DNV·GL

ENERGY TRANSITION OUTLOOK 2020
EXECUTIVE SUMMARY

A global and regional forecast to 2050

SAFER, SMARTER, GREENER

FOREWORD

At a time when we are trying to recover from the ongoing pandemic as individuals and as communities, we cannot afford to make costly mistakes. That is why I believe that the 2020 edition of our Outlook is needed now more than ever: to shine a light on a transition that represents the greatest source of risk, and opportunity, in our business environment.

For most of the current energy system we forecast a rapid energy transition between now and 2050 – effectively, within a generation. By mid-century we expect to see an energy mix split roughly equally between fossil and non-fossil sources, taking into account expected developments in policies, technologies and associated costs.

Our predictions are rooted in real-world experience with energy customers across the world spanning the full energy mix. Nevertheless, some of our readers may find our conclusions startling.

There is a massive, ongoing electrification of the global energy system; where electricity is less than 20% of the energy mix today, it will more than double its share by 2050. During that period, solar PV will grow 25-fold and wind 10-fold, and in roughly equal shares will together be responsible for over 60% of the electricity generated by 2050. The plunging costs and technological advances in renewables are remarkable, and nowhere more so than in fixed and floating offshore wind. Electricity powered by renewables is the main driver of accelerating efficiency gains in our global energy system that will outpace both population and GDP growth, such that the world will reach peak primary energy supply in just over a decade from now.

The COVID-19 pandemic continues to exact a tragic toll on lives and livelihoods and will greatly impact global energy use in the near term. Energy demand will fall 8% this year, and with a slow recovery, our whole energy demand forecast is rebased downwards by 8% relative to our previous forecast through to 2050. The pandemic has also brought forward peak emissions and will lead to an earlier plateauing of oil use. But that is not doing much, unfortunately, to advance the pace of decarbonization. Solutions exist to meet the Paris Agreement, including hydrogen, CCS and further energy-efficiency improvements, but these need a *significant* policy push to scale.

The world will need to achieve the same percentage of emissions reduction seen in 2020 every year through to 2050 to succeed in reaching the ambitions of the Paris Agreement. So, we urgently need to find more sustainable and lasting ways to reduce emissions. Some subsectors are well underway, like wind, solar PV and EVs; but we must also urgently tackle those areas, like heavy industry and long-distance transport, where emissions are hard to abate.

Tough business and policy choices lie ahead, but also plentiful opportunities for those who master the wave of the energy transition. As ever, I welcome your feedback on our Outlook, and encourage you to access our forecast data which we make available on our open industry platform, Veracity.

REMI ERIKSEN

GROUP PRESIDENT AND CEO, DNV GL

HIGHLIGHTS

SHORTER TERM

1. **COVID-19 will reduce global energy demand by 8% this year**
   - Although energy demand will pick up again from 2021, it will be from a lower base, and for the remaining years to 2050, annual global energy demand will fluctuate some 6 to 8% lower than our pre-pandemic forecast
   - Pandemic-linked behavioural shifts, like remote working and reduced commuting, will have a lasting effect lowering energy use

2. **Energy-related CO_2 emissions have peaked, brought forward five years by the pandemic**
   - Transport energy use peaked in 2019
   - COVID-19 has brought peak oil demand forward; oil use may never again exceed 2019 levels

3. **Technology can deliver a Paris-compliant future, if scaled properly**
   - Encouraging progress has been made and is expected to continue for solar PV, wind and battery storage

4. **Market forces alone will not fix hard-to-abate sectors; stronger policies and regulations are needed**
   - Decarbonization of high-heat processes in industry, the heating of buildings, and heavy transport is proceeding too slowly
   - Solutions exist, including hydrogen, CCS, and further energy-efficiency improvements, but these need a policy push to scale

LONGER TERM

1. **Rapid electrification will transform the energy mix by 2050**
   - The share of electricity in the final demand mix will more than double from today's level by 2050
   - Half of the passenger vehicles sold worldwide will be EVs by 2032

2. **Solar PV and wind – in equal shares – will dominate power generation**
   - Electrification, powered by renewables, drives decelerating energy intensity, which will see energy use peak worldwide in 2032
   - Significant investment in connectivity and flexibility will enable a 62% variable renewable share by 2050

3. **Natural gas will take over as the largest energy source this decade, and remain so until 2050**
   - However, only 13% of natural gas used in 2050 will be decarbonized

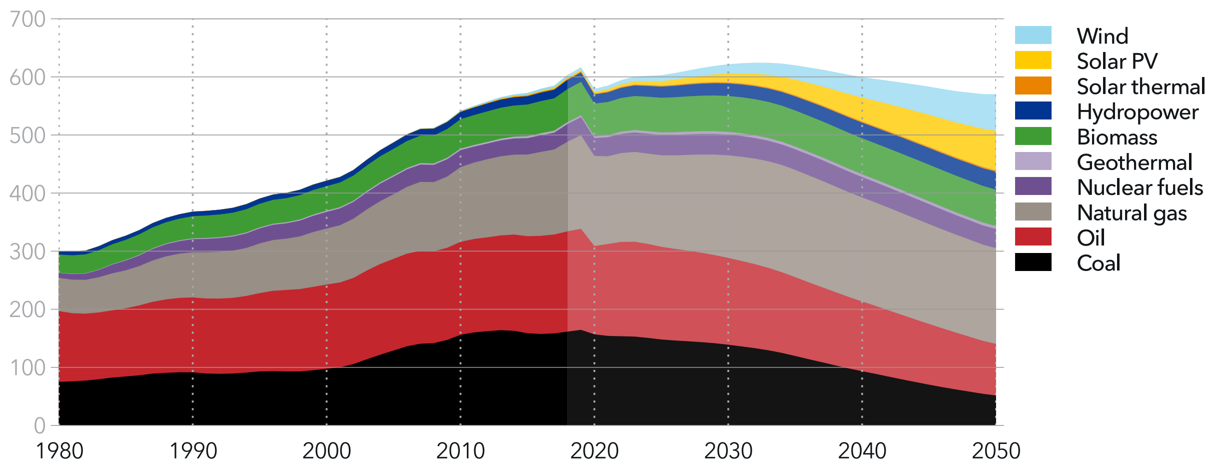
4. **Despite flat energy demand and a growing renewable share, the energy transition is nowhere near fast enough to deliver on the Paris Agreement**
   - Most likely we are heading towards 2.3°C warming by the end of the century
   - A lot more renewable power, decarbonization, energy-efficiency improvement, and carbon capture is needed
   - The world will spend an ever-smaller share of GDP on energy, allowing for additional investment to further speed up the transition

AT A GLANCE

FIGURE 1

World primary energy supply by source

Units: EJ/yr



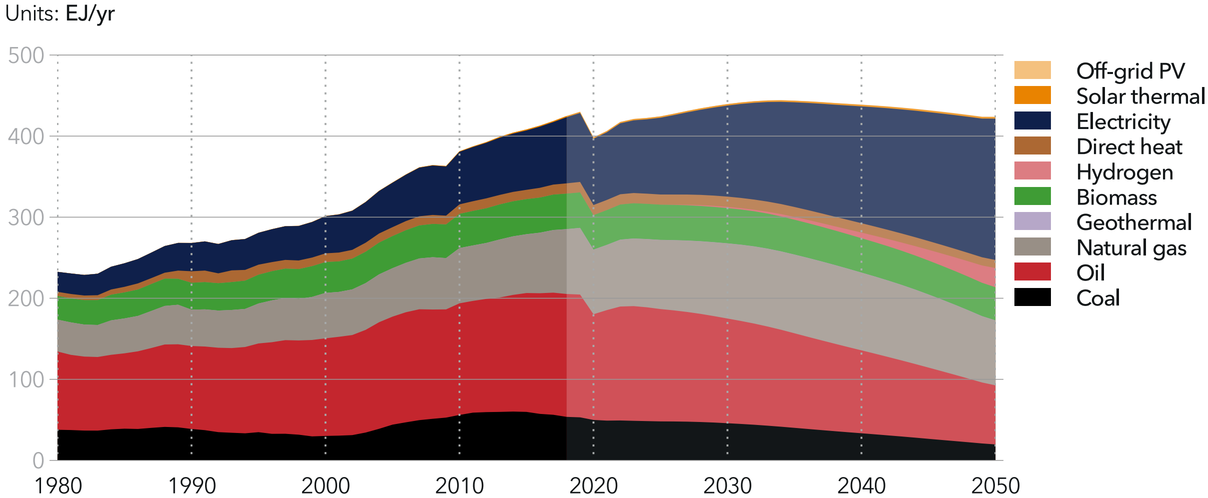
Historical data source: IEA WEB (2019)

Primary energy. We are approaching a future where the world will need less energy, even as the global population increases and the economy continues to grow. Large energy-efficiency improvements in all sectors, and accelerated electrification, will see primary energy supply peaking at 638 EJ in 2032. The fossil-fuel share of the energy mix will decline from 81% today to 54% by 2050.

FIGURE 2

World final energy demand by carrier

Units: EJ/yr



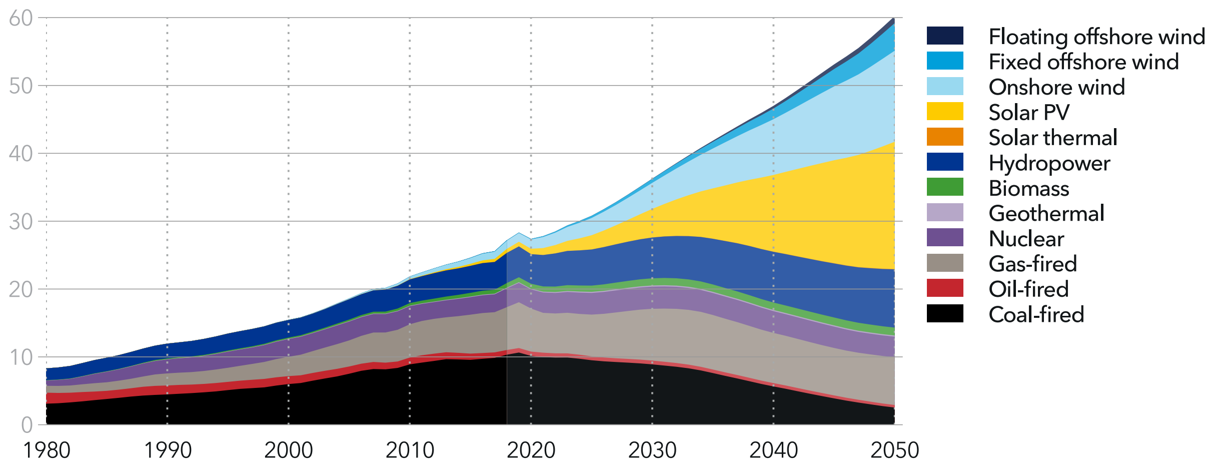
Historical data source: IEA WEB (2019)

The share of electricity in energy demand. One of the main drivers of peak energy supply is widespread electrification, which contributes significantly to accelerated improvements in energy intensity (unit of energy per dollar of GDP). The rate at which energy intensity improves outpaces GDP growth in our forecast period. The share of electricity in the final demand mix will more than double from today's level by 2050, from 27 PWh/year in our reference year (2018) to 60 PWh/year in 2050.

FIGURE 3

World electricity generation by power station type

Units: PWh/yr



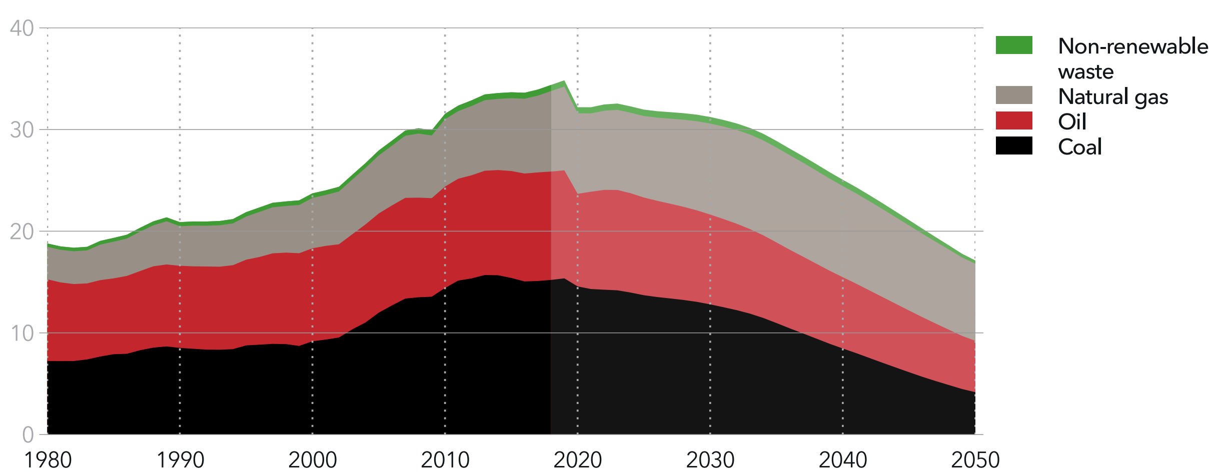
Historical data source: IEA WEB (2019), IRENA (2019)

Renewable share of electricity generation. Non-fossil sources will dominate electricity generation by 2050, with 62% of power supplied by variable renewables, half each from wind and solar PV. Considerable investment in grids and flexibility will be needed but will be aided by plunging battery costs and widespread use of vehicle-to-grid storage.

