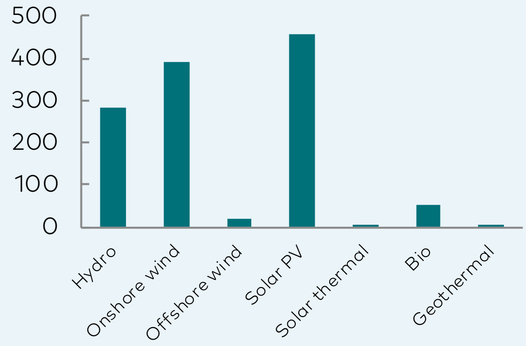
In *Reform*, global wind and solar PV power generation capacities therefore increase by averages of 65 and 111 GW per year respectively between 2016 and 2050. In *Renewal* average additions are 97 and 155 GW per year, and in *Rivalry* they are 49 and 91 GW per year. The relatively strong performance of wind and solar PV also in *Rivalry* reflects that renewable energy is an attractive domestic source of energy and that investment in these technologies is seen to become increasingly market driven and correspondingly less vulnerable to fluctuations in policy priorities. In *Reform* and *Renewal* capacity additions peak in the 2030s. Towards the end of the scenario period, abating electricity demand growth and increasing variable power integration costs dampen capacity growth. In *Rivalry*, wind and solar PV growth is more evenly spread out across the scenario period. In *Reform*, wind and solar PV generation makes up about one third of total global generation by 2050. In *Renewal*, marginally faster wind and solar PV growth and marginally slower electricity demand growth translate into a 49% share by 2050. In *Rivalry*, the combination of growth rates delivers a 29% market share by 2050. *Rivalry* is not a scenario where power system planners and investors turn away from new renewable electricity – there is interest in power

Renewable power generation by scenario
Thousand TWh



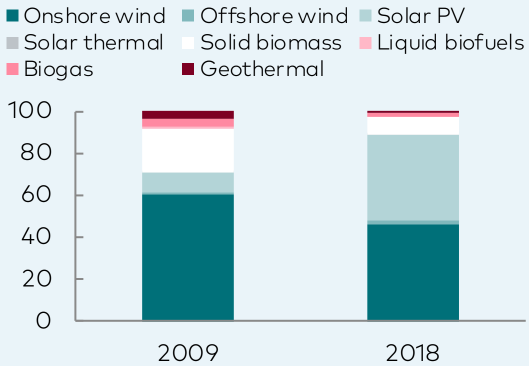
Source: IEA (history), Equinor (projections)

Global renewable power generation capacity additions, 2009-18
GW



Source: IRENA

Split of world's renewable power generation capacity net of hydro
%



Source: IRENA

that can be generated locally and lower one's dependence on imported fuels, in addition to being less costly than most options in an environment where finance may be scarce. Slow economic growth and constraints on international trade in high-tech products are the main factors preventing faster uptake.

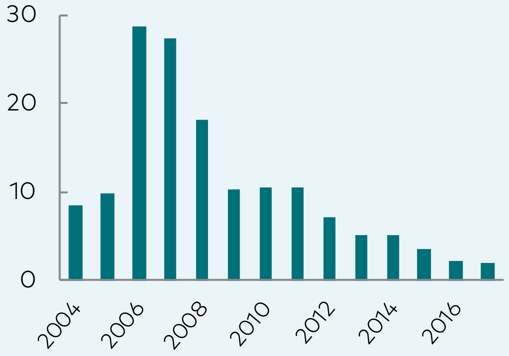
Other renewables: expanding more slowly

In 2016, hydro power made up 16% of total global electricity supply, dwarfing the contributions of the newer technologies. Hydro does not grow quickly, however – by an average of 3% per year between 2000 and 2017. In 2018, a total of 21.2 GW of capacity was added, representing a 1.7% increase on the 2017 total, with Asia accounting for 62% and Latin America for 20% of new plant completions. Europe and North America, which play host to 17% and 15% of existing capacity, respectively, contributed only 5% and 1.5% to the 21 GW of new capacity. China is the undisputed heavyweight of the hydro world, accounting for 40% of capacity additions in 2018 alone, and with more huge projects under construction. Hydro has an important role to play as a flexible zero carbon option in a climate constrained future, but there are not many hydro resources left to develop in the industrialised world, and large-scale hydro has become controversial as previous projects have been executed with little attention to social and environmental side effects. Small-scale hydro faces less opposition, but plants with a capacity of 50 MW, which is Bloomberg New Energy Finance's (BNEF) definition of small, make up only about 16% of total hydro capacity and cannot be expanded at a pace compensating for a scarcity of large projects. Hydro power generation increases between 2016 and 2050 by 1.3%, 1.6% and 1.0% per year in *Reform*, *Renewal*, and *Rivalry*, respectively, implying a 2 to 3 p.p. loss of market share in *Reform*, a smaller loss in *Rivalry* and a 1 p.p. gain in *Renewal*.

Biomass and waste are burned by end-users for heating and cooking purposes, are refined into liquid biofuels largely for the transport sector and are used by industry and for power and district heat generation. Biomass end-use is dominated by traditional technology like simple stoves and open fireplaces and tends to be inefficient and polluting. IEA estimates that between 2000 and 2017 traditional biomass use increased marginally in absolute terms. but declined relative to global total biomass and waste use from 63% to 48%. Due to its harmful health effects it needs both to be further reduced in relative terms and to be to be marginalised in absolute terms. The challenge is to accomplish this without pushing consumers towards fossil alternatives entailing CO_2 emissions. Helping households replace their inefficient stoves with modern, efficient stoves, and providing for distributed electricity supply, is a favoured strategy.

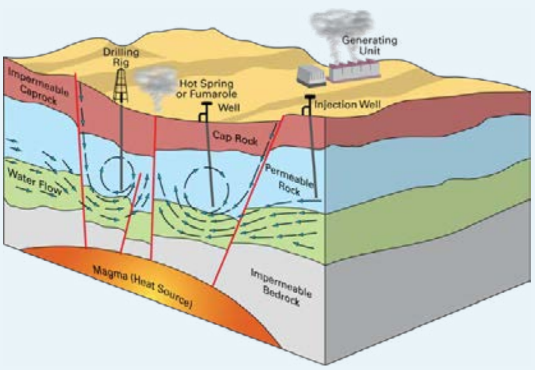
Of modern biomass and waste consumption, the power and industry sectors in 2017 accounted for close to 30% each, the buildings sectors for some 15%, the transport sector for 6% and other sectors for the remainder. Modern biomass and waste use increased by about 4% per year between 2000 and 2017 with road transport demand growing by 13% and power sector consumption by 8% per year. Whether the power sector will remain a key biomass off-taker, and whether the road transport sector will become one, is however uncertain. Bioenergy demand is supply constrained, and non-road transport, which has few decarbonisation options but to switch from oil products to biofuels, should arguably be prioritised for the supply

Annual global investments in biofuels supply
Bn USD



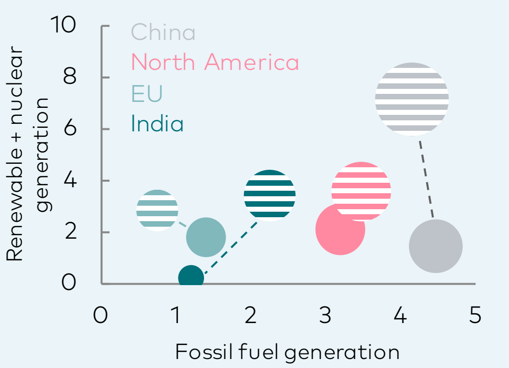
Source: Statista

Diagram of a geothermal power plant



Source: British Geological Society

Fossil fuel generation versus zero carbon power generation by region in Reform
Thousand TWh, 2016 = solid, 2050 = stripes



Source: IEA (history), Equinor (projections)
Note: The size of the bubbles indicates the level of total power generation in the individual countries/regions in the individual years, relative to each other

that will be provided. Investments in modern bioenergy have declined to a fraction of what they were a decade ago due to a number of factors: first generation bioenergy infringing on food supply, challenges scaling up second and third generation production at viable costs, and the ascendance of electric vehicles (EVs) as the preferred option to conventional vehicles slowing the outlook for road transport biofuels demand. The decisive issue for the long-term potential of biomass as a CO_2 emission mitigation tool is however how much bioenergy resources that may be sustainably supplied, should politicians and investors decide to prioritise this option. The range of estimates in the public domain is extremely wide. One recent calculation is that of the UK Committee on Climate Change (CCC). The CCC suggests a low, a medium and a high case for world "tradable" biomass availability by 2050. In the low case, with a context looking much like our *Rivalry* scenario, biomass availability drops to about half its current level, about 260 mtoe. In the medium case, linked to a business as usual development, availability increases by some 50% relative to today's level, to 810 mtoe. In the high case reflecting *Renewal*-type assumptions, availability increases almost fourfold, to about 2010 mtoe.

Reform projects an average growth in world total bioenergy consumption of 1.1% per year, and for *Renewal* an only marginally higher growth – 1.2% per year. Most regions use more bioenergy in *Renewal* than in *Reform*, but the poorest – especially in Africa – succeed in reducing their unsustainable residential sector bioenergy consumption so much that global growth is subdued. In *Rivalry*, bioenergy growth increases by 1.8% per year because the downscaling of unsustainable bioenergy use proceeds more slowly.

Geothermal, solar thermal and wave power generation are technologies that could become significant between now and 2050. Geothermal power is already important to certain countries with favourable geology. There is some investor interest – global capacity increased by 3.5% per year between 2000 and 2017 – but this was only enough to sustain a 0.2% share of total global generation capacity. Solar thermal electricity and heat generation holds promise in regions with substantial sunshine, as it provides energy storage and electricity export opportunities. Regional growth rates for geothermal power result in global averages of about 5%, 6% and 4% a year in *Reform*, *Renewal* and *Rivalry*, respectively. By 2050, this technology contributes slightly below 1% of total global generation in both *Reform* and *Rivalry*, and 1.5% of total generation in *Renewal*. Solar thermal and wave power generation are projected to pick up speed after 2030 and grow by 8-9% per year both in *Reform* and in *Renewal*, but from small base year values; they contribute 1-2.5% to total world power generation by 2050.

The build out of renewable energy supply has not been cost free. Global spending on renewable energy increased by more than 400% between 2004 and 2011, from USD 62 bn to USD 324 bn, according to BNEF estimates. Since 2011 annual investments have fluctuated in the USD 270-360 bn range with a shift in activity from Europe to Asia due mainly to China's embrace of renewable energy. The transition will require more investment resources going forward. IEA estimates cumulative global power sector investments over the 2018-40 period at USD 26 tn in its Sustainable Development (SDS) scenario, against investments of USD 20 tn in its New Policies (NPS) scenario.

The future of mobility

Road transport: new solutions required

Historically growth in GDP and population translates into a growing number of vehicles on the road to move people and goods. However, as an increasing number of regions, particularly big cities such as Beijing and Delhi, face severe issues with congestion and local pollution, governments are forced to take measures to limit the number of cars on the road. The rapidly growing urban population leaves a pressing need for more efficient ways to organise transport and mobility.

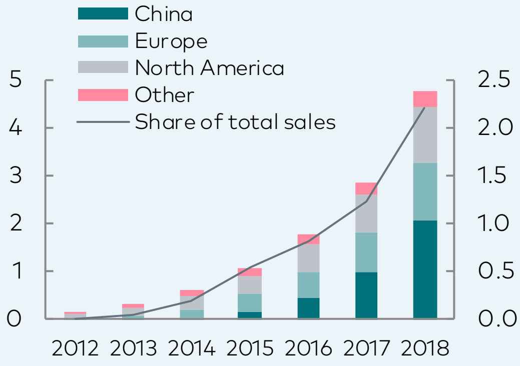
Since 1990, oil demand from transport has grown by 78%, reaching 55 mbd in 2017. Nearly 80% of this comes from road transport such as cars, buses, trucks and two-wheelers. However, transport also contributes to almost a quarter of global energy related greenhouse gas emissions and is growing faster than any other end-use sector. Recent years have therefore been characterised by a forceful global momentum aimed at lowering emissions from transport, particularly road transport. For future transport and mobility needs to be met in a sustainable manner, a new way of organising mobility is required. Several new trends and developments are evolving which could change the way we transport people as well as goods.

Regions such as OECD Europe and North America have reached saturation levels for passenger vehicles, while continued growth in non-OECD countries is expected. In addition to expanding public transport services such as buses, trains and subways, the widespread use of smartphones has allowed for the development of new business models, such as carpooling and novel cab services. Companies helping customers to get from A to B in the most flexible, convenient and affordable way, are currently growing rapidly in popularity, particularly in large cities where parking and congestion make private ownership less attractive. The recent popularity of e-bikes, electric scooters and segways, particularly in big cities, have also been an important step for solving the "last-mile" – between home and train stations and final destinations – making public transport services more easily available. When it comes to freight, technologies such as 3D printing and use of last-mile delivery drones could replace the use of trucks and vans for delivering goods.

Car manufacturers and technology companies have a strong focus on autonomous vehicles, which have the potential to be utilised more efficiently by a larger number of people, improving safety and increasing the utilisation of road capacity, but also increasing the number of people becoming potential car users. Removing the driver will make carpooling and public services considerably more cost competitive compared to owning a private car, further enhancing the trend of consumers increasingly perceiving mobility as a service. Fully autonomous vehicles are still several years away from being a common sight on the road, and its implementation is likely to raise several legal and ethical issues regarding safety and liability. Significant changes are therefore not expected in the private vehicle segment until toward the 2030s. For trucks and buses, however, an earlier introduction of autonomous vehicles is possible, as these could be dedicated to pre-defined routes and sections of the road networks.

EVs accumulated sales

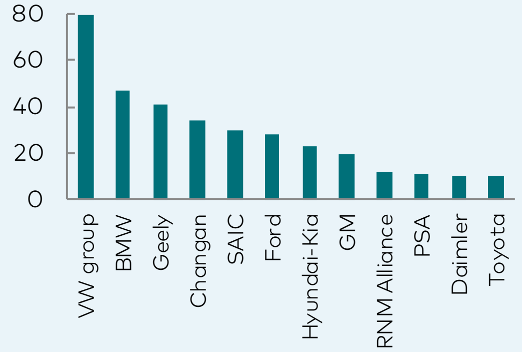
Million vehicles (lhs), % (rhs)



Source: BNEF

EV models announced by automakers to 2022

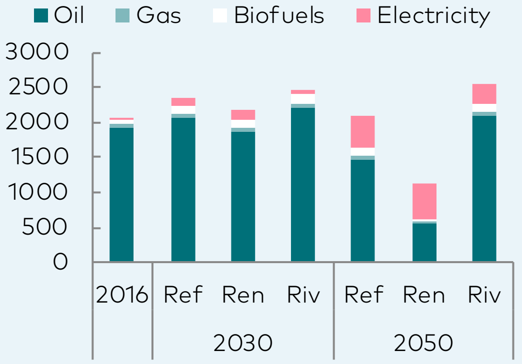
Number of models



Source: Bloomberg

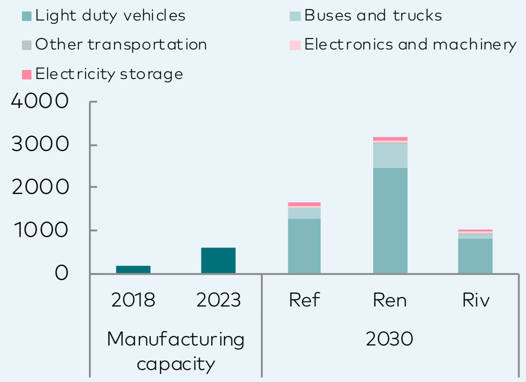
Road transport demand by fuel and scenario

Mtoe



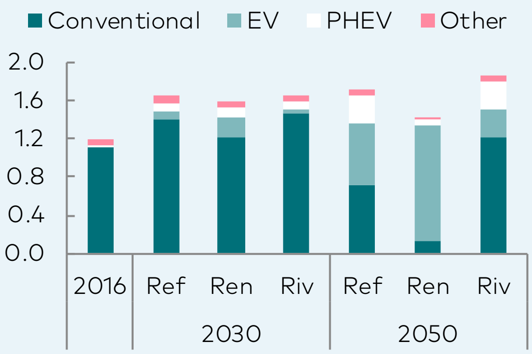
Source: IEA (history), Equinor (projections)

Annual Li-ion battery announced manufacturing capacity and projected demand by scenario
GWh



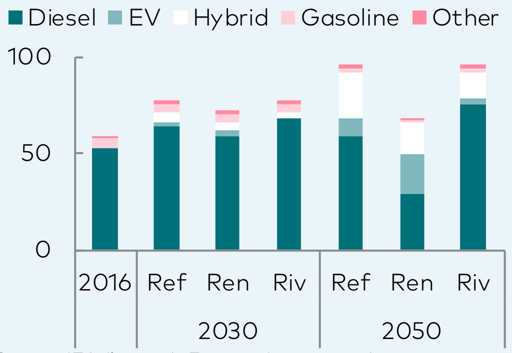
Source: PIRA, Equinor (projections)

LDV fleet by scenario
Bn



Source: IEA (history), Equinor (projections)

Truck fleet by scenario
Mn



Source: IEA (history), Equinor (projections)

Emission targets push technology development

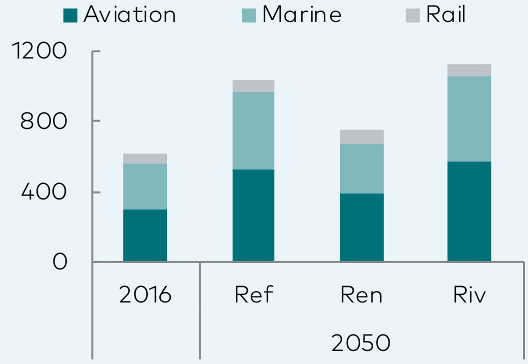
The global momentum towards a green shift in the transport sector has led to ambitious targets for decarbonisation. Several national governments and a number of cities are discussing a ban on fossil fuel cars between the mid-2020s to 2040. EU has been at the forefront of using legislation to drive change. From 2020 the average emissions from the fleet of new cars sold are limited at 95 g/km of CO_2, and by 2030 new targets imply a 37% reduction from 2021 levels. With today's available technologies car manufacturers will face significant challenges to meet future standards without a significant share of electric cars in their fleet. Late February 2019 a similar target structure in the EU was also proposed for trucks, which will be the next vehicle segment in line.

In China, EVs have also been identified as key tools to reduce local pollution and mitigate some of the enormous oil import dependency the country faces. Subsidies and credit systems for manufacturers have been implemented, resulting in China capturing over 60% of the global EV market in just a few years, with 2.6 mn EVs on the roads by the end of 2018. Despite falling passenger car sales in general, EV sales saw double-digit growth last year, with sales shares reaching 7% by Q4. Despite recent changes to subsidies, China is expected to be the global locomotive for EV growth also going forward. When it comes to electric buses, China is also far ahead of other markets.

Battery technology, the key for overcoming the main hurdles of EV driving range and cost, has seen a rapid improvement during the last years. Battery costs have dropped by over 80% the last decade. In addition, over the coming years a significant number of new car models will be released, most with stated ranges of 300 miles or more. This has already sparked increased interest among consumers, who up until now have had very limited choice of electrified models. However, despite obvious changes in consumer preferences and technology improvements, EV sales are still highly dependent on subsidies and/or government incentives to make up for the higher purchase price. Going forward, battery costs will benefit from scale and costs will decline further, so that the total cost of EV ownership is expected to be cost competitive with internal combustion engine (ICE) vehicles without subsidies by the mid-2020s.

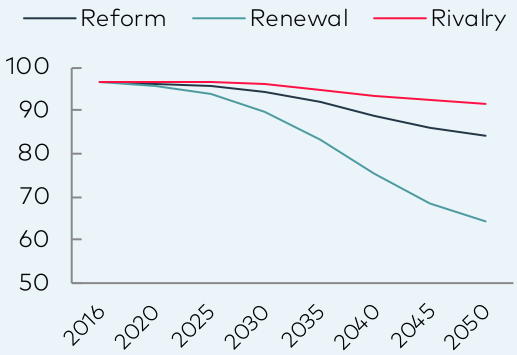
New technological advances as well as decarbonisation policies make the demand for energy in road transport more complex to predict. The key question is whether we will see a "break the link" between increased demand for mobility and fuel demand. In all scenarios, oil demand in road transport grows until the mid-2020s, but after this period there are different pathways for *Renewal* and *Rivalry* relative to *Reform*. By 2050, the difference in oil demand from the road sector between the scenarios is more than 30 mbd. In *Reform*, the current momentum to reduce emissions continues. Tightening regulations and increased investments are the main driver to improve competitive advantage of EVs against ICEs. In *Renewal*, technological breakthroughs occur sooner, EVs are competitive at an earlier stage and rapidly become the preferred choice for consumers, regardless of government targets and subsidies. In *Rivalry*, due to increasing geopolitical unrest, the global momentum on environmental efforts eases and investments are prioritised elsewhere. This leads to a slower growth in technology development and a parallel development of different technologies such as hybrids, LPG and fuel cells.

Global non-road transport by mode and scenario
Mtoe



Source: IEA (history), Equinor (projections)

Oil share of non-road transport
%



Source: IEA (history), Equinor (projections)

Unorthodox ways of reducing fuel consumption of ships: supplying air to the ship's underside to create a layer of tiny bubbles to reduce friction

Source: Marine Insight

Despite a growing share of electrification in the global LDV fleet, total oil demand from road transport remains robust for a sustained period, driven by continued growth in the passenger car fleet in non-OECD countries over the medium term as well as growth in the freight transport segment. Particularly in heavy trucking, the potential for electrification until the medium term is limited. By the end of the 2020s a decline in oil demand from road transport is expected, as several markets become saturated in terms of personal vehicles and the impact from changes in transport patterns such as car sharing and autonomous driving becomes visible. In addition, in the freight segment, digital technology, higher utilisation rates and wider choice of alternative fuels gradually start influencing fuel demand.

Non-road transport: unclear path to decarbonisation

While transport by road has several prospects of emerging mobility options, transport by air, sea and rail currently have fewer alternatives. Significant growth is expected, while methods of decarbonisation are limited. In 2016, transport by air, sea or railroads accounted for about 23% of total transport sector fuel use net of pipeline transportation fuel use. Aviation fuel made up 11%, and marine bunkers 10%, of the total. The world's trains consumed barely 2% of the total. Non-road passenger and freight transport fuel demand has increased by an average of 1.9% per year since 1990, i.e., less rapidly than road transport fuel demand which was up 2.4% per year in the same period. However, in recent years non-road transport – especially aviation – has accelerated while road transport decelerated somewhat, so that the two components of total sector fuel demand now increase at broadly the same pace.

Maritime transport: ambitious climate targets

Maritime freight measured in ton-km increased, according to IEA, by an average of 3.8% per year between 2000 and 2015, i.e., one third faster than global GDP. Maritime freight fuel use increased by only about 2% per year over this period thanks to vessel size growth and energy efficiency and fleet management improvements. The IMO aims to reduce sector greenhouse gas emissions by 50% between 2008 and 2050. The realism of this target is questionable. Seaborne trade will likely continue to increase – imports and exports of some goods like coal and oil may decline, but economic growth, the emergence of new products and the principle of comparative advantages could more than compensate for this. Ships have long lifetimes, implying low fleet turnover rates. The sector is heterogenous with lots of small operators alongside the big ones, making the design and implementation of policies to affect investment decisions challenging. While there is some enthusiasm for LNG and interest in biofuels, opportunities for switching from oil products to low or zero carbon fuels are constrained. Battery propulsion is an option only for smaller vessels serving local markets as today's batteries weigh too much and take up too much space for bigger, ocean going ships. Hydrogen and ammonia may become solutions, but only over the longer term.

Air transport: fast growth fuelled by new wealth

International aviation will likely remain the fastest growing transport sub-sector. As people become richer, and as globalisation and trade grows, business and private air travel grow. Between 2000 and 2015

Potential role of low-carbon liquid fuels

The political preference for how to decarbonise transportation is clear, as many governments are adopting policies to promote EVs. However, there seems to be a growing recognition that climate change mitigation will require both electrons and molecules. For long-haul heavy-duty road transport, aviation, and shipping, the high-density energy that hydrocarbon liquid fuels contain represents a fundamental advantage that will be challenging to overcome even with future battery technology. Alongside electric mobility, low-carbon liquid fuels will therefore remain important for future mobility.

There are many technological pathways currently being explored with the aim to reduce carbon emissions in transport: improvements in the efficiency of ICEs, increased use of advanced biofuels, or onboard capture of CO_2 emissions. The development of low-carbon liquid fuels is based on both established and emerging technologies. It is evolving by moving from first generation to other bio-feedstocks (2nd and 3rd generation) that do not represent an additional challenge for the environment, but the cost is currently high. However, in relative terms, low-carbon liquid fuels still represent a cost-effective option for cutting CO_2 from all transport segments, as existing infrastructure for production, distribution and storage can be used. In addition, they can be used interchangeably in the existing ICE vehicle fleet.

Development of low-carbon fuels may represent an opportunity for the refining sector, which is increasingly challenged by the regulatory changes addressing fuel efficiency and decarbonisation. Fuels Europe points out that refineries can diversify their feedstock base by using renewables, waste and captured CO_2 and further integrate in a cluster of industries such as petrochemicals, district heating, sustainable biofuels and power industry. These initiatives would require strong political drive, an enabling policy framework and regional incentives for refiners who diversify and process biomaterials, also requiring large investments in downstream.

Biofuels grow in all scenarios and in all regions, except for Europe and OECD Americas, where electrification displaces conventional ICE fuels and biofuel's share in road. In *Reform*, biofuels grow by 2.3 mbd to 4.6 mbd in 2050. *Renewal* and *Rivalry* only vary by 0.1 mbd from *Reform* in 2050, mostly due to constraints on the supply side and prioritisation towards electrification.