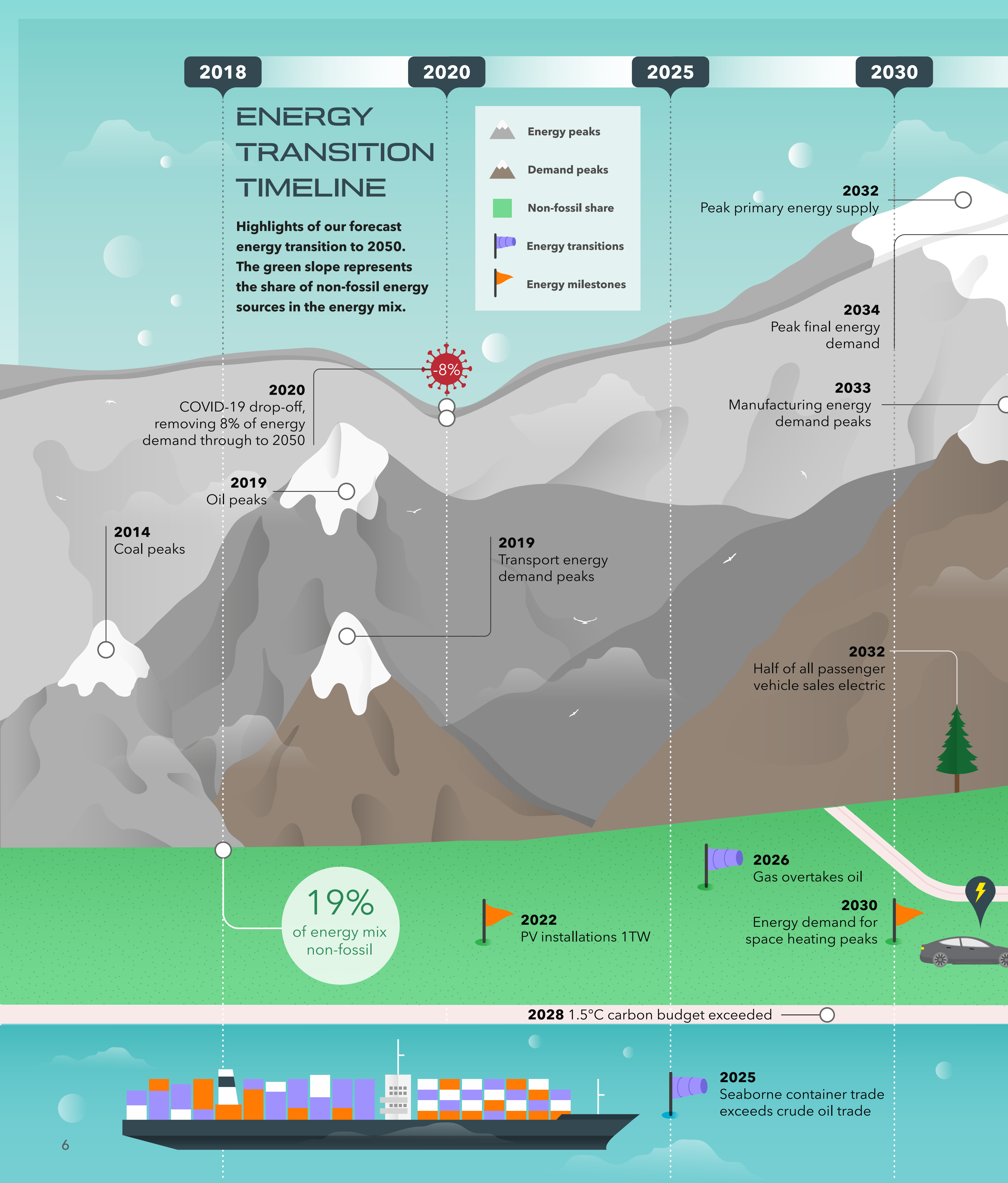
FIGURE 4

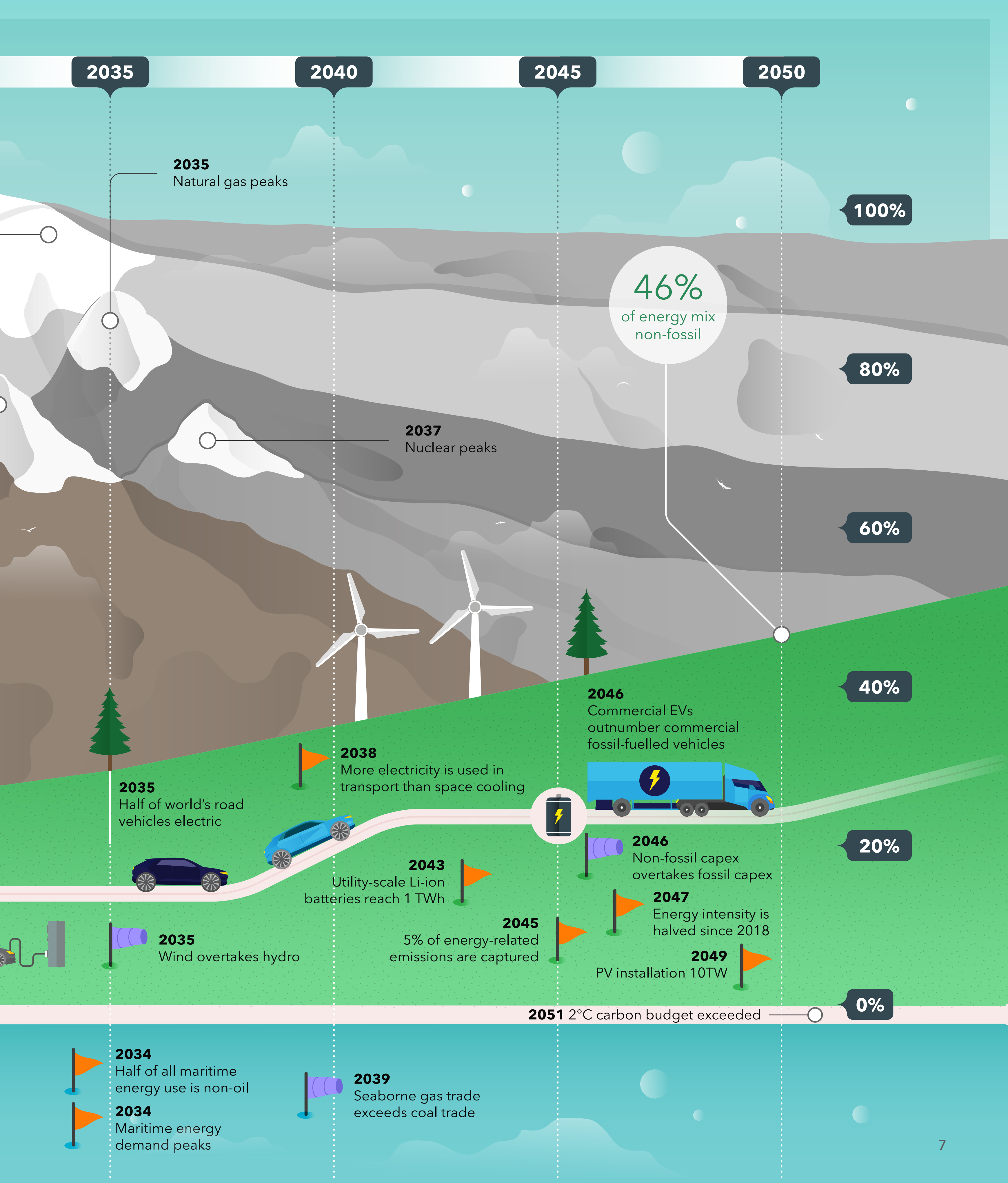
World energy-related CO_2 emissions by fuel

Units: $GtCO_2$/yr



Peak emissions. Emissions of CO_2 from human activity peaked in 2019 – brought forward five years by the impact of COVID-19. We caution however, that even with peak emissions behind us, and a flattening energy demand ahead, the transition we forecast will not be fast enough for the world to achieve the ambitions of the Paris Agreement.


2018
2020
2025
2030
ENERGY TRANSITION TIMELINE
Highlights of our forecast energy transition to 2050. The green slope represents the share of non-fossil energy sources in the energy mix.
Energy peaks
Demand peaks
Non-fossil share
Energy transitions
Energy milestones
2032
Peak primary energy supply
2034
Peak final energy demand
2033
Manufacturing energy demand peaks
-8%
2020
COVID-19 drop-off, removing 8% of energy demand through to 2050
2019
Oil peaks
2014
Coal peaks
2019
Transport energy demand peaks
2032
Half of all passenger vehicle sales electric
2026
Gas overtakes oil
19%
of energy mix non-fossil
2022
PV installations 1TW
2030
Energy demand for space heating peaks
2028 1.5°C carbon budget exceeded
2025
Seaborne container trade exceeds crude oil trade


2035
2040
2045
2050
2035
Natural gas peaks
2037
Nuclear peaks
46%
of energy mix
non-fossil
100%
80%
60%
40%
20%
0%
2046
Commercial EVs outnumber commercial fossil-fuelled vehicles
2038
More electricity is used in transport than space cooling
2035
Half of world's road vehicles electric
2043
Utility-scale Li-ion batteries reach 1 TWh
2046
Non-fossil capex overtakes fossil capex
2047
Energy intensity is halved since 2018
2035
Wind overtakes hydro
2045
5% of energy-related emissions are captured
2049
PV installation 10TW
2051 2°C carbon budget exceeded
2034
Half of all maritime energy use is non-oil
2034
Maritime energy demand peaks
2039
Seaborne gas trade exceeds coal trade

INTRODUCTION

ABOUT THIS OUTLOOK

This annual Outlook, now in its fourth edition, presents the results from our independent model of the world's energy system. It covers the period through to 2050 and forecasts the energy transition globally and in 10 world regions (see page 18). This report is intended as a strategy-forming tool for analysts and decision makers within the industry and other stakeholders. Our forecast data may be accessed at eto.dnvgl.com/data. The changes we forecast hold significant risks and opportunities for investment strategies, operating models, safety, fuel choice and so on. Some of these are detailed in our 'industry implication' supplements:

- Oil and Gas
- Maritime
- Power Supply & Use

OUR APPROACH

In contrast to scenario-based outlooks, we present a single 'best estimate' forecast of the energy future, with sensitivities discussed in relation to our key conclusions.

Our model simulates the interactions over time of the consumers of energy (transport, buildings, manufacturing and so on) and all sources of supply. It encompasses demand and supply of energy globally, and the use and exchange of energy between and within world regions. The selection of energy sources is driven algorithmically based on modelled costs, and in some cases, prices.

The analysis covers the period 1980–2050, with changes unfolding on a multi-year scale, that in some areas is fine-tuned to reflect hourly dynamics. We include policy factors in our forecast like subsidies, carbon pricing, pollution interventions and energy-efficiency standards. Some behavioural change is also accounted for, largely in relation to a changing environment.

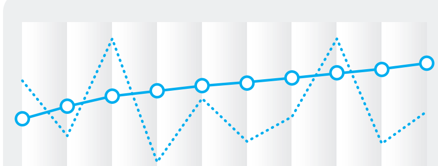
INDEPENDENT VIEW

DNV GL was founded 156 years ago to safeguard life, property and the environment. We are owned by a foundation and are trusted by a wide range of customers to advance the safety and sustainability of their businesses. More than 70% of our business is related to energy. Two of our main business areas focus, respectively, on oil and gas, and on power and renewables. This gives us a deep and balanced perspective on the relationship between fossil and non-fossil sources of energy.

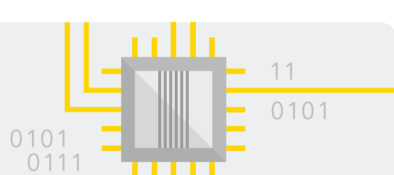
Developing an independent understanding of, and forecasting, the energy transition is therefore of strategic importance to both us and our customers.

Our **best estimate**, not the future we want

A single forecast, not scenarios



Long term dynamics, not short-term imbalances



Continued development of proven **technology**, not uncertain breakthroughs

Main **policy** trends included; caution on untested commitments, e.g. NDCs, etc.