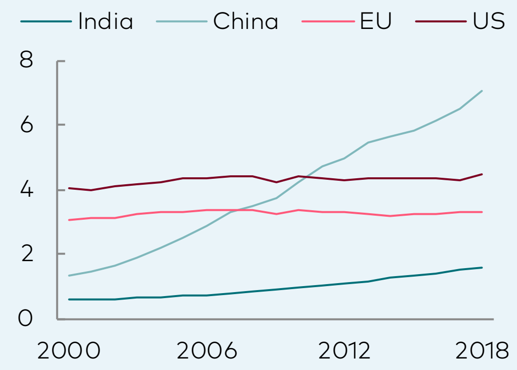
passenger-km travelled by citizens of non-OECD and non-CIS countries increased by an average of 10% per year, and barring economic setbacks or policy intervention or both, Airbus' expectation of a doubling of total – domestic and international – passenger-km between now and 2040 seems prudent.

The world's leading airlines have committed to try to stabilise CO_2 emissions by 2020 and reduce them to half of what they were in 2005 by 2050. Aircraft efficiency improvements and operational changes are hoped to stabilise emissions, and offsets like tree planting will play a part, but the 50% reduction will need to come mainly from the introduction of new fuels and – to the extent necessary – engines. Biofuels, and over the long term, hydrogen or synthetic fuels made from H_2 and CO_2, are the main options for wide-body aircraft flying long distances, with battery propulsion a possibility for smaller aircraft serving shorter domestic routes. But all these alternatives to conventional oil-based fuels face short- to medium-term constraints. Biofuels are more costly than conventional fuels, and whether the supply of sustainable biofuels that do not compete for land and water with food crops can be increased in line with the anticipated demand from the marine and air transport sub-sectors, is an open question. Hydrogen holds promise, but sustainable H_2 production will require either CCUS on a big scale or a massive expansion of electrolysis based on cheap renewable power. Given the economic lifetimes of aircraft, achieving ambitious emission targets by 2050 require significant changes in technology very soon.

Incentivising mode shifts could contribute to transport sector fuel savings and CO_2 emission reductions. Rail transport is much more energy efficient than other transport. IEA data suggests that whereas rail transport system including local subway and tramline systems account for about 8% of global passenger kilometres travelled, they contribute only about 1% to global passenger transport fuel use. Rail transport may not be an option for inter-regional travel but could be expanded in many regions. As for freight transport, much could be gained from switching from trucks to railroads or ships, given efficient and flexible mode shift opportunities along routes.

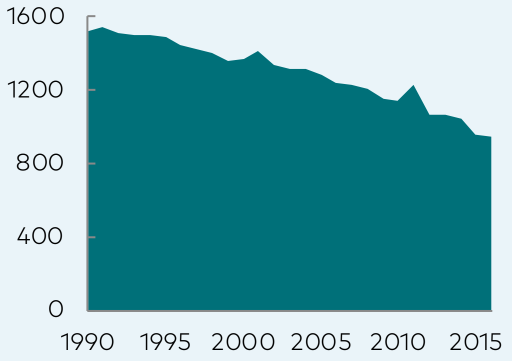
In *Reform*, global non-road transport energy demand increases by 2-3% per year until 2030, but levels out over the long term so that average annual demand growth over the entire 2016-50 period becomes 1.5% per year. The non-oil share of total sector energy demand increases from 3.5% by 2016 (representing the 42% of the world's rail transport systems that are electrified) to 16%. In *Renewal*, where tourism involving long-distance flights is discouraged by policy, and where business travelling is kept to a minimum, non-road fuel use increases by only 0.6% per year, and the non-oil share of total fuel use increases to about 35%. This share reflects assumptions of increased uptakes of electricity, biofuels and LNG. If hydrogen and synthetic fuels take off, a possibility that is not taken explicitly on board in any of the scenarios, all bets on the future fuel mix of the non-road transport sectors are off. In *Rivalry*, low economic growth dampens non-road transport fuel demand to 1.3% per year and non-oil fuels capture only 8% of the market.

Electricity demand in China, EU, US and India
Thousand TWh



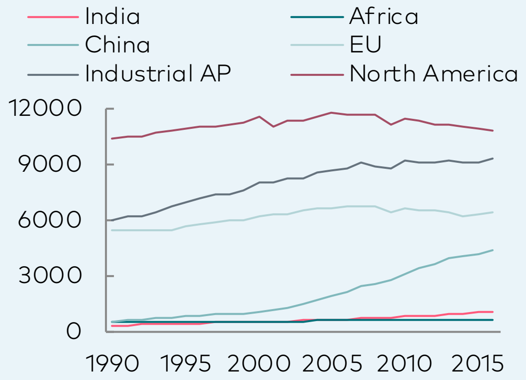
Source: BP Statistical Review 2018, IEA

Global population without access to electricity, 1990-2016
Million people



Source: United Nations, World Bank

Annual electricity demand per capita, 1990-2016
kWh



Source: IEA, UN

The future of electricity

Electricity demand: on the rise

Recent trends and developments

In 2012, China grew past the US to become the largest electricity consumer in the world. The role of China in the development of global electricity demand growth cannot be overstated. Since 2000, China has accounted for around half of global annual growth. Demand growth appeared to slow down in 2014 and 2015, but has since picked up, and 2018 looks to be a record year with global demand increasing by 4% or around 1000 TWh. Chinese electricity demand is reported to have risen by over 8%, or around 515 TWh, which is the largest annual growth in any single country ever recorded. To put it into perspective, this is about the same as total French electricity demand. The increase is attributed to strong growth in industry and service sector consumption, as well as the ongoing campaign to switch energy consumption from direct use of coal to electricity.

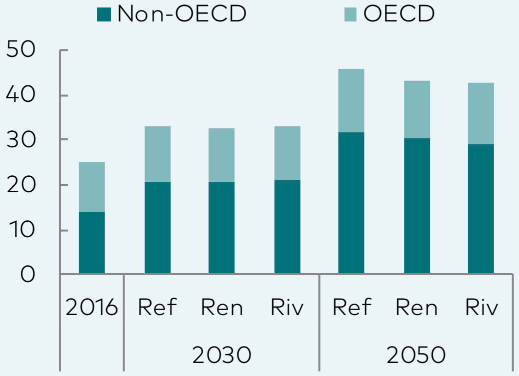
US electricity demand also experienced strong momentum in 2018. After a drop in 2017, electricity use grew by 4% in 2018 due to increased demand in the commercial and residential sectors, largely attributable to a hot summer and cold winter. This brought total demand up to the same level, or just above, the previous peak annual demand in 2007. EU, the third largest electricity market globally, experienced a rise in electricity consumption of 0.2% in 2018, the fourth consecutive year of growth. However, demand is still about 2% lower than the peak in 2010. The trend in 2018 followed a similar pattern to previous years of rising electricity consumption in Eastern European countries and stagnant elsewhere. Combined, China, US and EU make up around 55% of global demand. The fourth largest market, India, accounting for around 5% of global electricity use, grew by around 5% last year, or slightly below the average annual growth rate of the past decades.

Drivers for long-term demand growth

There are several drivers that affect the growth of electricity demand and how the share of electricity in TFC develops. Electricity can be a very efficient and clean source of energy, and electrification is one of the main pathways towards more efficient and lower carbon energy systems. Electrification of transport, industrial processes, heating and lighting can significantly reduce overall energy consumption. For instance, electric engines are three to four times more efficient than combustion engines, heat pumps are three to four more efficient than boilers and LED lights use 1/50 of the energy of a kerosene lamp. Technology improvements such as more efficient electronics and appliances and new technologies such as LED lights reduce electricity demand. New solutions enabled through smart meters, digitalisation and electricity storage may lead to smarter and more efficient use of electricity.

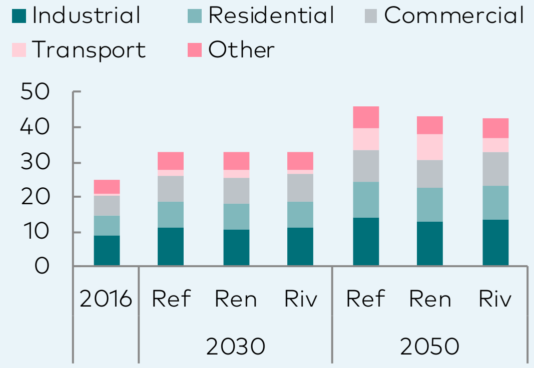
There are also factors that work in the opposite direction. Modern society is becoming increasingly electrified through the increased use of electronic gadgets and appliances, heat pumps and air conditioning, and electric vehicles – all driving demand for electricity. There are still almost 1 billion people in the world that do not have access to electricity, and in developing countries, the levels of electricity consumption per capita are far below what is common for developed nations. In India for instance, per capita electricity consumption is only 1/6 of the levels seen in EU and 1/10 of the US. The combination of a growing global population, expanding electricity

Electricity demand by scenario
Thousand TWh



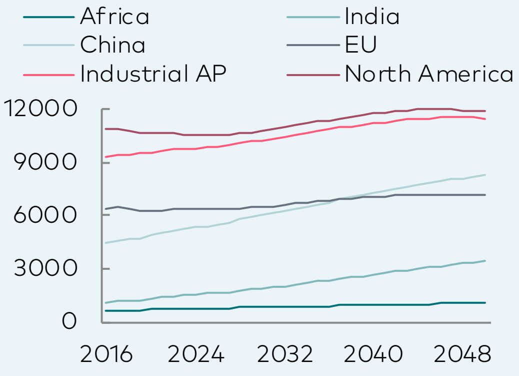
Source: IEA (history), Equinor (projections)

Electricity demand by sector and scenario
Thousand TWh



Source: IEA (history), Equinor (projections)

Electricity demand per capita in Reform
kWh



Source: IEA (history), Equinor (projections)

access to those without, and increasing electricity use per capita provide a massive potential for growth in long-term electricity demand.

Reform: highest electricity demand

The long-term outlook for electricity demand is bright in all scenarios. *Reform* exhibits the highest growth at an annual rate of 1.8% over the 2016 to 2050 period, due to less energy efficiency improvements than *Renewal* and higher levels of electrification than *Rivalry*. In total, global electricity demand reaches almost 46 thousand TWh by 2050, up almost 85% from 2016 levels. Electricity gains importance in the energy mix; measured as a share of TFC it increases its share from around 19% currently to 29%. There are important regional and sectoral dynamics that to a varying extent play out in all scenarios. Most of the demand growth happens in developing countries and regions, and all sectors of the economy increase their use of electricity. Currently, developing regions account for just below 60% of global electricity use, up from less than 40% in 2000. Towards 2050, developing regions are responsible for almost 90% of all incremental electricity demand and end up with a share of over 70% of the total.

The largest electricity consuming sector on a global basis is the industrial sector, closely followed by the commercial and public sector and finally, the residential sector. Over the past 15 years, the industrial sector has seen the largest growth in absolute terms, driven by the break-neck speed of Chinese industrial production growth. The Chinese industrial electricity demand is over three times as large as the industrial electricity demand in the EU or in North America. Demand continues to grow in these sectors, led by the developing countries and regions where economic growth leads to more electricity being used in all sectors of the economy. Electricity consumption per capita also sees sustained increases. In the developed regions, electricity demand in the industrial, commercial and residential sectors is largely flat over the projection period as efficiency improvements outweigh increased economic activity.

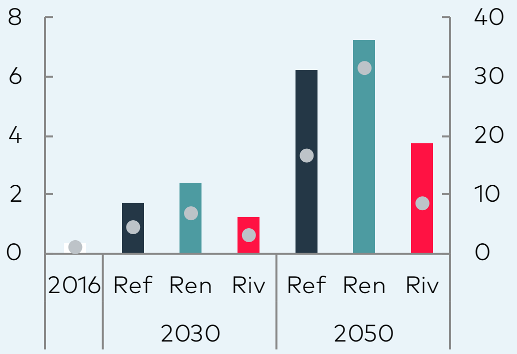
Transport emerges as an important new source of demand from the mid-2020s, in line with the electrification of road transport. In 2016, transport accounted for less than 2% of global electricity demand, with rail transport representing the bulk of this demand. By 2050, this grows to an impressive 14%. The largest growth is seen in China and North America, which are the two regions with the largest vehicle fleets in the world. In China there are over 200 million fully electric light duty vehicles on the road in 2050 and in North America almost 150 million.

Renewal: electrification drives energy efficiency

Electrification of the economy and the energy mix happens at a pace in *Renewal* that is much faster than both the historical trends and the projections in the two other scenarios. Due to its efficiency in end use, increasing the use of electricity is one of the main levers to improve energy efficiency in *Renewal*. Although electricity demand grows slightly less compared to *Reform* in absolute terms, reaching 43 thousand TWh by 2050, the share of electricity in TFC goes to 37%, almost a doubling compared to current levels.

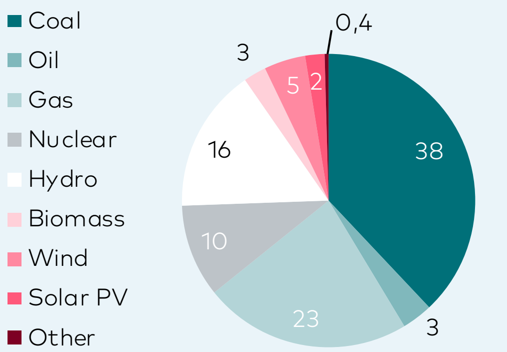
Regional demand patterns follow roughly the same path as in *Reform*, although developing regions account for an even larger share

Transport electricity demand and share of transport TFC
Thousand TWh (lhs), % share (rhs)



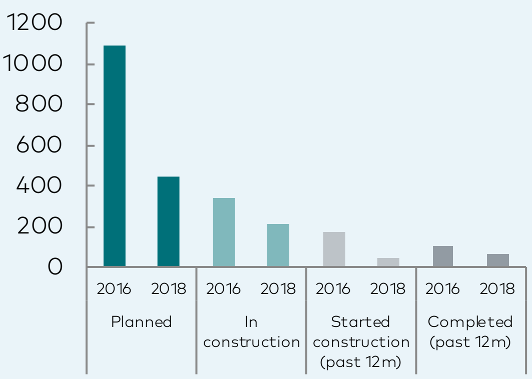
Source: IEA (history), Equinor (projections)

Global electricity generation mix in 2018
%



Source: IEA

Global coal project pipeline
GW



Source: The Global Coal Plant Tracker

of the growth in electricity consumption towards 2050, over 90%. Almost all regions see electricity shares in TFC around 40%, with the Middle East and Africa as notable exceptions. Their electricity shares today are also well below the global average. As in *Reform*, all sectors of the economy increase their electricity demand, although due a stronger emphasis on efficiency, the growth in absolute terms from industry, commercial and public sector and residential sector is lower. The largest growth is seen in transport demand, and by 2050 it accounts for 17% of all electricity demand.

Rivalry: slow-down in electrification

Rivalry marks a slow-down in the pace of electrification of TFC compared to the two other scenarios. Electricity reaches a share of only 24% by 2050, but due to the higher overall energy demand in *Rivalry*, electricity demand still reaches 43 thousand TWh by 2050 or roughly the same as in *Renewal*. In *Rivalry*, there is less focus on energy efficiency and the environment, which leads to a less efficient use of electricity compared to both *Reform* and *Rivalry*. Technology developments are generally slower and new solutions are implemented to a lesser extent. The largest difference on a sectoral level is the markedly lower electrification of transport. In *Reform* and *Renewal*, electricity use in transport grows to 6 and 7 thousand TWh respectively by 2050, compared to 0.4 thousand TWh currently. In *Rivalry*, it grows to 3.5 thousand TWh.

Electricity generation: increasingly driven by renewables

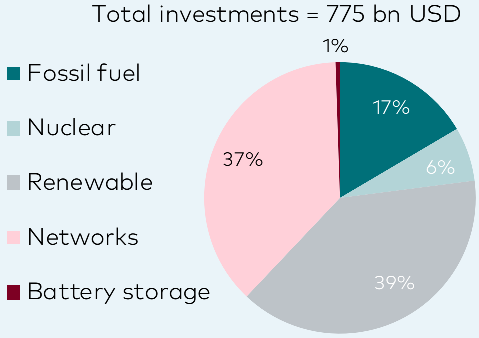
Recent trends and developments

On a global basis, coal is by far the largest source of electricity generation, representing close to 40% of the total. Over the past years, coal-based electricity generation has been on the decline in the US and EU, while in several Asian countries it continues to increase. Gas-based generation is the second largest source at 23%, followed by hydro (16%) and nuclear (10%). The fastest growing source of electricity generation is solar and wind, currently representing about 7% of total generation.

The 1000 TWh increase in global electricity generation in 2018 was met by rising generation from all sources, except oil-based generation. In China, the 8% increase in electricity generation to around 7000 thousand TWh was mainly covered by higher coal-fired electricity generation. Other sources of generation grew even faster, but from much lower shares in the mix. Solar and wind electricity generation was up by almost 25% to a share of 6% in the electricity mix, while nuclear, due to new plants entering service, grew by close to 20% to a share of 4%. US electricity generation rose by around 4% in 2018 to almost 4500 TWh. The growth was led by a massive 13%, or 180 TWh, increase in gas-fired electricity generation together with a 9% hike in solar and wind. EU electricity generation was fairly flat from 2017 to 2018, at around 3250 TWh, with renewable power generation increasing by almost 8% or 75 TWh to 1050 TWh, 32% of the generation mix. The increase in renewables was compensated by an equivalent drop in coal and gas-based electricity generation.

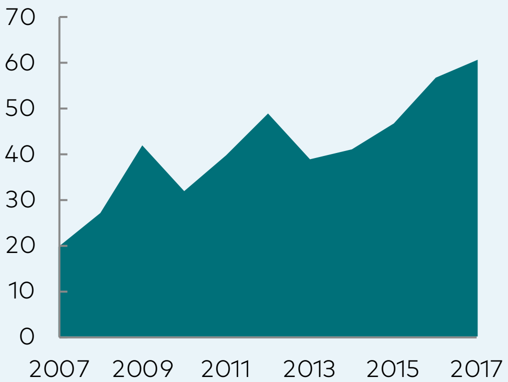
Developments in new electricity generation capacity provide an indication of what can be expected in terms of changes in the future electricity mix. Generally, the push for coal appears to be slowing down, the momentum for nuclear remains sluggish, and new large-

Global electricity sector investments 2018
%



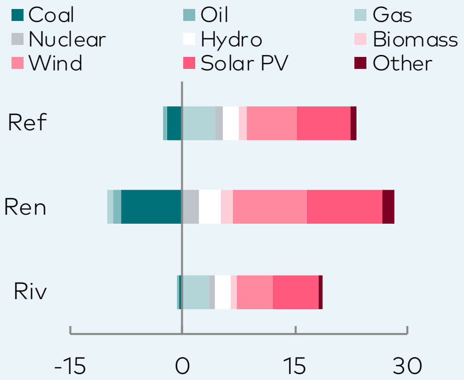
Source: IEA

Renewables (ex-large hydro) share of net new capacity
%



Source: UN, BNEF

Net change in generation by scenario
Change 2050 vs 2015, Thousand TWh



Source: Equinor

scale hydro is being developed at a moderate pace. Globally, there is just over 2000 GW of coal capacity in operation, with 240 GW currently under construction, and another 370 GW under different stages of planning. The number of plants in planning has been reduced dramatically from 2016, when there was over 1000 GW planned. Start-up of construction and completion of new capacity have also dropped precipitously, and if the trend continues, by 2022 the yearly retirements may exceed new capacity additions. Installed nuclear capacity worldwide amounts to 380 GW spread over 450 reactors, equivalent to about 15% of existing capacity. The number of installed reactors has, however, not increased much over the past decades – there were 420 reactors in operation in 1989. Over the past 5 years, an average of only three new reactors have been added per year. Global installed hydro power capacity stands at just under 1300 GW. Average capacity additions over the past decade have been over 30 GW per year, led by Asian countries. China alone accounted for over half of the global capacity additions. Hydro is a mature technology and many of the best resources have been developed, but still new hydro capacity continues to be developed.

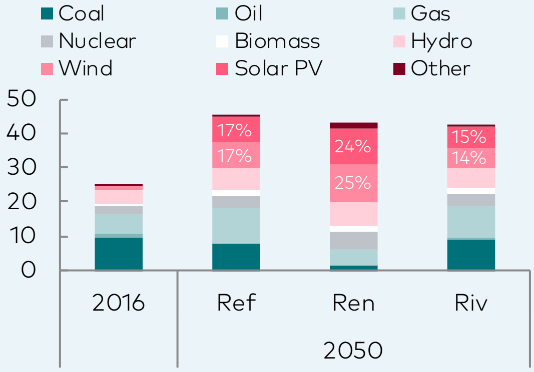
Renewables have gradually started to dominate new capacity additions, both on a regional and a global basis. New solar PV capacity noted another strong year in 2018, with 95 GW installed, and new wind capacity came in at around 50 GW, in line with recent years' levels. Globally, renewable electricity represented almost 70% of net new power capacity in 2017. In some regions the share is even higher. For instance, in 2018 three-quarters of all net new capacity in India was renewable, up from two-thirds the year before. In the EU, 95% of all new capacity in 2018 was renewable.

Investments in the power sector are heavily influenced by policies and regulation. According to IEA's World Energy Investments 2018, over 95% of these investments, including generation, networks and storage, rely on some type of regulated revenues or other mechanisms, rather than solely relying on wholesale markets. The growing share of intermittent renewables in the electricity mix will challenge existing electricity market designs even further. Although CO_2 costs will lift the wholesale market prices, intermittent renewables with zero short-run marginal cost depresses them, and as solar and wind continues to expand their share in the electricity mix, it will become even more challenging to attract long-term investments. Electricity markets are expected to remain heavily regulated in all scenarios, but how they are regulated will vary significantly between the scenarios.

Reform: strengthening trends

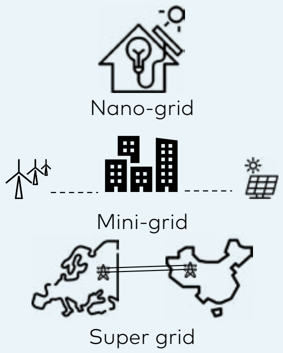
Reform builds on a strengthening of many of the trends that we see today. Coal has little support in developed regions and continues to be shut down to the benefit of gas and renewables. In developing countries, there is still some support for coal, but gradually the push for renewables takes over and gas play a stronger role. Globally, coal-fired net capacity additions turn negative in the 2020s, while gas-fired capacity additions continue, as the role of gas in both baseload and back-up supplies grows. Nuclear additions continue at a slow pace as it faces public opposition as well as cost, reputational and permitting challenges, adding on average a few reactors per year. Solar and wind capacity additions, on the other hand, continue to expand at a fast pace, going from just over 10% of all installed capacity today to around 50% by 2050, with the share in power

Electricity generation by scenario
Thousand TWh



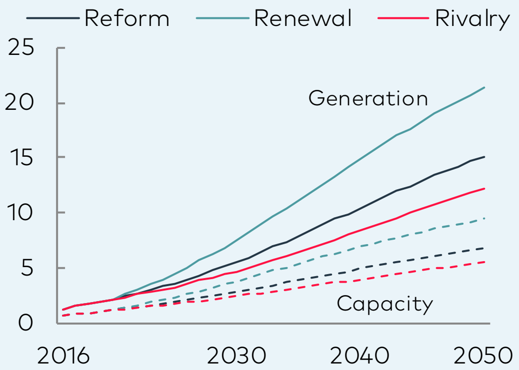
Source: IEA (history), Equinor (projections)

What will future electricity grids look like?



Source: Equinor, thenounproject.com

Solar PV and wind electricity generation and capacity
Thousand TWh (generation), TW (capacity)



Source: IEA (history), Equinor (projections)

generation reaching about 33%. The share of coal drops by 50%, while gas remains at around one-quarter. Nuclear and hydro drop slightly in the mix.

Renewal: a rapid transition

Renewal experiences the most radical shift in installed capacity and generation. Coal capacity and generation is quickly shut down and almost completely phased out from developed countries over the next 10 to 15 years, while developing countries close down most coal plants by the end of the projection period. Gas electricity generation grows, both in absolute terms and as a share in the mix towards 2030, as it plays an important role in replacing coal-based generation. Eventually, as all coal-based generation is phased out, gas increasingly starts to be pushed out by renewables. The upside for hydro and biomass is seen to be limited and paves the way for nuclear as an alternative low-carbon source of electricity. The pace of building new nuclear reactors needs to pick up, and in *Renewal* about 10 new reactors, or around 8 GW, are being added to the global nuclear fleet every year from 2020.

The main feature of *Renewal* however is the very rapid deployment of solar and wind electricity, accounting for half of total electricity generation by 2050. Several countries and regions see solar and wind penetration of well above 50%, which will imply fundamental shifts in how electricity is generated, stored and used, and how electricity markets operate. At such levels the electricity system cannot rely on existing tools to generate flexibility. Large investments in storage and interconnections will be necessary, and there will need to be solutions that can store electricity also on a seasonal level in addition to closer management of demand. Demand management tools, behavioural feedback, and new digital advances in technology such as smart metres will be key for system operators to offset intermittency challenges, and keep the grid balanced at all times.

Rivalry: different priorities

In *Rivalry*, political priorities turn towards energy security and affordability. Renewable capacity investments still do well in *Rivalry* and continue to grow, but at a slower pace than in the two other scenarios. Developing countries and regions that have domestic coal supplies continue to develop their resources, and the phase-out of coal in developed countries slows down. Gas-based electricity grows in almost all regions, but at a slower pace compared to *Reform*. There is also greater regional divergence; gas surplus regions maintain or increase the share of gas in the electricity mix, while gas importing regions will use less gas compared to *Reform*.

Solar and wind generation accounts for over 25% of total electricity generation in 2050. Coal-based electricity generation remains at similar levels as today in absolute terms but falls as a share in the mix. Nuclear and hydro experience a slightly decreasing share in the mix, similar to *Reform*.

An interconnected future

In 2016 and 2017, for the first time ever, investments were higher in electricity supply than in oil and gas supply. The recent increase in developmental capital for electrification projects, coupled with a decreasing cost of mini-grids that utilise more renewable energy sources, has led to an increase in rural electrification. Nonetheless, according to IEA's World Energy Outlook 2018, close to 1 billion people still lack access to electricity, mainly in Sub-Saharan Africa.