Behavioural changes: some assumptions made, e.g. linked to a changing environment

THE IMPACT OF COVID-19

Global GDP is forecast to decline by 6% this year according to the IMF's Longer outbreak scenario. Growth will be impaired by the pandemic for a further half-decade, resulting in world GDP 9% lower in 2025 than it would have been without the impact of COVID-19. Other energy-impacting changes are also likely to endure, including a 2% decline in commuting over our forecast period and lower office-space requirements.

Due to delayed economic growth and behavioural changes, global energy demand is forecast to reduce by 8% in 2020 and will continue to fluctuate 6-8% lower through to 2050 than in an equivalent non-COVID situation. The drop-off in demand will influence consumption for all energy sources: oil and coal are most severely impacted, followed by gas, with renewables least affected. Transport energy use will never again reach 2019 levels, and the demand for steel and construction materials for office buildings will be significantly lower.

Global energy demand will only see a modest growth post COVID-19, owing to continuous improvements in energy intensity. The energy mix, however, is undergoing a continuous shift towards more renewables. Coal use was at its highest in 2014, crude oil use likely peaked in 2019, and natural gas will peak in 2035. Aggregate hydrocarbon use has already peaked, and energy-related emissions are therefore not likely to return to 2019 levels.

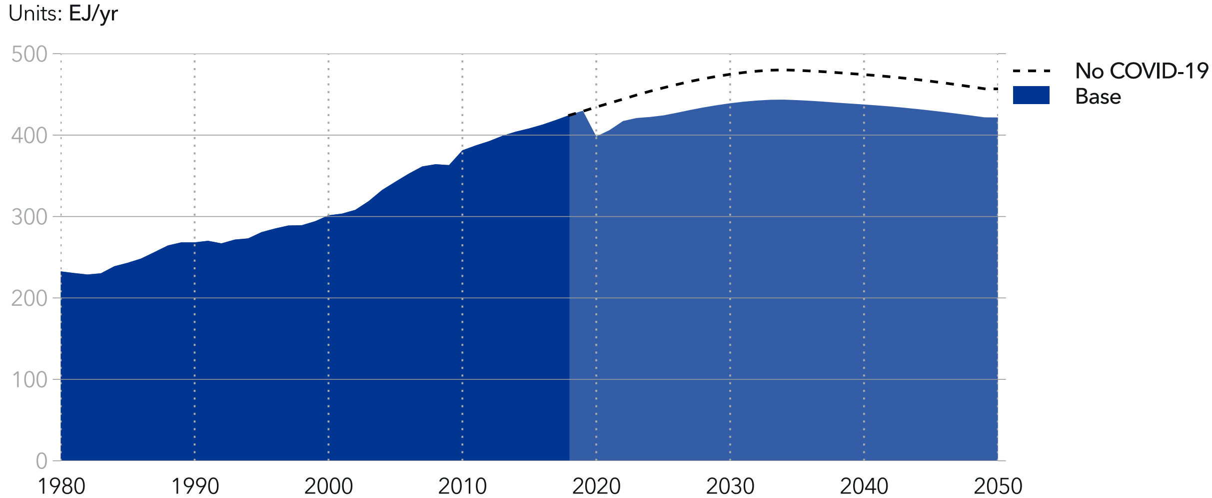
In 2030, emissions will be 10% lower than our pre-pandemic forecast predicted, and in 2050, global energy-related emissions will be at 17 $GtCO_2$ per year, exactly half the present level. The Paris Agreement however requires that level of reduction in emissions to be achieved 20 years earlier, in 2030. The pandemic has thus brought into stark relief the enormity of the global decarbonization challenge. The reductions this year have come at the expense of many lives and livelihoods, and new ways to tackle the emissions challenge need to be found that also address economic inequality. We explore some of those solutions in the final part of our Outlook (page 26 of this summary).

The post-COVID-19 stimulus packages may alter the speed of the transition, but at present they appear to be falling with equal weight on both the fossil and non-fossil sides of the energy mix. Uncertainty, therefore, remains high regarding whether COVID-19 will speed up the energy transition.

FIGURE 5

World final energy demand - with and without COVID-19

Units: EJ/yr



Historical data source: IEA WEB (2019)

MODEL INPUTS

POPULATION

The number of people in the world is a central input to any energy forecast. The UN's *World Population Prospects* is the resource most widely used by energy forecasters. However, the UN has been criticized for not paying enough attention to country-specific education levels – data that are relevant for future fertility trends.

Consequently, this Outlook follows the approach used by the International Institute for Applied Systems Analysis (IIASA), which specifically considers how urbanization and rising education levels are linked to demographic trends.

Following the latest (2019) update from IIASA, we arrive at a global population estimate of 9.4 billion by 2050 – some 4% lower than the most recent (2017) UN median population forecast. Energy use per person varies considerably and this is reflected in our model through a weighting process in calculating aggregate energy consumption first at a regional and then global level.

Irrespective of IIASA or UN figures, the uncertainty in population figures is considered low compared with other uncertainties in our forecast.

ECONOMIC GROWTH

World GDP is expected to grow from USD 134trn/yr in 2018 to USD 269trn/yr in 2050, measured in constant 2017 purchasing-power-adjusted USD. Owing to the effects of COVID-19, this is some 9% lower than the estimate we reached in last year's Outlook.

By mid-century, today's fast-growing emerging economies will experience significantly slower growth as they move into the tertiary (service) economy. Indeed, we expect all regions to experience a slowdown in productivity growth through our forecast period. The combination of slower population growth and decelerating productivity means global GDP growth rates will also slacken.

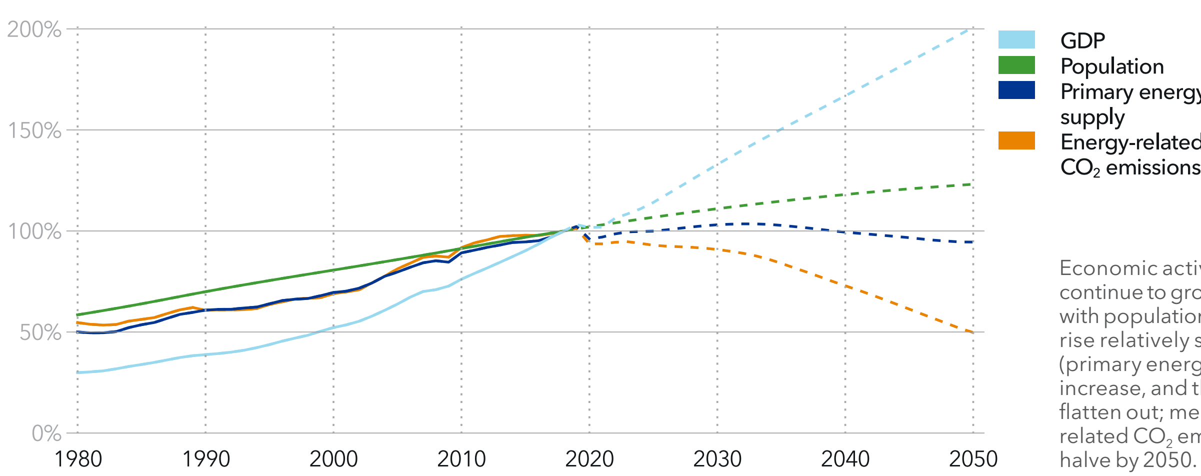
The doubling of global GDP over the 32-year period is a result of a 23% increase in population and an 63% increase in average GDP per capita, with large regional differences.

With or without COVID-19, leading up to 2030, the fastest growth in GDP per capita will be in Asia. Greater China will have the highest growth, at an average rate of 4.5%/yr, followed by the Indian Subcontinent at 3.9%/yr.

FIGURE 6

The decoupling of economic growth from other key parameters

Units: Percentages



Historical data source: UN (2017), World Bank (2018), Gapminder (2018), IMF (2020), IEA WEB (2019)

Economic activity (GDP) will continue to grow rapidly compared with population growth, which will rise relatively slowly. Energy use (primary energy supply) will first increase, and then essentially flatten out; meanwhile, energy-related CO_2 emissions will almost halve by 2050.

LEARNING CURVE EFFECTS

The cost of a technology decreases by a constant fraction with every doubling of capacity. This occurs because ongoing market deployment brings greater experience, expertise and industrial efficiencies, as well as further innovation and R&D.

Wind and solar PV have experienced historical cost learning rates (CLRs) of 16% and 18% respectively, and we project these to continue through our forecast period. In arriving at these figures, we separate out the cost of core technologies (e.g. PV panels) from supporting technologies (e.g. control systems and installation kits). Typically, the latter have a lower CLR. For some technologies, like batteries, which have a CLR of 19% (shown below), the core technology dominates.

Figure 7, illustrating the CLR for EV batteries, shows how the time for capacity doubling increases over time, leading to overall technology costs in 2050 being some 15% of today's costs – a key reason for the rapid uptake of EVs that we predict.

For all technologies, labour as well as operation and maintenance have slower cost compression than underlying technologies, and automation through the life cycle is therefore a key consideration for competitiveness.

POLICY

A wide range of policy objectives – such as climate goals, air quality, health, job creation, energy security – will drive changes in the energy mix. This year, economic recovery in the wake of COVID-19, is added to the list of concerns and government spending is being directed to both fossil and non-fossil energy. Our forecast factors in policy measures in various ways:

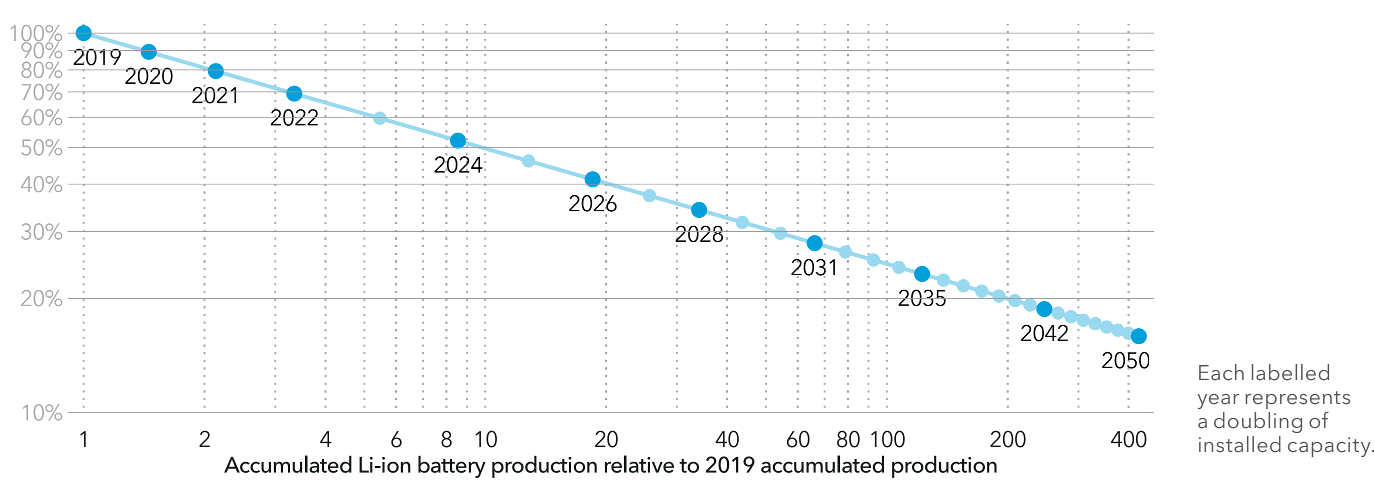
- Supporting technology and activating markets that close the profitability gap for renewable technologies competing with existing technologies;
- Restricting the use of inefficient or polluting products/technologies by means of technology requirements or standards; or
- Providing economic signals such as price incentives to reduce carbon-intensive behaviours.

In our model, country-level data are translated into expected policy impacts, then weighted and aggregated to produce regional figures for inclusion in our analysis. Examples include explicit regional carbon prices, expected to reach an average of between USD 20 to 80/t CO_2 by 2050, depending on the region. Support for renewable energy and for EVs will decline over time as they reach parity with their fossil-fuelled counterparts, but road sector fossil-fuel taxation will increase to account for air pollution and climate concerns.

FIGURE 7

EV battery cost learning curve

Units: Fraction of 2019 price



DEMAND

BUILDINGS

Of all demand sectors, the strongest energy demand growth will be seen in the buildings sector, driven by the needs of a more numerous and more prosperous population. Buildings will collectively consume 24% more energy in 2050 than in 2018, growing its share from 29% to 35% of global energy use.

While the sector's energy demand grows by a fifth, a major energy efficiency effect is also taking place enabling the delivery of a lot more energy services for each unit of energy supplied. For example, floor area of buildings is a major driver of demand, and residential and office floor space will grow by more than 50% over the next three decades. Within those spaces, the energy consumption of cooling equipment will more than triple during this period, and appliances and lighting will grow by 83%.

Other end uses – cooking, space heating and water heating – will stay relatively stable, as efficiency improvements, particularly the shift to modern cooking methods, will balance out any additional demand. In space heating, the shift to more efficient and cost-effective equipment such as heat pumps will raise the average efficiency significantly. Consequently, the final-energy demand for space heating will decline from 42 EJ/yr in 2018 to 35 EJ/yr in 2050, while the provided useful heat increases.