Countries with existing extensive grid networks face challenges in integrating increasing proportions of new renewables. The higher intermittency challenges grid operators' ability to balance supply and demand. In countries such as India and China, where generation capacity and demand centres are far apart, generated power needs to be transmitted over large distances. A different, grid-related challenge occurs when the demand for fast charging of electric vehicles and use of high-capacity domestic electric equipment at specific times during the day put strains on old, local grids in cities and communities.

Super-grids are being developed, using ultra-high voltage DC networks (>800 kV), to pool generation and consumption over longer distances. Pooling generation limits the impact of uncertain local conditions and pooling demand allows portfolio effects, flattening demand peaks. This leads to better grid efficiency and generation portfolio dimensioning, but also carries notable challenges. Technical constraints in gathering and using data, in balancing extended grids, in ensuring network integrity and security, and in limiting efficiency losses on long distances add to the challenges. The geopolitical environment needs to be supportive to overcome these challenges, with greater cooperation and trust between countries to develop transnational super-grids when greater connectivity may be seen to weaken a country's energy independence.

Despite this, ambitious projects have been communicated to shape the future of electricity networks. One of China's long-term ambitions is to interconnect the Northern Hemisphere with what could be labelled the "internet of electricity". The first stages, that would see the connection of China's Western provinces to Germany, have found support, if not of the financial kind yet, in EU. And while super-grids are being announced in the Northern Hemisphere, mini-grids are being developed in all parts of the world, disrupting legacy networks and enabling decentralised electrification in developing countries.

The future of energy is (much more) electric, and it is interconnected, but the extent and timing of such interconnectivity has yet to be shaped.

Potential and limits for electrification

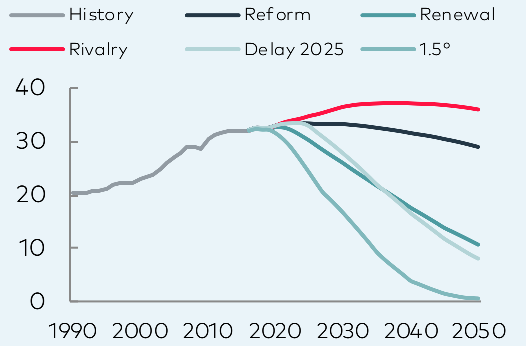
Electrification has been going on for over a century, but lately we have seen a material uptake in electrification of sectors previously associated with fossil fuels. In the short term, opportunities for electrification are mainly concentrated in transport and residential sectors, only limited by infrastructure and potential high up-front costs. Manufacturing, however, accounting for 29% of TFC and being the largest user of electricity, is often viewed as a sector where electrification falls short. Are there opportunities for industrial electrification on the horizon, or will industry keep its demand for fossil fuels?

Today, most of the industries' electricity use is within electric motors, such as pumps, ventilation and compressed air. Other uses that also require large amounts of electricity are the electrolytic process for producing non-ferrous metals such as aluminium and copper. In the steel industry, electric arc furnaces are accounting for over 25% of the world's steel production, melting recycled steel using much less energy compared to a conventional blast furnace.

Looking forward, opportunities for industrial electrification lie foremost in the electrification of heat. In the residential sector, converting from gas cooking to induction cooking offers twice the efficiency and speed, and higher precision. Similarly, technologies for industrial electroheating are emerging, with abilities to reach high temperatures very rapidly and with high precision. Industrial electroheating can hold high efficiency gains of 2-3 times the conventional heating, and facilitate demand responsiveness, where industry can take advantage of the high intra-day volatility in the electricity market. However, combined with potential high up-front cost; fossil fuel prices remain low compared to electricity, dampening progress on electrification initiatives.

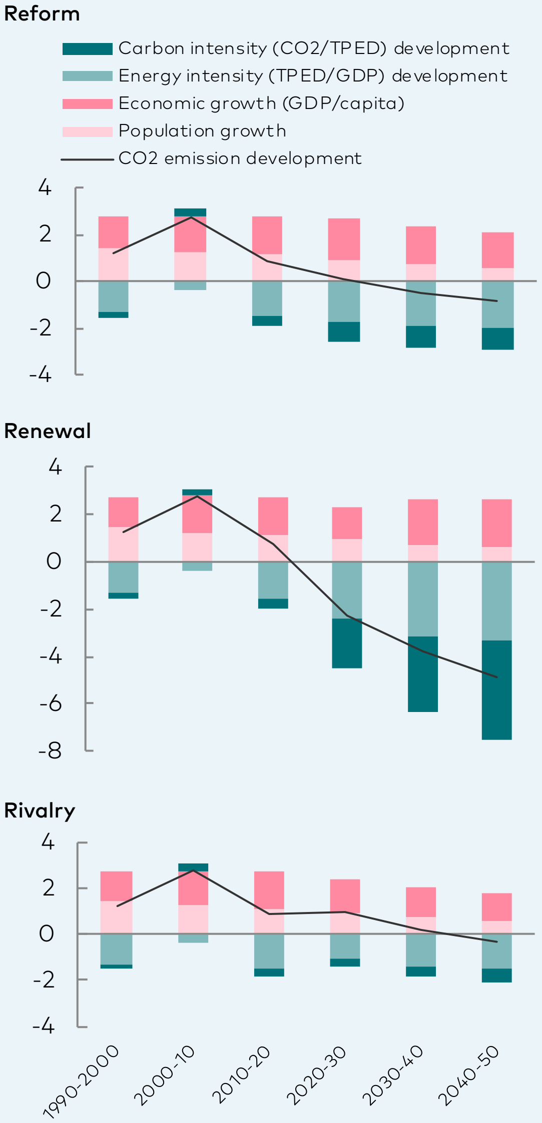
In all scenarios, electrification of industry increases from today's 27%, reaching 32%, 36% and 42% by 2050 in *Rivalry*, *Reform*, and *Renewal*, respectively. The 1.5° sensitivity, requiring extreme levels of electrification, sees more than a doubling of the industry's electricity share to 57% in 2050. Looking at the evolution of electrification in other sectors, are we reaching a limit for the industry, or is there room for more? In addition to availability and cost of electrification technologies, efficiency gains and cost between electricity and other fuels will play an essential role in the future potential. Beyond the energy and climate perspective, electrification can provide value-added manufacturing such as higher quality products and increased productivity, making the case for industry electrification not only a case for energy efficiency. Still, significant innovation and deployment support will be needed to develop alternative technologies and drive cost reductions.

Global CO_2 emissions by scenario and sensitivity
Gt



Source: IEA (history), Equinor (projections)

Development in world energy-related CO_2 emissions by emission driver
%



Source: IEA (history), Equinor (projections)

Greenhouse gas emissions

Global carbon emissions: can the tide be turned?

Global energy-related CO_2 emissions increased by 1.7% in 2018 to reach an all-time high of 33.1 Gt, according to the IEA. Emissions were flat in 2014-16, giving rise to hopes that they would soon go into decline. Instead we have experienced two consecutive years of significant growth. In some countries like Germany, the UK, France, Japan and Mexico emissions were down in 2018, driven mainly by the uptake of renewable energy sources and the phasing out of fossil fuel-based power supply. But in China, India and the US they were up due to rapid economic growth powered partly by coal and oil, and weather patterns requiring more than usual heating and cooling, in different proportions. The lack of progress in cutting global emissions underlines the pressing need for a coordinated global effort to instigate effective policy and incentives for decarbonisation.

In *Reform*, which is not tailored to any particular carbon budget, global energy-related CO_2 emissions increase into the early 2020s before plateauing and going into decline at a rate of 0.7% per year from 2030 onwards. The pace of decline increases marginally late in the scenario period towards 2050, driven predominantly by power sector decarbonisation and transport electrification. Cumulative emissions over the full scenario period are 1,090 Gt. This would, according to IPCC/IEA, result in a global temperature rise significantly above 2°, barring compensating reductions outside the energy sector.

In *Renewal*, which is designed to be a "well below 2°" back-casting scenario, emissions must peak almost immediately and decline at an average of 3.7% per year between 2020 and 2050, resulting in cumulative emissions of 773 Gt over the scenario period. This development would be expected to continue beyond 2050 until "net zero" emissions – entailing that remaining anthropogenic CO_2 emissions are matched by man-made sinks – have been achieved, stabilising the level of CO_2 in the atmosphere.

In *Rivalry*, emissions continue to grow year on year from their current levels, peaking at approximately 37 Gt per year in the late 2030s, before declining slowly. Cumulative emissions over the period are 1,216 Gt. This emission development places *Rivalry* above the middle of the range of global warming projections, suggesting gradually increasing negative climate effects on both the environment and the global economy.

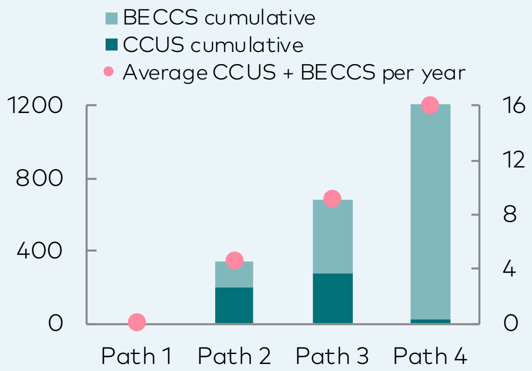
In Energy Perspectives 2019, two sensitivities have been introduced to *Renewal* to illustrate other potential energy pathways to a well below 2° world. The 'Delay 2025' sensitivity, with the same carbon budget as *Renewal*, but based on a *Reform* trajectory up to 2025, and the 1.5° sensitivity (see separate text box). Both these sensitivities require even more extreme mitigation than that of *Renewal*. This is achieved through further energy efficiency improvements and fuel mix changes that have little precedents in historical data, requiring accelerated phase out of fossil fuels from all sectors simultaneously. Achieving this under the conditions of continued, strong economic growth assumed for *Renewal* is challenging and might call for deeper lifestyle changes than normally assumed even for allegedly sustainable outlooks. In addition, one would expect increased problems in handling distributional effects if economic growth must be reduced. This highlights the urgency of establishing effective policies that would result in emission reductions immediately.

Renewal sensitivity results

Year 2050	Renewal	Delay 2025	1.5°
Gross CO_2 emissions - Gt	11	8	0.7
Annual growth TPED 2020-50	-0.5%	-0.8%	-0.7%
Oil demand - mbd	52	50	25
Gas demand - Bcm	3,200	2,700	900
Coal demand - mtoe	610	290	240
Total electricity generation - TWh	43,200	40,400	55,200
Solar/wind generation - TWh	21,300	21,600	33,200
Solar/wind share	49%	54%	60%

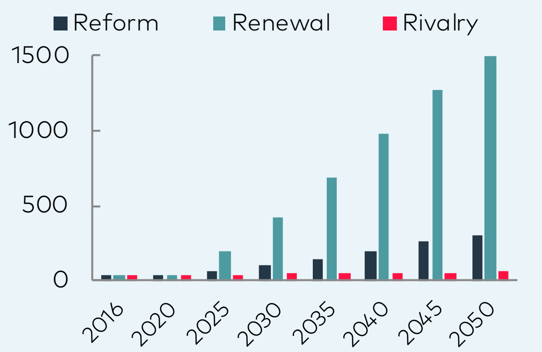
Source: Equinor

CCUS and BECCS play a significant role in three of the IPCC's illustrative 1.5° scenario pathways
Gt in 2100 (lhs), Gt per year 2025-2100 (rhs)



Source: IPCC

Global CCUS in the scenarios
Mt per year



Source: Global CCS Institute (history), Equinor (projections)

Carbon capture, utilisation and storage: lack of incentives

Most scenarios showing alternative ways to limit the build-up of greenhouse gases in the atmosphere at levels consistent with the well below 2° or 1.5° targets include significant amounts of CCUS. Market and technology developments and delivery on the policy commitments made in Paris in 2015 will likely put an end to emission growth. However, today's CO_2 budgets consistent with climate stabilisation cannot settle with flat or gently declining emissions, but rather, is a call for rapidly declining emissions.

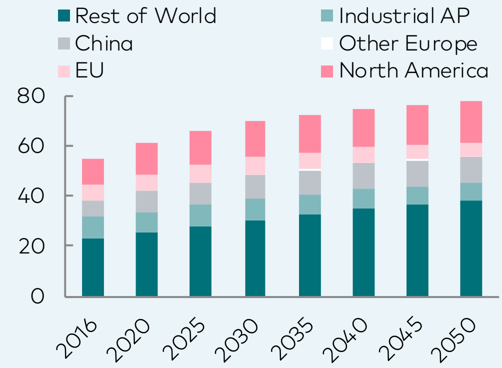
The number of options to achieve such declines is limited. In principle, it is possible to pull harder on the energy efficiency and energy supply decarbonisation levers, and add some natural sink enhancement, but most energy and climate modelers consider that achieving net zero emissions by these methods alone would be very expensive, and many simply cannot make their models return sustainable outlooks with so few policy tools to play with.

The 1.5° report published by the IPCC last autumn offers four illustrative model pathways, where one excludes CCUS and negative emission technologies, one tries not to lean too heavily on these options, but still needs to get rid of several Gt of CO_2 per year, and the last two relies on vast amounts of capture and storage. If CCUS project development activity does not pick up significantly before 2025, which seems a reasonable assumption, these two pathways would on average require capture of 9 and 16 Gt CO_2 respectively every year.

Global CO_2-capture capacity, according to the Global CCS Institute, is 41-42 Mt of CO_2 per year. Enhanced oil recovery projects account for more than 80% of this total. However, the Global CCS Institute sees reasons for optimism, pointing to five projects in the construction phase and 20 being planned. Moreover, policy support for CCUS is strengthening. There is less talk today than a few years ago about CCUS as intended mainly to extend the fossil age, and many countries have adopted or reinforced existing CCUS support arrangements. Still, high costs and an absence of business models for projects without options to monetise the captured CO_2, remain hurdles to growth. Interest in the "U" in CCUS, i.e., in finding ways apart from EOR to make money from the emitted gas, is therefore increasing.

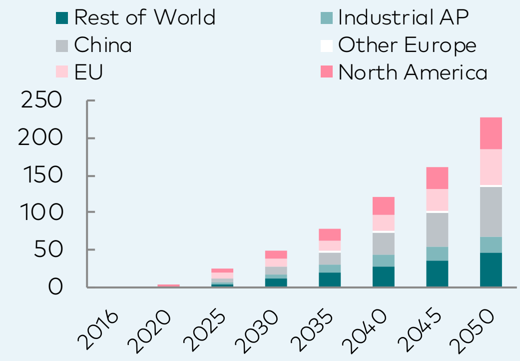
In *Renewal*, CCUS is assumed to increase to a level around 1.5 Gt per year by 2050. This is very modest by IPCC scenario standards, but the phenomenal growth in CCUS in the 2030s and 2040s suggested is difficult to believe in based on current development. 1.5 Gt per year corresponds to over 1500 Sleipner-scale ventures, and the need for infrastructure to handle a mass of CO_2 equivalent to twice the current global wheat market. CCUS will likely remain a secondary contributor to global warming mitigation. In *Reform*, CCUS reaches 0.3 Gt by 2050, whereas *Rivalry* delivers very limited development beyond current projects. If CCUS does not happen on a large scale, efficiency improvements and fuel mix changes will need to do correspondingly more of the heavy lifting to put CO_2 emissions on a pathway consistent with the *Renewal* carbon budget. Whether the elevated assumptions on these drivers are more realistic than an assumption of more CCUS would have been, remains to be verified.

Hydrogen for feedstock - illustrative pathway
Mt H_2



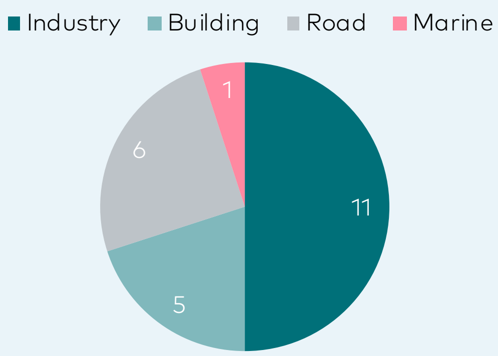
Source: Equinor

Hydrogen for TFC and power - illustrative pathway
Mtoe



Source: Equinor

Hydrogen TFC in EU, 2050 - illustrative pathway
Mtoe



Source: Equinor

Hydrogen: to the rescue?

The interest in hydrogen as a fuel is on the rise. It has been on the agenda before, only to recede in the face of high costs and distractions in the form of breakthroughs for other new energy solutions, like EVs. However, recent progress on the hydrogen technology and cost side, and a conclusion that global CO_2 emissions must be reduced at a pace calling for all available zero carbon fuel technologies, have put hydrogen back in the limelight.

Hydrogen has historically been used as an input in steel and chemicals manufacturing and refinery operations. Currently, global demand totals some 55 million tons (Mt) – or, in energy terms, 158 mtoe – per year. The use of hydrogen as a fuel is miniscule in comparison, and largely limited to road transport on a niche basis. However, the prospects for increasing this demand – and for using hydrogen as a medium to store and transport excess wind and solar PV electricity – are currently exciting the energy community. Hydrogen emits no CO_2 when burned or used chemically in fuel cells to produce electricity.

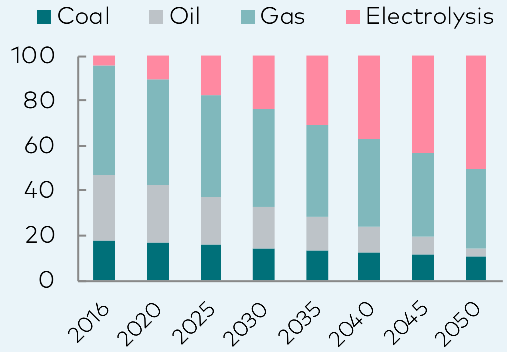
The competitiveness of hydrogen as a fuel depends on the costs of producing and transporting it safely to consumers, and on costs of modifying boilers, engines etc., to accommodate the new fuel. Cost estimates vary, reflecting different assumptions on production technology, plant utilisation, scope for investment cost reductions and fuel price developments. Historically, hydrogen has been produced from fossil fuels, mainly gas, but it can also be manufactured from electricity and water by means of electrolysis. If hydrogen is to be part of an energy transition, fossil fuel-based production must be equipped with CCUS or replaced by electrolysis-based production utilising zero-carbon electricity.

Assessing the impact of hydrogen in our scenarios requires assumptions on how it will be used and produced. Hydrogen has potential in all energy end-use sectors – industry, the building and transport sectors, with long distance trucking and marine transport (possibly using ammonia, a handy hydrogen carrier) being particularly promising markets. Assumptions are needed on which sectors in which regions will be affected, how fast the uptake will progress, and how other fuels' market share will be influenced. On the supply side, a hydrogen industry based on fossil fuels will generate demand for gas, coal and/or oil, raising the question of which fossil fuel will be used where. On the other hand, an industry based on electrolysis will add to the demand for electricity, raising the question of how and where this electricity will be generated. The net impact on fossil fuel use, and consequently CO_2 emissions, needs to be investigated case by case.

Illustrative H_2 pathway to Renewal

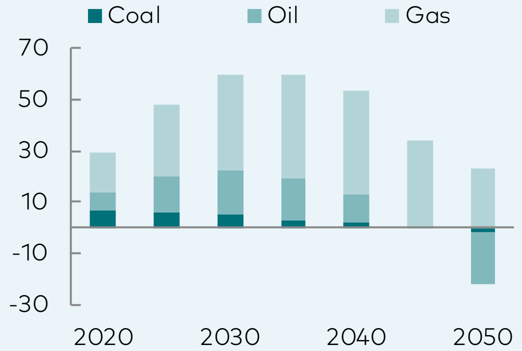
Renewal relies heavily on electrification of energy end-use and some post-combustion CCUS. The hydrogen pathway represents an additional lever to limit global warming to well below 2°. Hydrogen could become a clean alternative to fossil fuels for the industry and transport sub-sectors that cannot easily be electrified and could potentially save costs by enabling continued use of existing fossil fuel infrastructure or provide an outlet for surplus renewable electricity, or both. In the following a simplified hydrogen uptake case roughly tailored to *Renewal* is presented to illustrate select linkages and the outcome of a given set of drivers.

Hydrogen supply fuel mix - illustrative pathway
%



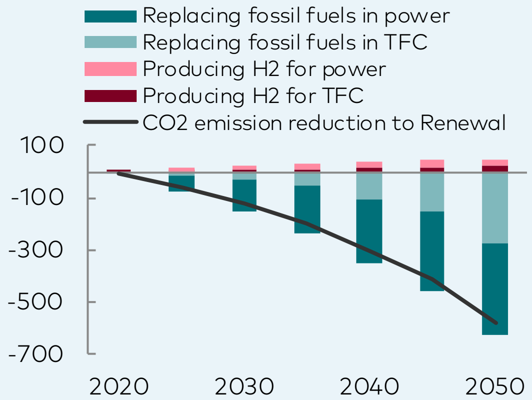
Source: Equinor

Net impact of hydrogen on fossil fuel use relative to Renewal - illustrative pathway
Mtoe



Source: Equinor

Changes in global CO_2 emissions relative to Renewal related to the penetration of hydrogen as a fuel - illustrative pathway
Mt per year



Source: Equinor

How will the use of hydrogen for non-energy purposes develop over the years to 2050? It is assumed that demand for hydrogen feedstock will mirror the overall growth in demand for fossil fuels for non-energy purposes, and total about 78 Mt – or 263 mtoe in energy terms – by 2050. As for the uptake of hydrogen as a fuel, we suggest penetration rates varying in the 2-4% of TFC range for the world's industrialised regions and China, and a more modest penetration of 0.5% for the rest of the world, by 2050. Hydrogen captures market share in all demand sectors, with road transport providing initial growth opportunities, but with industry, the building sector and marine transport becoming target markets during the 2020s and especially after 2030. Total hydrogen for TFC is calculated at 108 mtoe by 2050, which converts to roughly 120 bcm methane equivalent, approximately the level of Norwegian gas exports today. Hydrogen is also a potential flexible power sector fuel, and globally 119 mtoe of hydrogen is used for power generation by 2050 generating over 700 TWh of electricity, which brings total global hydrogen demand to 490 mtoe.

Which other fuels from energy end-use could hydrogen push out? In the transport sector hydrogen vehicles could capture market share from EVs and dampen electricity demand, but for simplicity, hydrogen is assumed to replace oil products in transport. Industry is seen to use hydrogen to lower its coal use and later its gas use, and in heating hydrogen replaces mostly gas but also some oil. How will 490 mtoe of hydrogen demand by 2050 be supplied? Existing hydrogen production for non-energy purposes is projected to continue as it is, dominated by steam methane reforming (SMR), oil and coal gasification. For existing production based on electrolysis, producers are assumed to buy power from the grid, which is gradually decarbonised. For incremental hydrogen production – everything above the 55 Mt currently supplied – we have assumed a shift towards electrolysis based on new renewable electricity so that by 2050 half of total supply is "blue" and the other half is "green".

The uptake of hydrogen initially adds to global coal demand, but by 2050 hydrogen has reduced coal use by 2 mtoe relative to the *Renewal* baseline with no hydrogen. The net impact on natural gas peaks at 45 bcm by 2040, before abating to 23 bcm in 2050. The increase in the use of hydrogen as feedstock initially adds to oil demand, but this small addition turns into a reduction by 2050 as electrolysis captures more of the market. Electricity demand due to electrolysis sees a continued increase to 4,861 TWh in 2050 – slightly more than 10% of global generation. In total, global TPED increases with 207 mtoe due to the transformation of other fuels to hydrogen.

If hydrogen supply and demand develop in line with these assumptions, and if CCUS is applied as assumed, it is estimated that global hydrogen related CO_2 emissions would be reduced from 732 mt in 2016 (related entirely to the production without CCUS of 55 mt of hydrogen for non-energy purposes) to a 184 mt deduction by 2050. If we net out emissions from hydrogen production for non-energy purposes and focus on hydrogen for energy, the introduction of hydrogen saves about 580 mt of CO_2 per year by 2050. Cumulatively over the 2016-50 period, hydrogen for energy purposes generates a CO_2 emission reduction of about 7.3 Gt, equivalent to 1/3 of the global cumulative CCUS by 2050 assumed for *Renewal*.

Negative CO_2 emissions: new technologies in store?

The concept of negative CO_2 emissions has been an integral part of the climate policy debate since the 2° target was introduced and became critical with the turn towards the 1.5° ambition as a point of reference for avoiding serious consequences of global warming. It reflects the conclusion that the world needs to eliminate CO_2 emissions in net terms, which means finding ways to pull CO_2 out of the air in volumes matching residual anthropogenic emissions from industry and transport that cannot be eliminated with known technology. Another reason for studying negative emissions is that the world most likely will overshoot the carbon budget, i.e., emit much more than the 1.5-2° targets prescribe. Excessive emissions in the short and medium term can however be compensated for – at least in principle – by pulling more CO_2 out of the air in the longer term.

The negative emission technologies that are most likely to play the biggest roles in the near term focus on emissions from agriculture, forestry and other land use. The cheapest way to achieve negative emissions is to plant trees. Forests absorb CO_2 from the atmosphere in addition to regulating hydrological cycles, hosting valuable ecosystems, protecting biodiversity and supporting communities and cultures. Frameworks have been developed under UN direction and bilaterally to incentivise reductions in deforestation and forest degradation, and support conservation and sustainable forest management, as well as reforestation, in developing countries (known as REDD+) by paying governments for achieving verified emission reductions or removals. A big "if" is whether there is enough land available both for afforestation and reforestation on a scale that would matter, and for adequate food and biofuel production. Other issues are how long the captured CO_2 will reside in the new forests, and how to secure them against authorised and unauthorised logging.

Another relatively low-cost approach is changing land management practices to increase the organic carbon content on the top layer of the soil. There are various ways of increasing the input of carbon to, or reducing the losses of carbon from the soil. And if implemented on a global scale, these measures could remove several Gt of CO_2 from the atmosphere per year, while also improving yields and carbon binding in plants. A main snag with this approach is that soil carbon sequestration may only work for a limited period – the soil will eventually get saturated with carbon and fail to respond to additional efforts.