MANUFACTURING

Compared with the continued growth in buildings, manufacturing energy demand peaks in the mid-2030s, slightly higher than today, and then declines by 10% towards 2050. Manufacturing will be replaced by buildings as the largest consumer of energy by mid-century, despite the value of manufacturing growing by some two thirds over the next three decades. This reflects strong efficiency gains of the sector, mainly driven by electrification.

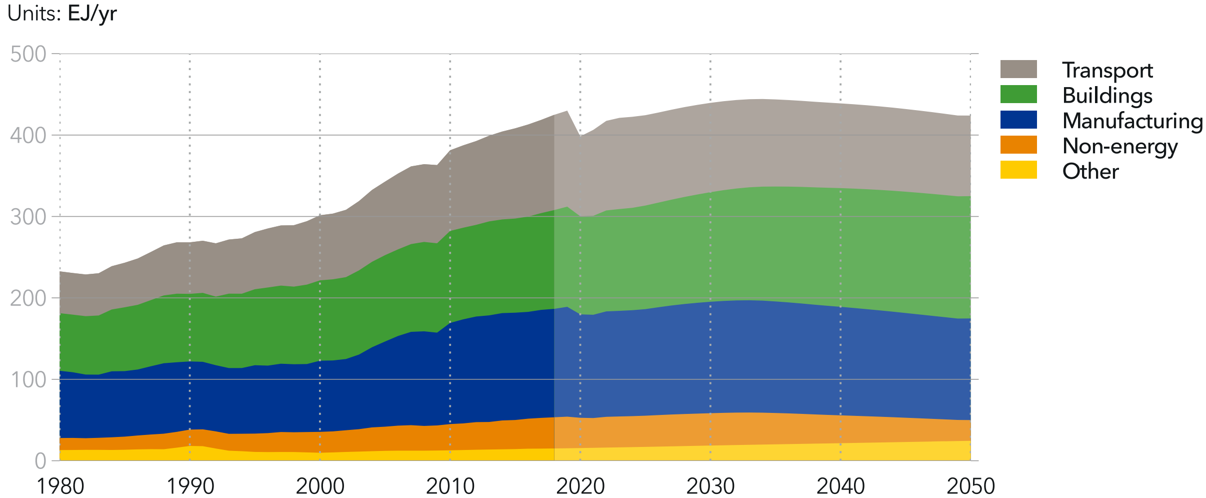
The manufacturing sector consumed 133 EJ or 31% of final energy demand in 2018. Of this total, base materials and manufactured goods used 40% each, while iron and steel represented the final 20% of manufacturing energy demand. As recycling and efficiencies continue to affect energy demand, the split between the three categories will shift and by 2050 manufactured goods will use more than half of manufacturing energy demand.

The energy demand for manufactured goods rises by 32% to 2050, reflecting the growth in underlying demand from a more prosperous and populated world. Automation and digitalization will change the nature of production however, and agile supply chains and near-shoring will drive efficiencies. For base materials, demand drops initially owing to the effects of COVID-19 and takes a decade to return to pre-COVID-19 levels. Thereafter there will be a steady

FIGURE 8

World final energy demand by sector

Units: EJ/yr



Historical data source: IEA WEB (2019)

decline to 2050 ending up at 37 EJ, 30% lower than today's level. This reduction is driven largely by the efficient re-use of already-processed materials instead of extracting and processing virgin raw materials, as secondary-production processes require much less high-grade heat.

FEEDSTOCK

In 2018, 8% of global primary fossil-fuel supply was used for non-energy purposes. This category represents the consumption of coal, oil, and natural gas as feedstock. Petrochemicals are the largest consumer of feedstock and, of the consumption in this sector, about 45% was used to produce plastics in 2018, with the rest going to the manufacture of cosmetics, fertilizers, paints, and other chemicals. We expect that in 2050 the plastic proportion will have grown to about 60% of petrochemical feedstock demand.

While plastic demand continues to grow to 2050, recycling grows more rapidly. We estimate the global rate of plastic recycling will improve from around 13% in 2018 to 47% in 2050 as it is bolstered by more efficient (and potentially circular) chemical recycling, which supplements or replaces traditional, mechanical recycling. That is a major reason for non-energy feedstock use peaking in 2033 and then declining sharply towards 2050, along with reduced demand for engine oil as the road transport fleet electrifies.

TRANSPORT

Transport consumed 119 EJ, or 27% of global final energy demand in 2018. Oil fuelled over 90% of the road, aviation and maritime subsectors, with biofuels and natural gas at some 3% each, while the only significant current use of electricity was in the rail subsector. By 2050, transport energy use will drop slightly to 112 EJ, despite a considerable expansion in transport services. Transport is thus one of the great engines of the energy transition, where electrons gain primacy over molecules of fossil fuel.

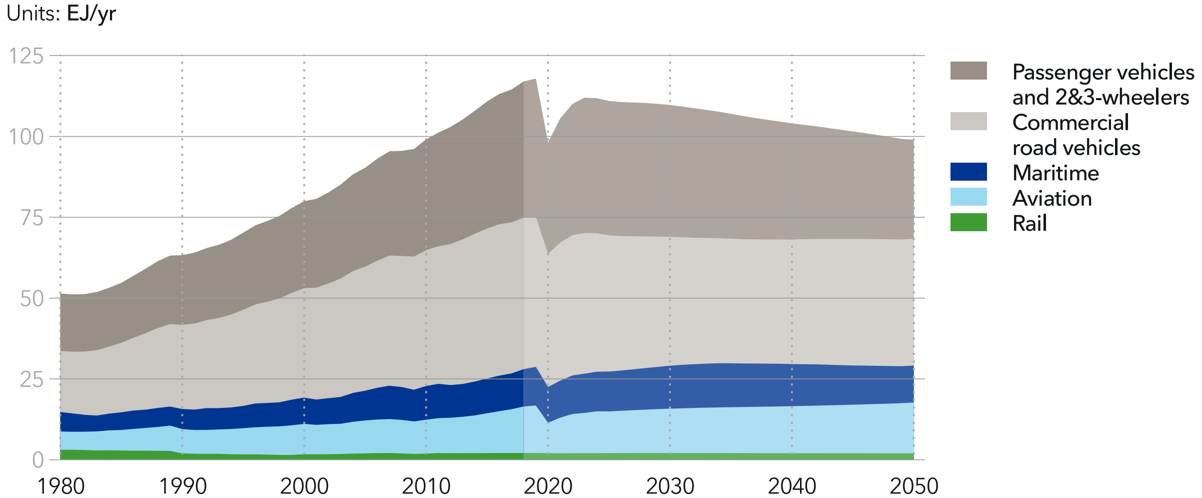
Decarbonization and fuel efficiency are interlinked, and some regions, notably China and OECD countries, use a mixture of push and pull strategies to achieve their decarbonization ambitions. Moreover, UN bodies, such as the International Maritime Organization (IMO), have opted for firm targets.

We envisage public policy targeting of emissions reduction, to continue for at least another decade. However, over time, battery cost learning rates and ever-reducing EV costs will take over as the strongest driver – at least in the road sector, which accounts for almost 80% of transport energy use. However, EV uptake does hinge upon policy support in the near term and removing such support would slow or reverse EV-uptake dynamics.

FIGURE 9

World transport sector energy demand by subsector

Units: EJ/yr



Historical data source: IEA WEB (2019)

DEMAND

ROAD TRANSPORT

The uptake of EVs – 2&3 wheelers first, then passenger, and later commercial vehicles – is occurring rapidly. The total cost of ownership (TCO) of EVs will decrease only slightly between 2020 and 2025 as battery capacity in vehicles increases. After 2025 dramatic cost drops will re-emerge, particularly for commercial vehicles.

Beyond perceived cost, we model four other factors, each with a different weight, which contribute towards the relative utility of EVs compared with internal combustion engine vehicles (ICEVs):

- Recharging/refuelling speed
- Charging/fuelling stations within range
- EV convenience
- EV carbon footprint advantage

Taken together, these factors indicate a significantly slower uptake for electric commercial vehicles than for passenger EVs – despite the heavy subsidies. Worldwide, we see passenger EVs outnumbering ICEVs by 2041, while for commercial vehicles this watershed will be reached five years later. We forecast that passenger EVs will reach 50% of new vehicle sales in Greater China, Europe and North America in the late 2020s. In less-developed regions, uptake will come later as charging-infrastructure density is much lower. The 2&3-wheeler fleet in Asia is a major consumer of energy. We see a very rapid conversion of those vehicles to electricity – already today over one third of all Chinese 2&3-wheeler sales are EVs.

The global passenger vehicle fleet will increase by some two thirds by 2050, while the commercial fleet expands by 50% in this same period. Mileage growth will be even higher, but increased sharing and automation of vehicles limits the growth in absolute vehicle numbers. However, this growing fleet of vehicles and mileage driven will not result in a similar pattern of growth in road-sector energy demand, as EVs have energy efficiencies that are much higher than those of combustion engines. Consequently, road-sector energy demand in 2050 will be lower than it is today.

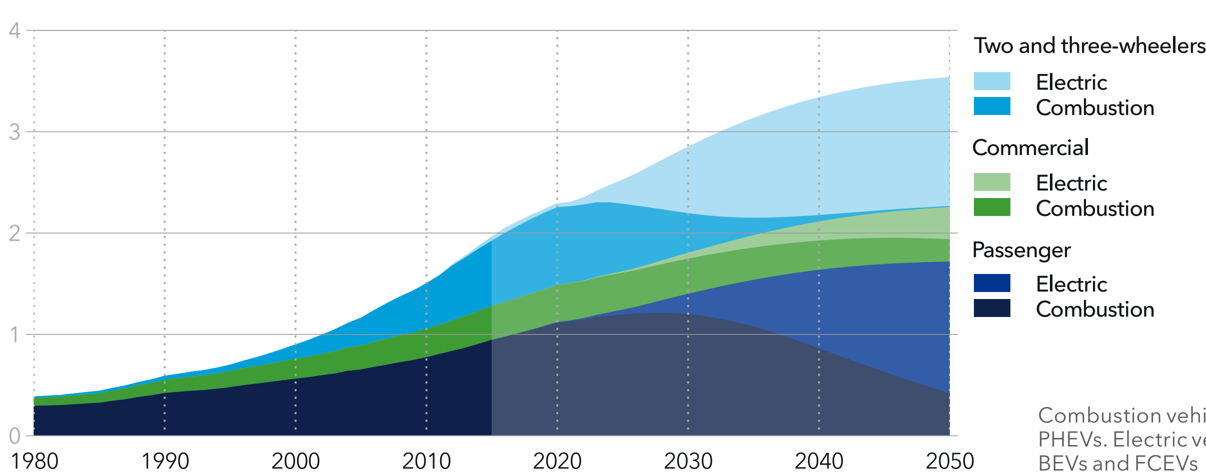
While the vast majority of vehicles globally in 2050 will be EVs, they will constitute just 36% of the road subsector's energy demand; and their energy consumption will be considerably lower than that of the remaining ICEVs with their still-significant use of oil, biofuels, and natural gas. By mid-century, the global road subsector's energy mix will be 51% oil; hydrogen will account for 7% (mainly long-distance heavy goods transport), with biofuels and natural gas taking niche shares of just 3% each.

In sum, our forecast indicates a rapid and significant electrification of all parts of road transport, in all regions.

FIGURE 10

World number of road vehicles by type and drivetrain

Units: Billion vehicles



Combustion vehicles include ICEs PHEVs. Electric vehicles include BEVs and FCEVs

Historical data source: OICA (2016), IEA GEVO (2018)

MARITIME

Shipping is the most energy-efficient mode of transport by energy/tonne-kilometre – consuming close to 3% of the world's energy, including 8% of the world's annual oil supply.

IMO's global sulfur cap has come into force in 2020, driving a much larger share of lighter distillates. IMO now targets a 50% reduction in GHG emissions from 2008 to 2050. Our forecast assumes that a mixture of improved utilization and energy efficiencies, combined with a massive fuel decarbonization, will see this goal being met.

Digitalization of logistics and supply-chain improvements will boost fleet efficiencies significantly. However, a world GDP that doubles by 2050 will see cargo tonne-kilometres increase in almost all ship categories. The exception is coal and oil transport, where tonne-kilometres will be reduced by more than 50% and 30%, respectively.

There is uncertainty regarding which low and zero-carbon fuels will dominate, but our best estimate is that shipping's fuel mix in 2050 will have switched from being almost entirely oil dominated today, to a mix dominated by low- and/or zero-carbon fuels (60%) and natural gas (30%, mostly LNG). Low-carbon fuels include ammonia, hydrogen and other electro-fuels such as e-methanol. See our Maritime Outlook companion report for further details.