The negative emission technology that has received most attention is to combine bioenergy use with carbon capture and storage. BECCS, as this technology is called, could conceivably handle significant amounts of CO_2 per year and deliver negative emissions. But BECCS needs CCUS on a large scale and would require vast amounts of biomass supply and thus probably land and water dedicated to biomass production. Another technology, direct air capture and carbon storage or DACCS, also envisions to move CO_2 from the air to underground deposits. DACCS remains at the research and small pilot project stages, with one issue being how to make the processes less energy intensive and costly, and more easy to scale up.

Yet another couple of negative emission technologies are so-called enhanced weathering and ocean fertilisation. Enhanced weathering makes use of the fact that when silicate or carbonate minerals dissolve in rainwater, CO_2 is drawn from the atmosphere into the solution. The idea is simply to crush and grind such minerals and cover large swaths of land by the resulting pebbles to increase the area exposed to rain. Accelerating the CO_2 uptake process which in nature takes a long time, and mining, crushing and transporting enough rock around to make a difference, are the key challenges to this approach. Ocean fertilisation means adding nutrients to the oceans to stimulate the production of algae and plankton, which absorb CO_2 from the top layer of the sea before disappearing to the bottom, thereby paving the way for the top layer to absorb more CO_2 from the air. The fertiliser requirements would be substantial, the ecological systems involved are incompletely understood and the negative side effects could be significant.

The concept of negative CO_2 emissions remains highly controversial. Offsetting residual emissions after all feasible reduction options have been implemented, with some combination of negative emission technologies, may be defensible. But negative emissions on the scale suggested by most scenarios underpinning the IPCC's 1.5° report and motivated by the currently limited will to adopt and implement tough emission reduction policies, raises ethical as well as practical issues. There are warnings against over-selling the potential of unproven technologies and giving the public the impression that there will be technical fixes to global warming further out in time, implying that we do not need to rapidly reduce emissions in the short term.

Although there is growing interest in negative emission technologies, and strong precautionary reasons for prioritising R&D on how to pull CO_2 out of the air, it is difficult to see deployment on scale of anything but afforestation and reforestation starting before 2050. We have therefore not made assumptions neither on BECCS, DACCS nor on the other more immature technologies in this edition of Energy Perspectives.

Biogas: a viable alternative for decarbonising Europe?

Biogas is receiving increased attention as a decarbonising pathway for the European gas market. Biogas, like methane, can be used directly for electricity and heat generation, but for use in transport or grid injection it needs to be upgraded to biomethane. Biogas is mainly produced from digesting crops, animal manure and food waste in an oxygen-free environment, known as anaerobic digestion. Biomethane can be produced directly via thermal gasification, but that is a far less commercially proven technology today.

Global biogas production has experienced an annual average growth of 10% since 2000, and today it registers 34.8 bcma in methane equivalent (corresponding to around one third of Norwegian gas supply). Driven by favourable support schemes, EU accounts for more than half of the global production (18.4 bcm). Biogas contributed to 12% of EU's gas production, satisfying 4% of its gas demand, with Germany being the largest producer, followed by Italy and the UK. Combined with China and the US, the five countries account for 75% of global biogas production. While most of biogas produced in the EU is used in the power and heat sector, virtually all biogas in China is used in the residential sector.

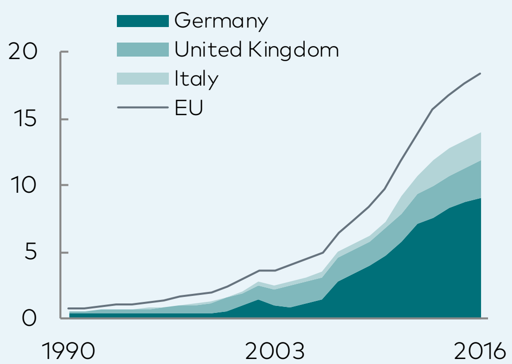
The regional differences can be explained by demographics and current support programs in place. While countries in Asia have large programmes for domestic biogas production in households, EU and the US focus on biogas on larger scale: farm-based and commercial combined heat and power (CHP) biogas plants, as most households in developed regions already are supplied with electricity and gas from established infrastructure. Recent changes in legislation for biogas production in European countries, such as capping the use of land in Germany and lowering feed-in-tariffs, show a trend towards reduction of support, which has been followed by a declining growth rate in the last six years.

Despite dynamic growth rates, questions related to resource availability and economic viability are not yet answered. Energy crops and waste for anaerobic digestion have experienced a significant development the past decade, with energy crops now being the primary feedstock for biogas production in Europe. Energy crops are however expected to have to compete for arable land with food crops, increasing the uncertainty of its future potential as a possible decarbonisation pathway. Wastewater sludge as feedstock is recognised as a low hanging fruit, but most large sewage treatment plants already utilise this process, limiting its future potential. Animal manure, estimated to hold the highest emission reduction potential, is mostly produced on farms where decentralised production makes more economic sense.

Looking past biogas' current limitations for being a major decarbonising pathway for European gas, it can still contribute to significant emission reductions. In the future, if commercially unlocked, gasification technology of waste and biomass residue has the potential for larger scale biomethane production. Recent studies have attempted to estimate the biogas and biomethane production for 2050 in Europe, some more optimistic than others. Ranging from 27 bcm to 98 bcm methane equivalent in 2050, most conclude on the mid- to low-end.

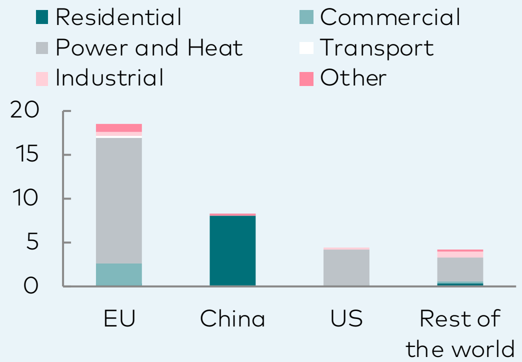
Renewal projects a 19% increase in EU biomass supply towards 2050, leaving little room for biogas to progress at rates suggested by more optimistic projections. In *Reform*, a modest 4% increase of EU biomass supply suggests a relatively stable biogas production in the coming years.

EU biogas production
Bcm, methane equivalent



Source: IEA

Biogas use in 2016
Bcm, methane equivalent



Source: IEA

Key figures

	2016	2030 or 2016-2030			2050 or 2016-2050		
		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Population (Bn)	7.5	8.6	8.6	8.6	9.8	9.8	9.8
GDP growth CAGR	-	2.7%	2.5%	2.6%	2.5%	2.6%	2.2%
Energy intensity CAGR	-	-1.7%	-2.2%	-1.2%	-1.9%	-2.8%	-1.3%
Total primary energy demand CAGR	-	0.9%	0.2%	1.3%	0.5%	-0.3%	0.8%
Coal share of TPED	27%	22%	16%	25%	17%	5%	21%
Oil share of TPED	32%	31%	30%	32%	26%	19%	30%
Gas share of TPED	22%	24%	25%	22%	24%	22%	22%
New renewables share of TPED	2%	5%	7%	4%	12%	22%	8%
Coal demand (Mtoe)	3,742	3,439	2,267	4,042	2,816	612	3,731
Oil demand (mbd)	94	105	90	112	93	52	118
Gas demand (bcm)	3,607	4,471	4,246	4,422	4,787	3,182	4,765
New renewables demand (Mtoe)	235	773	1,018	614	1,936	2,745	1,476
Electricity demand (TWh)	24,973	32,924	32,613	33,073	45,685	43,200	42,819
Electricity share of TFC	19%	22%	24%	21%	29%	37%	24%
Solar and wind share of electricity generation	5%	17%	23%	14%	33%	49%	29%
Fossil fuel share of electricity generation	65%	55%	44%	58%	40%	15%	44%
Light duty vehicle fleet (bn)	1.2	1.7	1.6	1.7	1.7	1.4	1.9
Light duty vehicle sales (mn)	94	117	106	116	107	81	120
Share of EVs and PHEVs in LDV fleet	0.2%	10%	20%	7%	54%	90%	31%
Share of EVs and PHEVs in LDV sales	0.8%	26%	54%	17%	59%	99%	32%
CCUS per year (Gt)	0.03	0.09	0.41	0.04	0.31	1.50	0.05
Energy-related net carbon emissions per year (Gt)	32	33	26	36	29	11	36

Data appendix

Global GDP	2016	2030			2050			2016-50, growth per year (%), CAGR		
Trillion 2010-USD		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	77.5	112.9	108.8	110.3	176.6	183.7	161.4	2.5	2.6	2.2

Energy intensity	2016	2030			2050			2016-50, growth per year (%), CAGR		
Indexed 2016, %		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
	100	78	73	84	53	38	63	-1.9	-2.8	-1.3

Global energy demand	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total primary energy demand	**13.8**	**15.7**	**14.1**	**16.5**	**16.5**	**12.3**	**18.1**	**0.5**	**-0.3**	**0.8**
Coal	3.7	3.4	2.3	4.0	2.8	0.6	3.7	-0.8	-5.2	0.0
Oil	4.4	4.9	4.2	5.2	4.3	2.3	5.5	-0.1	-1.8	0.6
Gas	3.0	3.7	3.5	3.7	4.0	2.6	4.0	0.8	-0.4	0.8
Nuclear	0.7	0.8	0.9	0.8	1.0	1.3	0.9	1.1	1.9	0.9
Hydro	0.3	0.4	0.5	0.4	0.5	0.6	0.5	1.3	1.6	1.1
Biomass	1.4	1.7	1.7	1.7	1.9	2.0	2.0	1.1	1.2	1.1
New renewables	0.2	0.8	1.0	0.6	1.9	2.7	1.5	6.4	7.5	5.6
Oil (mbd)	*94*	*105*	*90*	*112*	*93*	*52*	*118*			
Gas (Bcm)	*3,607*	*4,471*	*4,246*	*4,422*	*4,787*	*3,182*	*4,765*			

Global energy mix	2016	2030			2050		
Shares of TPED, %		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Coal	27.2	21.9	16.1	24.5	17.1	5.0	20.7
Oil	32.0	31.2	29.6	31.8	26.1	19.1	30.3
Gas	21.8	23.7	25.1	22.3	24.1	21.5	21.9
Nuclear	4.9	4.9	6.6	4.8	5.9	10.4	5.1
Hydro	2.5	2.7	3.3	2.5	3.3	4.9	2.8
Biomass	9.8	10.6	12.0	10.4	11.7	16.7	11.0
New renewables	1.7	4.9	7.2	3.7	11.7	22.4	8.2

CO_2 emissions	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion tons		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**32.1**	**33.2**	**25.9**	**36.4**	**29.0**	**10.6**	**35.9**	**-0.3**	**-3.2**	**0.3**
North America	5.9	5.3	4.2	5.5	4.1	1.3	5.2	-1.1	-4.4	-0.4
Other Americas	1.3	1.3	1.0	1.5	1.4	0.6	1.8	0.3	-2.1	1.0
European Union	3.4	2.7	2.2	3.1	1.6	0.6	2.4	-2.2	-5.0	-1.0
Other Europe	0.5	0.5	0.4	0.6	0.4	0.1	0.6	-0.4	-3.9	0.4
CIS	2.2	2.2	1.9	2.3	1.9	1.0	2.2	-0.3	-2.1	0.0
Industrial Asia Pacific	2.4	2.0	1.5	2.1	1.4	0.4	1.9	-1.6	-4.9	-0.7
South East Asia	1.3	1.7	1.5	1.9	2.0	0.7	2.3	1.3	-1.7	1.8
Other Asia Pacific	0.6	0.7	0.6	0.7	0.7	0.3	0.8	0.2	-2.5	0.6
China	9.2	9.6	7.0	11.3	7.6	2.1	9.9	-0.6	-4.2	0.2
India	2.1	3.1	2.3	3.3	3.7	1.2	4.2	1.7	-1.5	2.0
Middle East	2.0	2.4	2.1	2.5	2.5	1.1	2.8	0.7	-1.7	1.0
Africa	1.2	1.6	1.4	1.6	1.7	1.0	2.0	1.1	-0.5	1.4
World CO_2 stripped by CCUS	0.03	0.09	0.41	0.04	0.31	1.50	0.05			

LDV sales	2016	2030			2050			2016-50, growth per year (%), CAGR		
Millions		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total sales	**94.2**	**116.7**	**106.0**	**116.1**	**107.1**	**81.1**	**119.5**	**0.4**	**-0.4**	**0.7**
Gasoline	69.7	64.7	36.1	74.6	26.8	0.2	61.6	-2.8	-15.7	-0.4
Diesel	17.7	5.2	0.8	5.2	0.7	0.0	0.7	-9.1	-	-8.9
Hybrids	2.9	11.8	8.4	11.4	13.3	0.5	15.4	4.6	-5.2	5.0
PHEV	0.2	13.7	12.2	12.5	18.4	0.9	17.9	13.9	4.1	13.8
EV	0.5	16.2	45.5	7.0	44.4	79.4	20.1	14.2	16.1	11.5
Others	3.2	5.0	3.0	5.4	3.6	0.1	3.8	0.3	-9.5	0.5