AVIATION

More than 3% of the world's energy is consumed by civilian aircrafts. The industry is expected to take several years to recover from the severe COVID-19 setbacks - but, over time, increased prosperity will see annual air trips more than doubling by 2050 compared with 2018. That is however, 15% less growth than we expected a year ago. Despite strong passenger – and cargo – growth ahead, fuel use will increase by only 9% by mid-century. This is due to efficiency gains through higher load factors and developments in engines and aerodynamics.

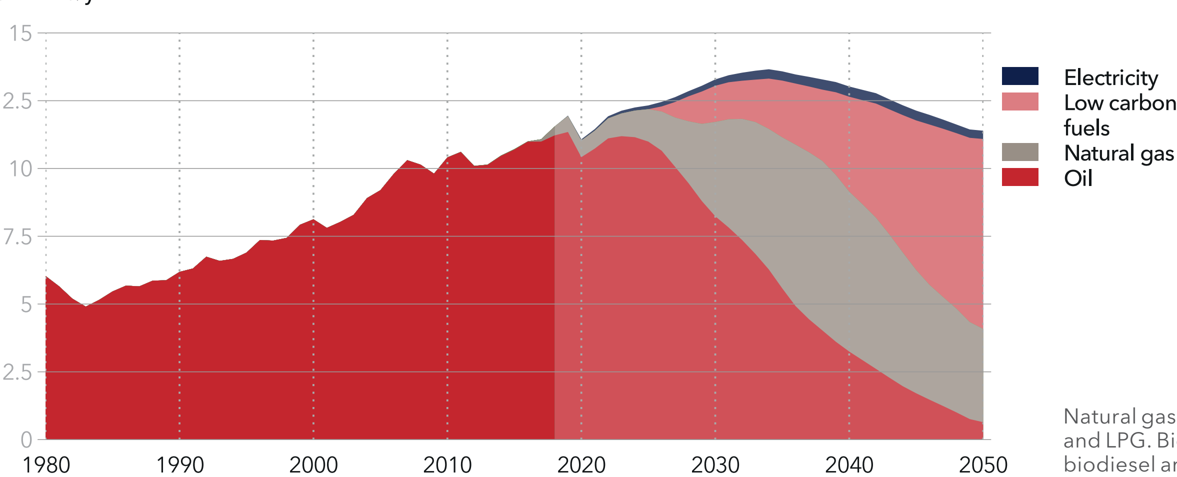
The most significant driver of emissions reduction will be sustainable aviation fuels (SAF), most likely biofuel blends.

A combination of technology advances, supply-chain buildout and successful decarbonization policies will prompt the strong growth in biofuels, as driven by the CORSIA scheme that aims to achieve carbon-neutral growth by 2050 (from a 2019 baseline). Our best estimate includes that the fuel mix will contain 6.5 EJ (41%) biofuels by 2050 – 3.5 times more than the road sector – and electricity will account for 3%, with pockets of short-haul flights electrified. Oil retains an important role through to 2050. As for maritime, there is high uncertainty over low-carbon fuel choices.

FIGURE 11

World maritime subsector energy demand by carrier

Units: EJ/yr



Historical data source: IEA WEB (2019)

Natural gas includes LNG and LPG. Biomass includes biodiesel and LBG.

ELECTRIFICATION

ELECTRICITY

Electricity demand will more than double over the next three decades, raising the share of electricity in the global energy mix from 19% in 2018 to 41% in 2050. Over that time frame, the growth in electricity demand in manufacturing will be 46%, in buildings 100%, and in the transport sector electricity use will grow 26-fold.

In short, the world is electrifying, not least road transport – facilitated mainly by plunging battery costs, but also, as with the other demand sectors, by the relative price of electricity itself. Once the price of electricity starts to decouple from the price of fuels, as they constitute an ever-smaller share of power generation, carbon prices will impact fossil fuels without significantly affecting the price of electricity. This will result in electricity becoming even more competitive.

In 2018, only 26% of electricity was supplied from renewable sources, and two thirds of that was hydropower. With continued declines in the costs of solar, wind, and related technologies such as batteries, variable renewable energy sources (vRES) will gradually – but steadily – transition from being marginal to becoming the dominant electricity sources in 2050. By then, 78% of the world's electricity will be generated from renewable sources, and 62% alone from vRES. In 2050, fossil fuels will generate only 17% of power needs, and nuclear only 5%.

A high vRES share requires a considerably more flexible system and the flexibility provided by conventional generation technologies will remain significant. However, storage capacity will also expand enormously – from the current 650 GWh to over 30 TWh, with battery storage taking the largest share. Through vehicle-to-grid networks, we expect 10% of the global EV fleet's storage capacity to be available for grid flexibility at any time.

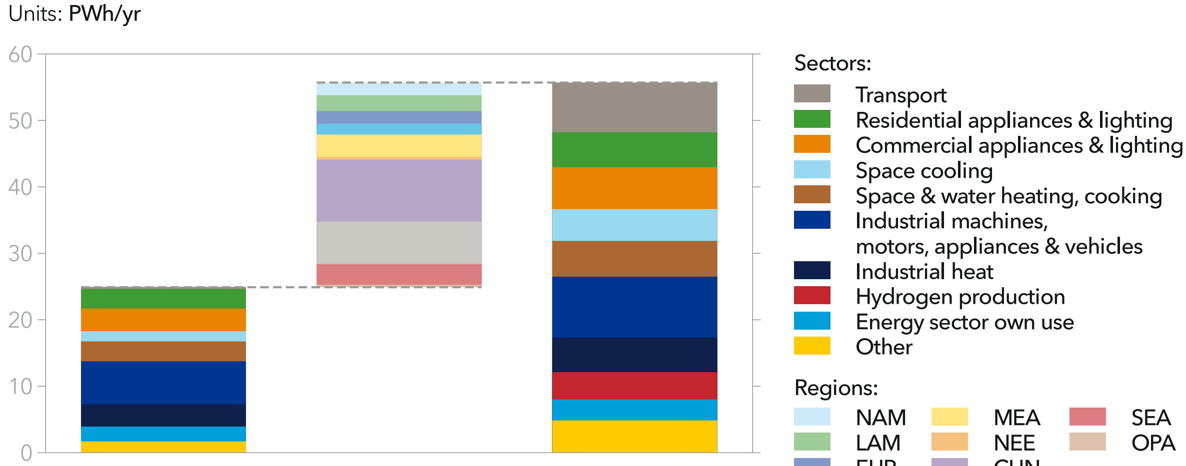
The power market will become more complex as dispatchable, non-dispatchable and storage compete as sources of supply. We found it necessary to model power market dynamics down to hourly intervals, as we discuss in detail in Chapter 3 of our Outlook.

Grid capacity will grow by over 170% in our forecast period. As long-distance connections become more important, 12% of grid capacity will be covered by ultra-high voltage lines by 2050. By then, nearly a third of the world's electricity grids will be in Greater China, with the Indian Subcontinent taking the second-largest share.

FIGURE 12

World electricity demand by sector, growth by region

Units: PWh/yr



Historical data source: IEA WEB (2019), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), EIA RECS (2015), Ürge-Vorsatz et al (2015)

ENERGY EFFICIENCY

Energy efficiency is a key driver of the transition during our forecast period. In fact, it is the most cost-effective resource in transforming our energy systems and should be the number one priority for authorities and other stakeholders in the industry.

One measure of this is the energy intensity of the global economy – expressed as units of energy per unit of GDP. For the last two decades, energy-intensity has reduced by 1.7% annually. Over the next 30 years, energy intensity improvements will accelerate to an average of 2.3% per year worldwide, with the strongest improvement in the 2030s, resulting in our forecast peak in global primary energy use. The cumulative effect of this is significant: whereas it took 4.5 megajoules (MJ) to produce a dollar of global GDP in 2018, it will take just 2.1 MJ in 2050.

The main driver of energy-intensity improvements is the electrification of the energy system and the rapidly growing renewable share in electricity, eliminating enormous heat losses (See Sankey diagram, page 30.). Efficiency comes not just from how energy is supplied, but also how it is used. On the demand side, the biggest improvement is in road transport, with the twin effect of steadily improving efficiency for fossil fuelled vehicles and the introduction of much more efficient EVs.

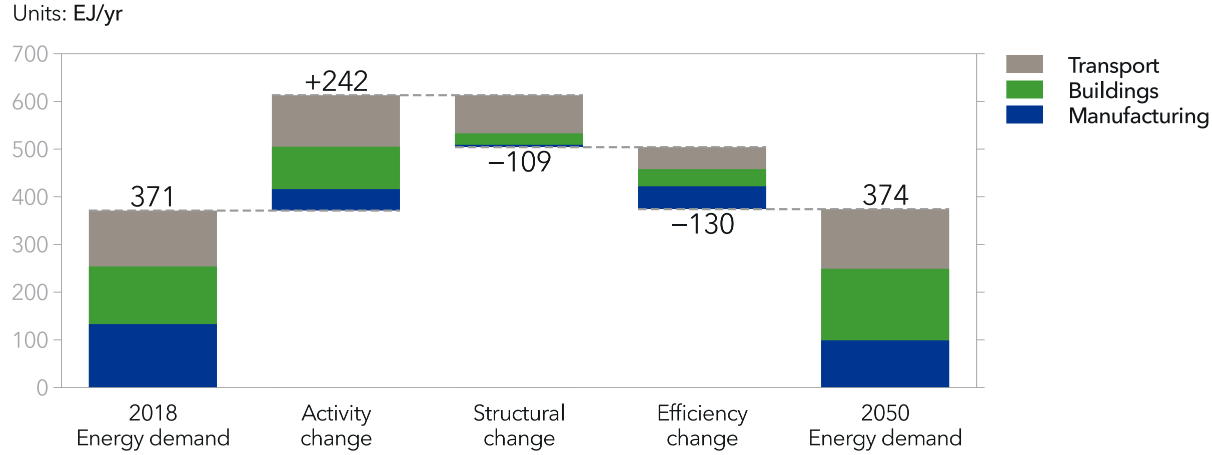
There are efficiencies at work in the other demand sectors as well (Figure 13), not least from electricity replacing the extremely inefficient use of biomass and oil for heat, cooking, and lighting. Consider that kerosene used for lighting is 50 times less efficient than a solar-powered LED light, a stark reminder that less affluent people spend disproportionately more for the energy they use. That is one reason why Sustainable Development Goal (SDG) #7 'Affordable and Clean Energy' emphasizes the need to 'double the rate of improvement in energy efficiency'. Our analysis shows that while this will not be met entirely, solid progress will be made towards 2030.

There is considerable scope for policy frameworks to accelerate efficiency gains beyond the improvements we forecast. Figure 13 illustrates the importance of what is already included: in the absence of any efficiency improvements, final energy demand globally in 2050 would be some 65% higher than today, in contrast to the almost flat demand that we forecast.

FIGURE 13

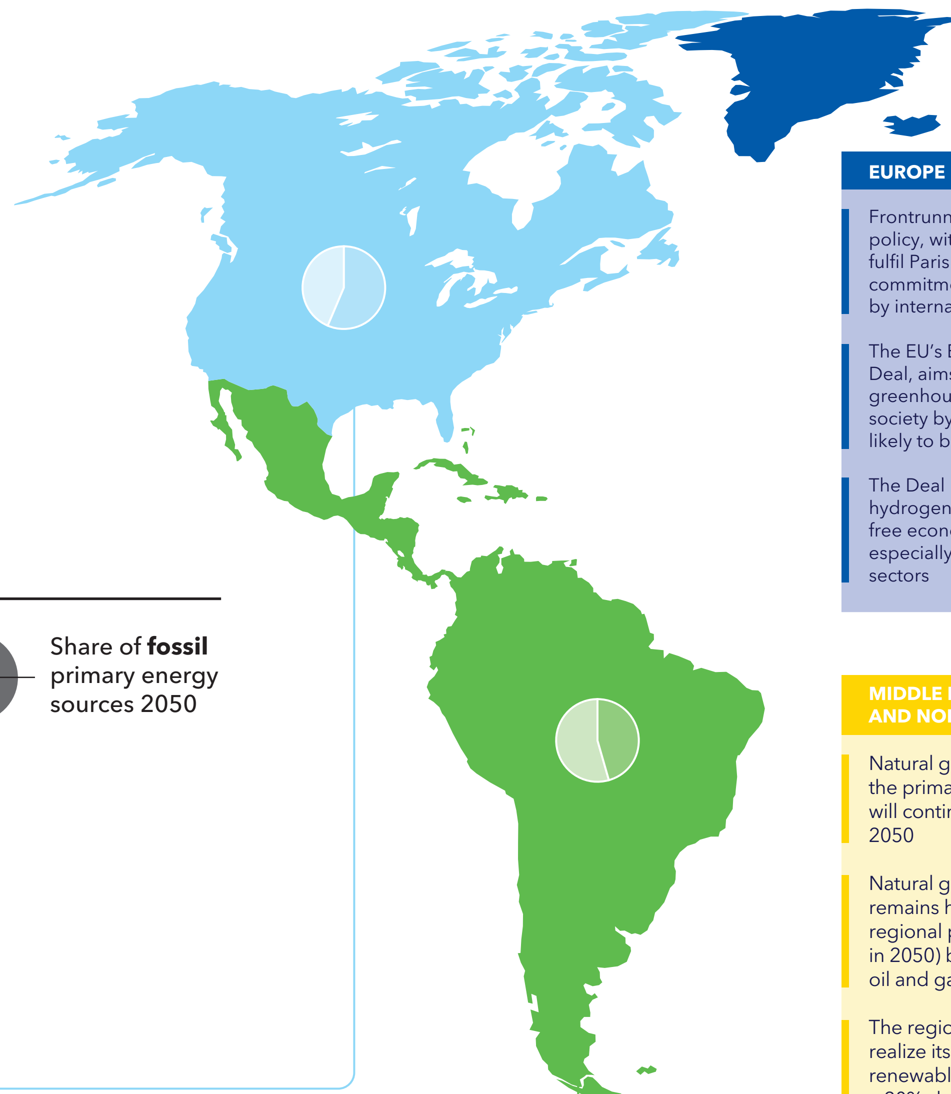
Energy efficiency developments in the main demand sectors