Fuel mix in LDV transport	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**1.14**	**1.24**	**1.17**	**1.30**	**0.98**	**0.40**	**1.23**	**-0.4**	**-3.0**	**0.2**
Oil	1.06	1.06	0.98	1.14	0.62	0.14	0.96	-1.6	-5.7	-0.3
Gas	0.02	0.02	0.02	0.02	0.02	0.00	0.02	-0.4	-4.7	-0.3
Biofuels	0.06	0.09	0.08	0.09	0.05	0.01	0.08	-0.3	-6.2	0.8
Electricity	0.00	0.07	0.09	0.05	0.29	0.25	0.18	19.3	18.8	17.6
Oil (mbd)	22.6	22.6	20.8	24.2	13.2	3.0	20.4			
Electricity (thousand TWh)	0.0	0.8	1.1	0.6	3.3	2.9	2.1			

Fuel mix in other transport	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**1.60**	**2.04**	**1.80**	**2.12**	**2.23**	**1.58**	**2.54**	**1.0**	**0.0**	**1.4**
Oil	1.47	1.80	1.52	1.91	1.74	0.92	2.17	0.5	-1.4	1.2
Gas	0.08	0.11	0.11	0.10	0.13	0.13	0.13	1.4	1.3	1.3
Biofuels	0.02	0.05	0.06	0.05	0.11	0.16	0.09	4.7	5.7	4.1
Electricity	0.03	0.08	0.11	0.06	0.25	0.37	0.15	6.4	7.7	4.8
Oil (mbd)	30.3	37.1	31.3	39.3	35.7	18.9	44.6			

Fuel mix, power and heat	2016	2030			2050			2016-50, growth per year (%), CAGR		
Thousand TWh		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total generation	**29.0**	**37.0**	**36.3**	**37.2**	**49.4**	**46.5**	**46.7**	**1.6**	**1.4**	**1.4**
Coal	11.3	10.2	6.5	11.9	8.9	1.5	10.8	-0.7	-5.7	-0.1
Oil	1.1	0.8	0.5	1.0	0.4	0.1	0.7	-2.7	-7.3	-1.2
Gas	7.5	10.5	10.4	10.0	11.7	6.7	10.9	1.3	-0.3	1.1
Nuclear	2.6	3.0	3.6	3.0	3.8	4.9	3.5	1.1	1.9	0.9
Hydro	4.1	5.0	5.4	4.9	6.3	7.0	6.0	1.3	1.6	1.1
Biomass	0.9	1.4	1.7	1.3	2.0	3.0	1.8	2.6	3.7	2.1
Wind	1.0	3.1	4.1	2.6	7.5	10.8	5.9	6.3	7.4	5.5
Solar	0.3	2.5	3.4	2.1	7.6	10.5	6.4	9.7	10.7	9.1
Geothermal	0.1	0.3	0.3	0.2	0.5	0.8	0.3	5.3	6.4	3.6
CSP,marine,other	0.2	0.3	0.4	0.2	0.7	1.2	0.5	3.8	5.7	2.8

Fuel mix other uses	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**5.81**	**6.45**	**5.55**	**6.95**	**6.56**	**4.54**	**7.65**	**0.4**	**-0.7**	**0.8**
Coal	1.43	1.43	0.98	1.69	1.16	0.32	1.71	-0.6	-4.3	0.5
Oil	1.62	1.85	1.54	1.97	1.86	1.27	2.19	0.4	-0.7	0.9
Gas	1.65	1.92	1.77	1.97	2.08	1.53	2.19	0.7	-0.2	0.8
Biomass	1.07	1.17	1.12	1.24	1.27	1.12	1.39	0.5	0.1	0.8
New renewables	0.04	0.09	0.13	0.08	0.20	0.29	0.16	4.6	5.7	4.0

Global oil product demand	2016	2030			2050			2016-50, growth per year (%), CAGR		
mbd (incl. biofuels)		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total liquids	**96.54**	**109.12**	**93.68**	**116.31**	**97.53**	**56.50**	**122.21**	**0.0**	**-1.6**	**0.7**
Residual fuel oil	7.1	6.7	5.4	7.1	6.9	4.1	7.9	-0.1	-1.6	0.3
Gasoil	27.7	29.8	25.0	32.3	24.1	11.2	32.4	-0.4	-2.6	0.5
Gasoline	25.5	27.4	23.9	29.1	18.6	5.1	26.7	-0.9	-4.6	0.1
Jet/Kero	7.2	9.3	7.9	9.7	11.1	8.3	12.6	1.3	0.4	1.7
Naptha	6.2	8.0	7.4	8.5	8.9	7.7	10.1	1.1	0.7	1.5
NGL/LPG	11.4	15.6	13.7	16.6	15.2	11.6	18.3	0.8	0.0	1.4
Other products	11.5	12.2	10.5	13.0	12.6	8.5	14.2	0.3	-0.9	0.6

Regional energy demand

North America	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**2.68**	**2.70**	**2.42**	**2.76**	**2.40**	**1.65**	**2.73**	**-0.3**	**-1.4**	**0.1**
Coal	0.37	0.17	0.06	0.20	0.13	0.02	0.17	-3.1	-9.0	-2.2
Oil	1.04	1.06	0.87	1.09	0.68	0.34	0.93	-1.3	-3.3	-0.3
Gas	0.79	0.93	0.88	0.95	1.03	0.46	1.08	0.8	-1.6	0.9
Nuclear	0.25	0.21	0.24	0.21	0.16	0.24	0.15	-1.4	-0.1	-1.4
Hydro	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.2	0.4	0.2
Biomass	0.12	0.14	0.16	0.15	0.14	0.20	0.15	0.4	1.4	0.6
New renewables	0.04	0.12	0.14	0.10	0.21	0.34	0.18	4.8	6.2	4.3
Oil (mbd)	*23.0*	*23.9*	*19.8*	*24.6*	*15.9*	*8.5*	*21.5*			
Gas (Bcm)	*953*	*1,124*	*1,056*	*1,137*	*1,233*	*548*	*1,298*			

Other Americas	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**0.68**	**0.78**	**0.69**	**0.82**	**0.95**	**0.71**	**1.04**	**1.0**	**0.2**	**1.3**
Coal	0.03	0.02	0.01	0.03	0.01	0.00	0.04	-2.9	-11.6	0.5
Oil	0.30	0.32	0.26	0.35	0.33	0.16	0.43	0.3	-1.7	1.1
Gas	0.14	0.16	0.12	0.16	0.20	0.11	0.19	1.1	-0.8	1.0
Nuclear	0.01	0.01	0.01	0.01	0.01	0.02	0.01	2.5	3.0	2.2
Hydro	0.06	0.07	0.08	0.07	0.11	0.11	0.10	1.7	1.9	1.6
Biomass	0.13	0.16	0.15	0.16	0.19	0.18	0.19	1.0	0.8	1.0
New renewables	0.01	0.04	0.05	0.03	0.10	0.14	0.08	7.3	8.5	6.6
Oil (mbd)	*6.3*	*6.7*	*5.5*	*7.2*	*7.0*	*3.5*	*8.8*			
Gas (Bcm)	*164*	*191*	*145*	*193*	*235*	*124*	*228*			

European Union	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**1.69**	**1.47**	**1.40**	**1.56**	**1.21**	**1.03**	**1.37**	**-1.0**	**-1.4**	**-0.6**
Coal	0.24	0.14	0.08	0.19	0.03	0.01	0.13	-5.5	-7.9	-1.6
Oil	0.62	0.52	0.43	0.58	0.35	0.17	0.50	-1.7	-3.7	-0.6
Gas	0.38	0.37	0.37	0.36	0.30	0.20	0.29	-0.7	-2.0	-0.8
Nuclear	0.22	0.17	0.19	0.16	0.14	0.17	0.14	-1.2	-0.7	-1.4
Hydro	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.5	0.5	0.5
Biomass	0.16	0.15	0.17	0.15	0.16	0.18	0.14	0.1	0.5	-0.3
New renewables	0.05	0.10	0.12	0.08	0.18	0.25	0.14	4.2	5.1	3.3
Oil (mbd)	*12.9*	*10.9*	*9.1*	*12.2*	*7.4*	*3.8*	*10.4*			
Gas (Bcm)	*465*	*446*	*449*	*441*	*368*	*238*	*353*			

Industrial Asia Pacific	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**0.98**	**0.95**	**0.87**	**0.99**	**0.82**	**0.57**	**0.96**	**-0.5**	**-1.6**	**-0.1**
Coal	0.24	0.18	0.08	0.19	0.09	0.01	0.17	-2.9	-9.1	-1.0
Oil	0.44	0.39	0.35	0.42	0.30	0.19	0.38	-1.1	-2.5	-0.4
Gas	0.20	0.21	0.21	0.20	0.20	0.08	0.18	0.0	-2.8	-0.3
Nuclear	0.05	0.06	0.10	0.09	0.05	0.05	0.07	0.2	0.3	1.3
Hydro	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.8	1.0	0.7
Biomass	0.03	0.05	0.05	0.04	0.07	0.08	0.06	2.6	3.1	2.2
New renewables	0.02	0.05	0.06	0.04	0.10	0.16	0.08	5.6	7.1	4.8
Oil (mbd)	*9.2*	*8.2*	*7.3*	*8.8*	*6.2*	*3.9*	*8.0*			
Gas (Bcm)	*230*	*241*	*245*	*227*	*234*	*86*	*210*			

China	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**3.03**	**3.82**	**3.21**	**4.19**	**3.88**	**2.83**	**4.30**	**0.7**	**-0.2**	**1.0**
Coal	1.95	1.84	1.31	2.22	1.38	0.35	1.82	-1.0	-4.9	-0.2
Oil	0.58	0.79	0.66	0.90	0.66	0.35	0.96	0.4	-1.4	1.5
Gas	0.17	0.41	0.35	0.40	0.53	0.43	0.43	3.4	2.8	2.8
Nuclear	0.06	0.18	0.20	0.18	0.31	0.39	0.31	5.2	5.9	5.2
Hydro	0.10	0.13	0.14	0.12	0.15	0.15	0.14	1.1	1.3	1.1
Biomass	0.11	0.20	0.22	0.19	0.26	0.42	0.23	2.5	3.9	2.1
New renewables	0.06	0.27	0.32	0.19	0.59	0.72	0.40	7.0	7.7	5.8
Oil (mbd)	*12.3*	*16.8*	*14.1*	*19.1*	*13.9*	*7.4*	*20.4*			
Gas (Bcm)	*201*	*485*	*413*	*468*	*620*	*512*	*510*			

India	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**0.85**	**1.29**	**1.16**	**1.35**	**1.81**	**1.41**	**1.90**	**2.3**	**1.5**	**2.4**
Coal	0.37	0.52	0.35	0.57	0.61	0.13	0.70	1.5	-3.0	1.9
Oil	0.21	0.33	0.30	0.35	0.42	0.30	0.47	2.0	1.0	2.4
Gas	0.05	0.09	0.10	0.08	0.11	0.15	0.10	2.5	3.4	2.3
Nuclear	0.01	0.03	0.05	0.03	0.12	0.14	0.09	7.5	8.1	6.6
Hydro	0.01	0.02	0.02	0.02	0.03	0.04	0.03	3.0	3.7	2.5
Biomass	0.19	0.24	0.25	0.26	0.28	0.31	0.31	1.1	1.5	1.4
New renewables	0.01	0.05	0.08	0.05	0.24	0.34	0.20	11.6	12.8	11.0
Oil (mbd)	*4.4*	*6.9*	*6.3*	*7.3*	*8.8*	*6.2*	*9.8*			
Gas (Bcm)	*55*	*108*	*120*	*93*	*129*	*170*	*120*			

Rest of World	2016	2030			2050			2016-50, growth per year (%), CAGR		
Billion toe		Reform	Renewal	Rivalry	Reform	Renewal	Rivalry	Reform	Renewal	Rivalry
Total	**3.84**	**4.68**	**4.32**	**4.81**	**5.41**	**4.05**	**5.75**	**1.0**	**0.2**	**1.2**
Coal	0.53	0.57	0.38	0.65	0.56	0.09	0.70	0.1	-5.2	0.8
Oil	1.22	1.48	1.29	1.54	1.57	0.83	1.79	0.7	-1.1	1.1
Gas	1.26	1.54	1.49	1.53	1.61	1.23	1.68	0.7	-0.1	0.8
Nuclear	0.09	0.11	0.14	0.11	0.18	0.26	0.15	2.0	3.1	1.4
Hydro	0.08	0.11	0.11	0.10	0.14	0.18	0.13	1.8	2.4	1.5
Biomass	0.61	0.73	0.68	0.76	0.84	0.67	0.91	1.0	0.3	1.2
New renewables	0.06	0.15	0.24	0.12	0.51	0.79	0.40	6.6	8.0	5.8
Oil (mbd)	*26.2*	*31.8*	*27.8*	*33.1*	*33.8*	*18.8*	*38.7*			
Gas (Bcm)	*1,538*	*1,875*	*1,817*	*1,863*	*1,968*	*1,503*	*2,047*			

Source: IEA (history), Equinor (projections)

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