Units: EJ/yr



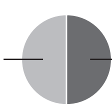
Activity changes include: growth in passenger & freight volumes (transport); rise in heating, cooling, appliance use (buildings); increase in manufacturing output
Structural changes include: vehicle kilometres shifting to EVs; shift to more efficient heating & cooling technologies (buildings); regional shifts (manufacturing)
Efficiency changes include: battery and ICE efficiency gains (transport); equipment efficiency improvements (buildings); more efficient processes (manufacturing)

WE ANALYSE 10 GLOBAL REGIONS



KEY

Share of **non-fossil** primary energy sources 2050



Share of **fossil** primary energy sources 2050

EUROPE

- Frontrunner in transition policy, with the EU aiming to fulfil Paris Agreement commitments, but hampered by internal discrepancies
- The EU's European Green Deal, aims at a net-zero greenhouse gas emission society by 2050, which is not likely to be met
- The Deal prioritizes green hydrogen to support carbon-free economic growth, especially in hard-to-abate sectors

MIDDLE EAST AND NORTH AFRICA

- Natural gas and oil dominate the primary energy mix and will continue to do so until 2050
- Natural gas consumption remains high (50% of the regional primary energy mix in 2050) benefitting from low oil and gas extraction costs
- The region will start to realize its vast potential for renewable energy, reaching a 20% share in primary energy mix in 2050

NORTH AMERICA

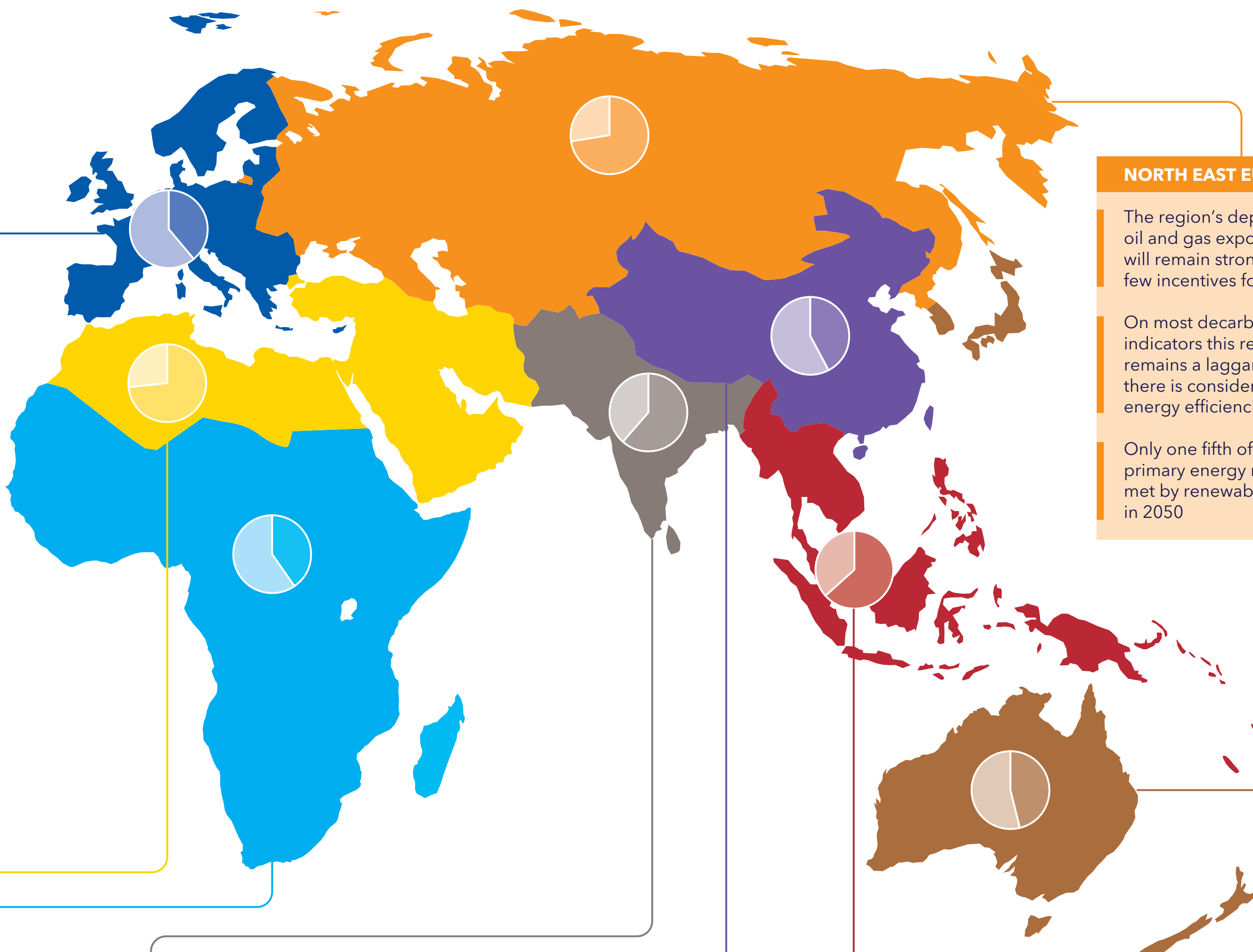
- Business cases and sub-regional policies will drive towards substantial regional decarbonization
- Oil use declines by more than two thirds and coal will have a marginal role from the mid-2020s on
- Strong natural gas growth supplies increasing domestic demand and unfolds LNG export boom in the coming decade

LATIN AMERICA

- Will switch from energy exporter to energy importer for reasons such as global energy system transformation, international competition behind supply, and shrinking demand for fossil fuels
- Electricity production from hydropower, natural gas and fuel oil will diversify into hydropower, solar, and wind
- Fossil fuels will represent less than 50% of the primary energy mix in 2050

SUB-SAHARAN AFRICA

- Least-developed and least-electrified world region; only 42% of its people currently have access to electricity
- Soaring energy demand from a growing population and economy will be counteracted by efficiencies, e.g. traditional biomass cooking replaced by gas and electricity
- Off-grid solar PV plays a significant role in energy access, and with grid-connected solar, accounts for almost 40% of power generation in 2050



NORTH EAST EURASIA

The region's dependence on oil and gas export revenues will remain strong, and give few incentives for change

On most decarbonization indicators this region lags and remains a laggard, although there is considerable focus on energy efficiencies

Only one fifth of the region's primary energy needs will be met by renewable sources in 2050

SOUTH EAST ASIA

Energy demand, especially from space-cooling and appliances, grows significantly but levels off towards the end of the forecast period

Increasing use of natural gas and renewables to supply domestic demand for electrification, will result in lower importance of coal and oil

Manufactured goods production more than doubles until 2050, driving demand for natural gas and transforming this region into a net-importer of LNG

OECD PACIFIC

Falling population and improved efficiencies will almost halve energy use over the forecast period. 2050 electricity mix is dominated by wind, and at 50% of final energy demand, is the second-most electrified region in 2050 after China

Hydrogen will gain a foothold (9% of energy use), sourced initially from Australia through SMR processes, but later mainly via renewably powered electrolysis

INDIAN SUBCONTINENT

500 million more people and GDP growing fourfold will see rising energy demand in this region

Despite the rapid growth of renewables, fossil-energy sources will also grow and represent 62% of the energy mix in 2050

The region's enormous two- and three-wheeler vehicle fleet will transition almost entirely to electricity before 2040

GREATER CHINA

Powerhouse for renewables growth and the energy transition, both for domestic use and abroad

The share of electricity in final energy demand will grow from 23% in 2018 to 52% in 2050 –highest of all regions, over 90% from renewable sources

Coal will reduce its dominant share in the power mix (currently 60%) to 12% over the forecast period

SUPPLY

PEAK HYDROCARBONS

Coal – peaked in 2014 at 7.7 Gt/yr. Since then, coal use has declined significantly in Europe and North America, where it is losing ground to gas and renewables. Coal demand is flattening in air-quality plagued China, but rising in India and South East Asia. However, that growth will not be enough to stave off a rapid decline, such that coal use in 2050 will be less than one third of current levels.

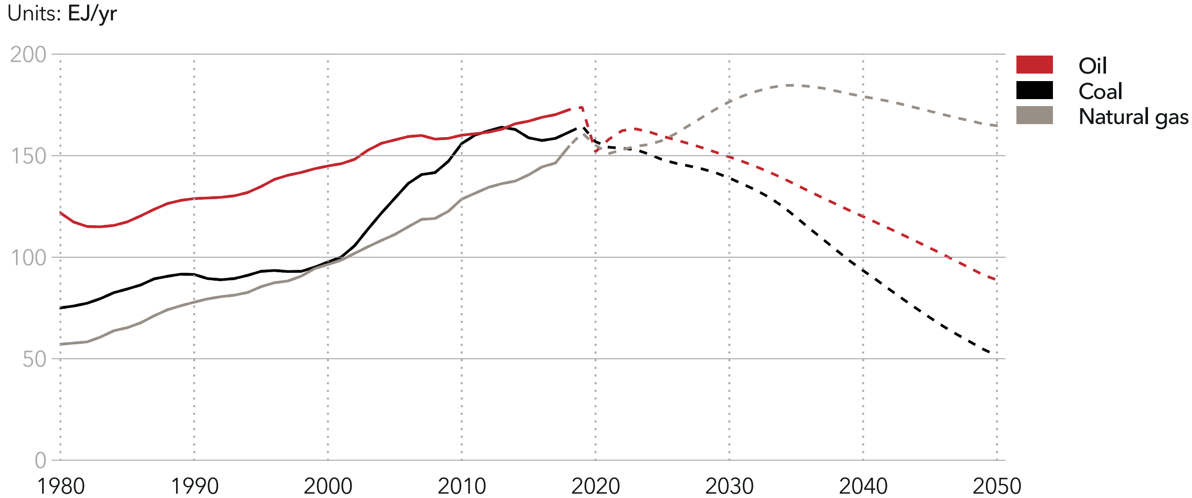
Oil – without COVID-19 effects, oil would have plateaued in 2023, and declined more gently towards 2050. The pandemic will likely lead to a 13% reduction in global crude-oil demand in 2020, mainly due to the impact on the transport sector. Oil demand has already reached a plateau, peaking in 2019, and will not increase further. The transport sector accounted for two thirds of oil demand in 2018, and most of that sector's 53 Mb/d crude oil demand was from road vehicles. Passenger vehicles and two- and three-wheelers will experience the most dramatic conversion to electricity, while the decline in oil demand from commercial road vehicles will be slower. By 2050, oil demand in the road-transport sector will have reduced by 56% compared with 2018. Maritime may see an even-faster reduction, dropping to only 6% of its current oil demand. Aviation will be dependent on oil for longer, maintaining 61% of current consumption by 2050.

Natural gas – will surpass oil as the largest source of primary energy in 2026, a position that it will hold throughout our forecast period. It will peak in 2035 and then taper off gently to 2050, reaching a level only slightly higher than 2019 (i.e. pre-pandemic). Demand changes will differ regionally: in OECD countries, gas consumption will gradually decline; in Greater China, it will peak around 2035 and then start to decline; in the Indian Subcontinent, demand will almost triple by mid-century. By 2050, 41% of all gas use will be for power generation, underscoring its role as a bridge fuel for renewables. With regional shifts in demand, LNG will experience greater increases than occur in overall gas production. Global capacity for regasification will more than double by 2050, whereas the global capacity for liquefaction will more than triple. For the oil and gas industry, decarbonizing its production is a major factor in the energy transition. While decarbonizing oil is virtually impossible, gas can be decarbonized through carbon capture either when producing 'blue' hydrogen or post-combustion in power plants or industry. However, decarbonization of gas will not start in earnest until after 2035 and, even then, will be quite slow, with just 13% of natural gas effectively decarbonized by 2050.

FIGURE 14

World primary fossil fuel supply by source

Units: EJ/yr



Historical data source: IEA WEB (2019)

THE RISE OF RENEWABLES

Wind and solar PV – In a few decades, power systems in most regions will be dominated by solar and wind – boasting CLRs of between 16 and 28% for the core technologies. From 2018 to 2050, solar PV capacity will grow 20-fold, reaching 10 TW just before 2050, while, installed wind capacity will increase ten-fold to 4.9 TW for onshore, 1 TW for fixed offshore and 260 GW for floating offshore wind.

With improved technologies in solar tracking, bifacial solar panels, larger and taller wind turbines, investments in locations with better insolation, and wind characteristics becoming financially feasible – the worldwide annual capacity factor will rise. According to our best estimate, solar and wind will provide 24% of the world's electricity in 2030 and 62% in 2050. By then they will mainly compete with each other, and the ratio is therefore sensitive to individual assumptions on wind and solar PV CLRs.

Solar PV and wind capacity additions in every decade will consistently exceed those of the previous decade until 2050. As they start from a lower base, the pace of expansion will be highest for fixed and floating offshore wind. In the present decade, floating wind will progress from full-scale demonstration projects to commercial-scale deployments.

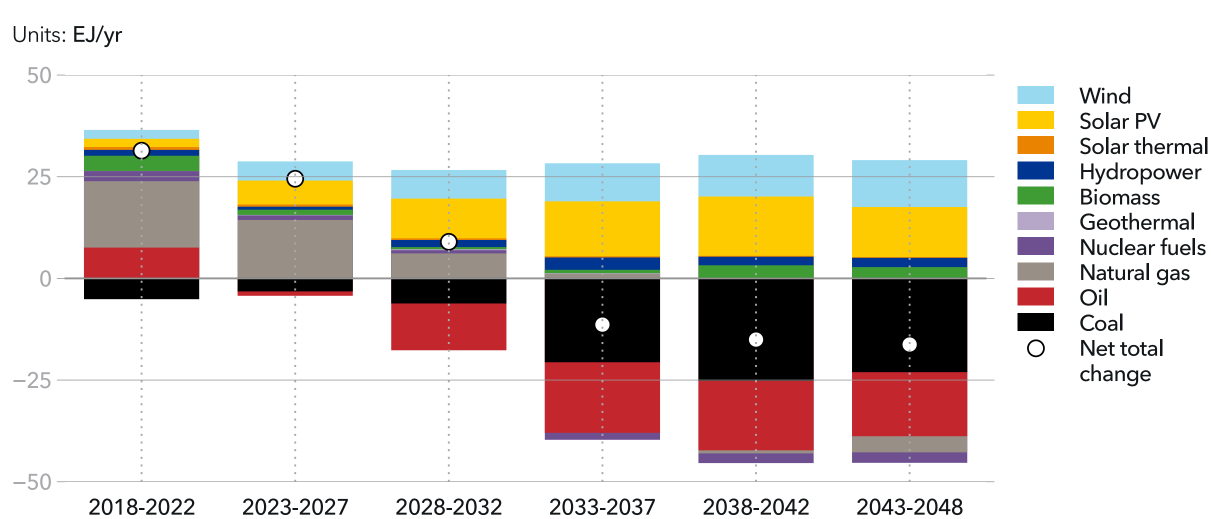
Hydrogen – Not all sectors can be electrified, and hydrogen is increasingly being seen as key to decarbonization targets. This year, we have modelled the CLRs and associated distribution costs for two key hydrogen supply chains: production from steam methane reforming (SMR) of natural gas, with CCS of the CO_2 ('blue hydrogen'); and 'green' hydrogen produced via renewably-powered electrolysis.

We do not expect 'surplus' electricity from vRES to be available for hydrogen production to any great degree before 2035. There are a range of other uses for such surpluses, not least various forms of storage for grid flexibility.

Hydrogen from SMR will dominate in the next decade – reaching 2.3 EJ/yr in 2035, three times higher than hydrogen from electrolysis. After a slow start, increasing carbon prices and a self-reinforcing reduction in technology costs will have more effect from 2035 and, from then on, we will see the start of a more rapid hydrogen uptake. Both supply chains will continue to grow through to 2050, and, by then, electrolysis will supply slightly over half of the 23 EJ/yr of hydrogen (just above 5% of the global energy mix).

FIGURE 15

Net change in primary energy supply by source



5-yr average primary energy supply subtracted from the previous 5-yr average. Historical data source: IEA WEB (2019)

AN EXPENSIVE TRANSITION?

Affordability is the acid test of the energy transition that we forecast. Will the annual cost of the future energy system that we see developing be higher than today? If so, less-costly options than those that we forecast could perhaps crowd out our projections.

The 'good news' on affordability is that while world GDP will more than double by 2050, the share of GDP devoted to energy expenditure will halve, dropping from its current level of 3% to 1.6% by mid-century (Figure 16). These expenditures include major expansions in high capital-cost renewables and electricity networks. Informed by several commercial studies DNV GL has undertaken, we conclude that the energy transition that we forecast is, indeed, affordable, and that compliance with the Paris Agreement is entirely feasible within energy's current share of global GDP.

In contrast to a near-doubling of global GDP between now and mid-century, global energy expenditure will increase by only 5%, rising from USD 4.2trn in 2018 to USD 4.4trn in 2050. The fossil-energy share will decline by almost half of today's 77%, dropping to 44% of expenditures by mid-century. Most of the upstream fossil-fuel expenditure will disappear due to oil CAPEX falling by a factor of 9 from today to mid-century. Neither oil OPEX nor gas CAPEX will decline by more than a quarter to 2050, and gas OPEX will remain at the same level.

On the power-system side, grid expenditures will grow even more strongly than power supply, representing one third of global-energy outlays in 2050. World grid expenditures will increase from about USD 410bn today to about USD 930bn in 2050.

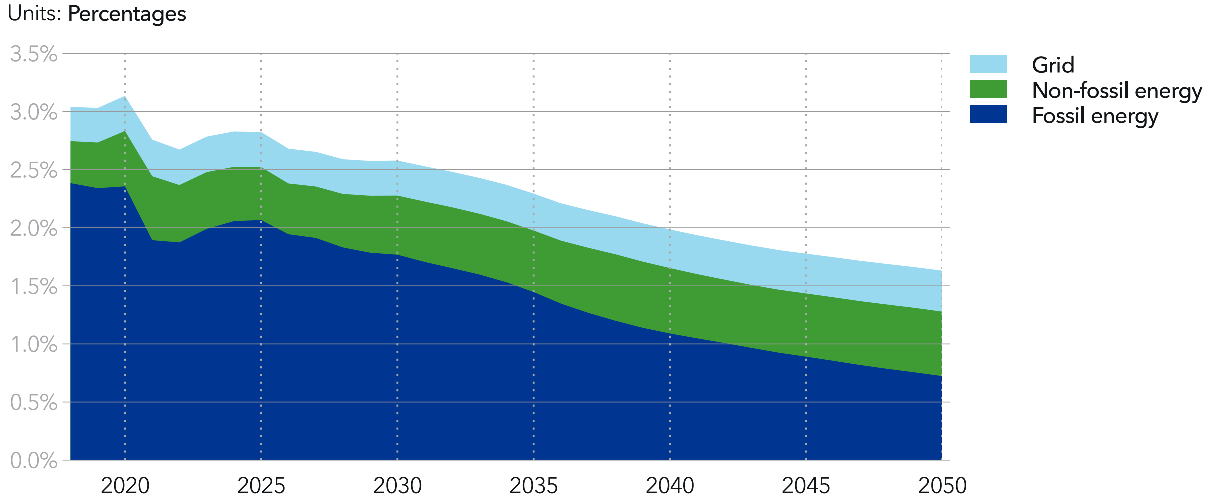
CAPEX in non-fossil plants will more than triple, reaching USD 1trn globally in 2050. vRES power plants typically require much less maintenance and operating care than traditional non-fossil nuclear and hydropower plants. Thus, even with the majority of power coming from vRES plants in 2050, their share of OPEX will not surpass a quarter of OPEX at that time. Nevertheless, the tripling of global non-fossil power generation capacity will lead to OPEX more than doubling.

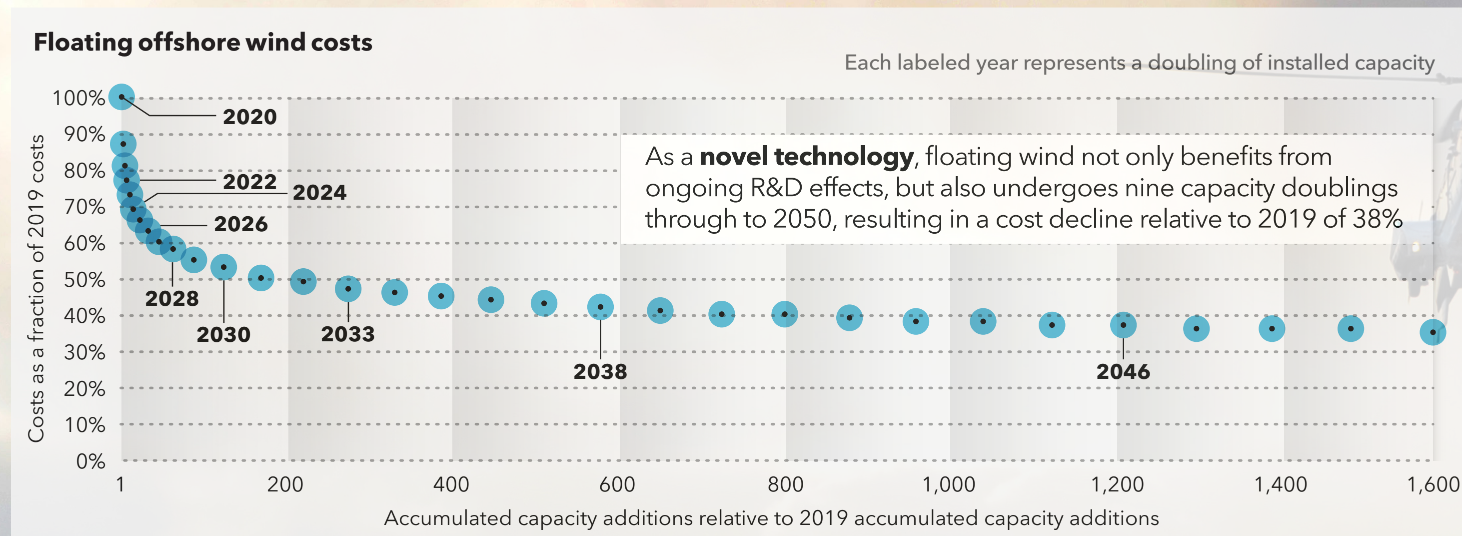
> "While world GDP will more than double by 2050, the share of GDP devoted to energy expenditure will halve

FIGURE 16

World energy expenditure as a fraction of world GDP

Units: Percentages





Our projections are that floating offshore wind will grow to reach a total capacity of 260 GW by 2050. That is almost 3,000 times the size of Equinor's Hywind Tampen floating wind power project intended to provide electricity for the Snorre and Gullfaks offshore field operations in the Norwegian North Sea from 2022. Image: courtesy, Equinor.

NOT FAST ENOUGH

Despite relatively flat global energy demand through to 2050 and a rapidly growing share of renewables, the energy transition that we forecast is not fast enough to bring the world to within reach of the goals established by the Paris Agreement. Our forecast points towards a warming of 2.3°C by the end of this century, a level considered dangerous by the world's scientific community.

EMISSIONS

After staying virtually flat from 2014-2016, global annual energy-related CO_2 emissions grew to reach a peak of 34.4 Gt CO_2 in 2018. Due to the COVID-19 pandemic, emissions in 2020 will reduce by some 8%, and, by 2050, annual energy-related emissions are expected to be down to 17.1 Gt CO_2, some 50% less than 2018 levels.

Coal is currently responsible for 44% of CO_2 emissions, but will see a 75% decline towards 2050 compared with 2018. Emissions from oil will halve by 2050, whereas emissions from natural gas will grow towards 2030 and then drop back to today's level. On the demand side, emissions from manufacturing will decline by 60%, and the transport and buildings sectors will each see a reduction of almost 50%.

There are significant non-energy emissions from industrial processes (e.g. cement and chemicals) and from agriculture, forestry and other land use (AFOLU). We expect that industrial emissions will reduce by a third through to 2050 owing to improved production and technical efficiencies. We assume CO_2 emissions from land use to stay at current levels until 2030, and then decline by 50% to 2050, as governments pursue decarbonization targets and take firmer action on land-use changes.

REGIONS

Absolute emissions will increase in the Indian Subcontinent and Sub-Saharan Africa to 2050. Greater China, currently the largest emitter by far, will reach peak emissions before 2030; its emissions will then decline by almost 80% from 2030 levels. All other regions will reduce their emissions, with OECD Pacific, together with Europe, experiencing the biggest relative change. North America and North East Eurasia will have the highest emissions per capita at 4.4 tonnes/person, in 2050.

CARBON CAPTURE

CCS uptake will be limited; it is only in the 2040s, when carbon prices start to approach the cost of CCS, that uptake will accelerate, and deployment begins at scale. By 2050, total carbon capture will amount to 11% of all energy-related emissions, i.e., 2.1 Gt per year.

IMPACT OF COVID-19

In addition to the pandemic causing a drop in energy-related emissions of approximately 8% in the near term, it will also result in lower emissions throughout the entire forecast period due to delayed growth and because some activities, like air travel, will undergo lasting changes. The cumulative reduction in CO_2 emissions to 2050 is estimated to be 75 Gt CO_2, compared with a non-COVID situation. This represents about two years' worth of present emissions and will not significantly change the long-term temperature increase. In order to achieve the ambitions of the Paris Agreement, the world needs emissions reductions that are equivalent to those associated with the pandemic to happen every single year, from now until 2050.

CARBON BUDGET OVERSHOOT

By 2050, the trajectory of CO_2 emissions will be in steep decline. Remaining emissions may be increasingly difficult to abate, and, extrapolating our trends, we consider it likely that the world will achieve net-zero CO_2 emissions by the end of the century. In order to derive the cumulative CO_2 emissions for the remaining years of this century, we have added an estimate of those for the years between 2050 and 2100 to the aggregated emissions associated with our forecast to 2050. Comparing this result with IPCC values, we find that the 1.5°C carbon budget will be exhausted in 2028. It then takes a further 23 years (to 2051) to exhaust the 2°C budget. That leaves an 2100 overshoot of 1,280 $GtCO_2$ beyond the 1.5 °C target and 530 $GtCO_2$ beyond the 2°C target. (To put these numbers into perspective, global energy-related emissions during their peak year – 2019 – were 36 $GtCO_2$.)

At these levels of budget overshoot, our forecast indicates a global warming of 2.3°C by the end of the century – and thus an enormous gap between the warming trajectory that we are on and the goals of the Paris Agreement. Although there are significant uncertainties associated with our warming estimate, there is no escaping the fact that there is an urgent need to find solutions to close the gap.

FIGURE 17

World energy-related CO_2 emissions - with and without COVID-19

Units: $GtCO_2/yr$

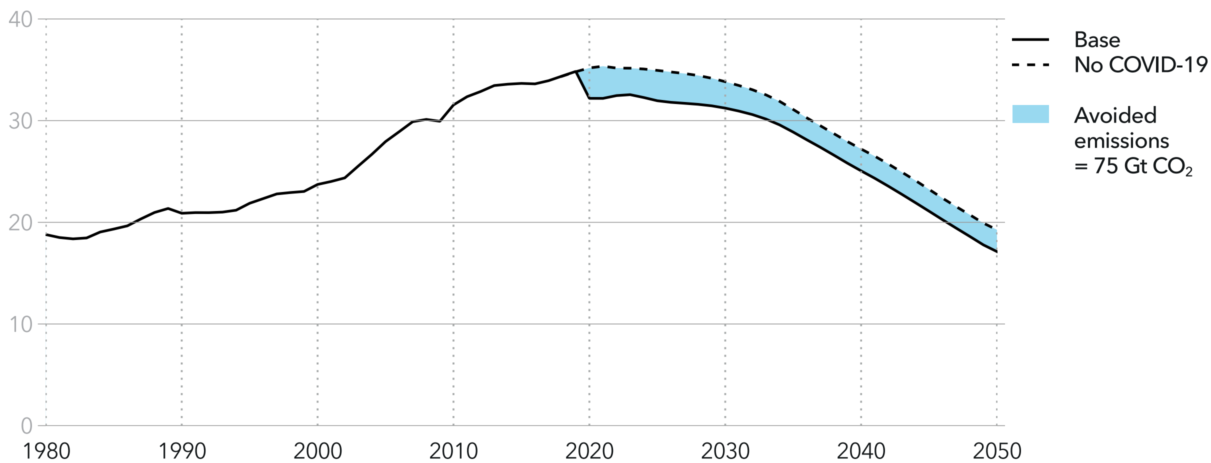
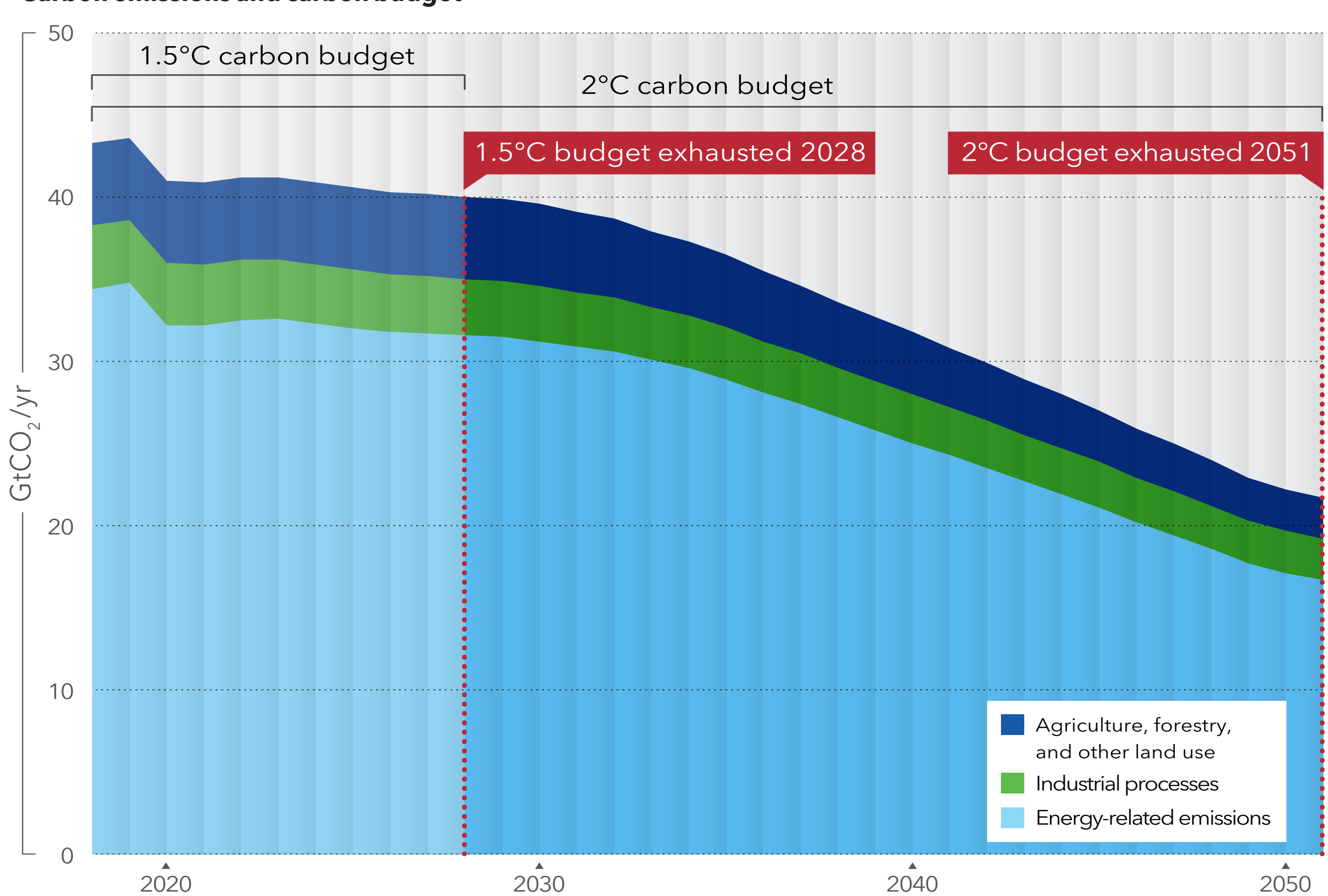


FIGURE 18

Carbon emissions and carbon budget



SOLUTIONS

When considering how to close the emissions gap, two precepts are of importance:

- No silver bullet exists to close the gap on its own; a combination of many different solutions is needed.
- There is no established pathway to close the gap. There are several alternative combinations that must be explored.

To narrow the range of decarbonization measures, we focus on the most energy- and carbon-intensive elements of our three main demand sectors – transport, buildings and manufacturing. Power supply is a separate important sector, but easier to abate and not included here.

Solutions with the potential to close the gap require many initiatives and actions. Most of these fall into one of two broad categories:
- Implementation track – known and readily available solutions, but requiring full-scale implementation in the coming decade. (The UN has declared the 2020s the Decade of Action for sustainable solutions.)
- Development track – possible solutions identified, but currently less mature and significantly more expensive than currently installed technology. Hence the need for targeted policies, including incentives for additional R&D and funding for projects to trigger technology readiness and scaling-up.

While we focus on individual sectors in this short summary, we are mindful of the role of sector coupling, which links both technologies and policies across sectors to maximise synergies and efficiencies.

TRANSPORT

Transport ranges from the relatively easy-to-abate passenger vehicles and rail industries to hard-to-abate heavy road transport, maritime, and aviation, and solutions cover an equally wide span.

From a technology perspective, there are many design and engineering improvements, including digitalization, that can that can significantly improve energy efficiency for all transport categories. However, electrification is key, and for those transport subsectors that cannot be easily electrified, there is an urgent need to identify and prioritize low- and zero-carbon fuel alternatives. These include various forms of biofuels, hydrogen, ammonia and a range of electrofuels.

The most important priorities over the next five years include:
- Improving utility for EVs, e.g., number of fast charging stations and availability of renewable power.
- Policies to foster the further uptake of EVs and fuel-cell EVs in heavy transport, such as electric buses in cities and fuel-cell heavy trucks.
- Ramped-up support for R&D on sustainable and carbon-neutral fuels for maritime and aviation; policies and funding to boost commercial-scale production and mandate uptake.

BUILDINGS

While some of the buildings subcategories (cooling and appliances and lighting) depend almost exclusively on electricity, several alternatives exist for heating, and also for cooking and water-heating.

Space heating is the largest subcategory, and continuous improvements in energy efficiency and switching to low- or zero-carbon fuels for heating applications will be the main drivers of reductions in emissions. This calls for continued improvements in heating technologies, including the widespread use of condensing gas boilers and heat pumps for space- and water-heating applications.

At the same time, strategies are needed to reduce heating demand through, for example, better insultation and/or the renovation of buildings. On the supply side, the share of renewable sources, such as solar-thermal heating and renewables-based district heating systems, needs to be scaled up.

Biomethane and hydrogen – in pure or fuel blends – can play an important decarbonization role. The current and planned gas grids will accommodate both pure and fuel-blend hydrogen piping at low additional cost, although an upgrade of heating appliances will be required for utilizing pure hydrogen.

The most important priorities over the next five years include:
- Displacing traditional biomass combustion.
- Scaling up high-efficiency heat pumps.
- Insulation of buildings.

MANUFACTURING

Heat is the end use responsible for most manufacturing emissions. Low-grade heat processes can be supplied by several technologies, amongst which, industrial heat-pumps are a promising low-carbon solution. High-grade industrial heat processes, used mainly in the raw-materials sectors, need a dense energy carrier in the form of fossil fuels or energy-intensive electric heating.

Common to all hard-to-abate industries is the difficulty in finding low- or zero-carbon technologies that compete on cost and efficiency with existing furnace technology that is fossil fuel-based. Electrification and hydrogen from electrolysis are technologies that can solve the decarbonization challenge, but most electricity today is fossil-fuel based, and thus suffers heat losses compared with direct-heat technologies. An alternative is to apply post-combustion CCS for coal and natural-gas use – a technology that can be applied by both the power industry and manufacturing.

The most important priorities over the next five years include:
- Increase recycling and availability of scrap that requires much less energy for processing, e.g., steel, aluminium.
- Support on-site renewable electricity production, and/or relocation of manufacturing to production areas with a low-carbon electricity mix (for electricity-based heating).
- Facilitate growth in electric arc furnace usage based on renewable electricity.
- Where appropriate, deploy CCS-application in the production process.

DECADE OF ACTION

7 AFFORDABLE AND CLEAN ENERGY

ENERGY TRANSITION OUTLOOK MODEL

Figure 19 below presents the ETO model framework. The arrows in the diagram show information flows, starting with population and GDP per person, while physical flows are in the opposite direction. Policy influences all aspects of the energy system. Energy-efficiency improvements in extraction, conversion and end-use are a cornerstone of the transition.

A subset of the feedback loops in our model is shown opposite for the road transport and power sectors. Two of the cross-sector feedbacks are highlighted. Note that Figure 20 is a simplified illustration. There are similar feedback processes in other parts of our model.

FIGURE 19

ETO model framework

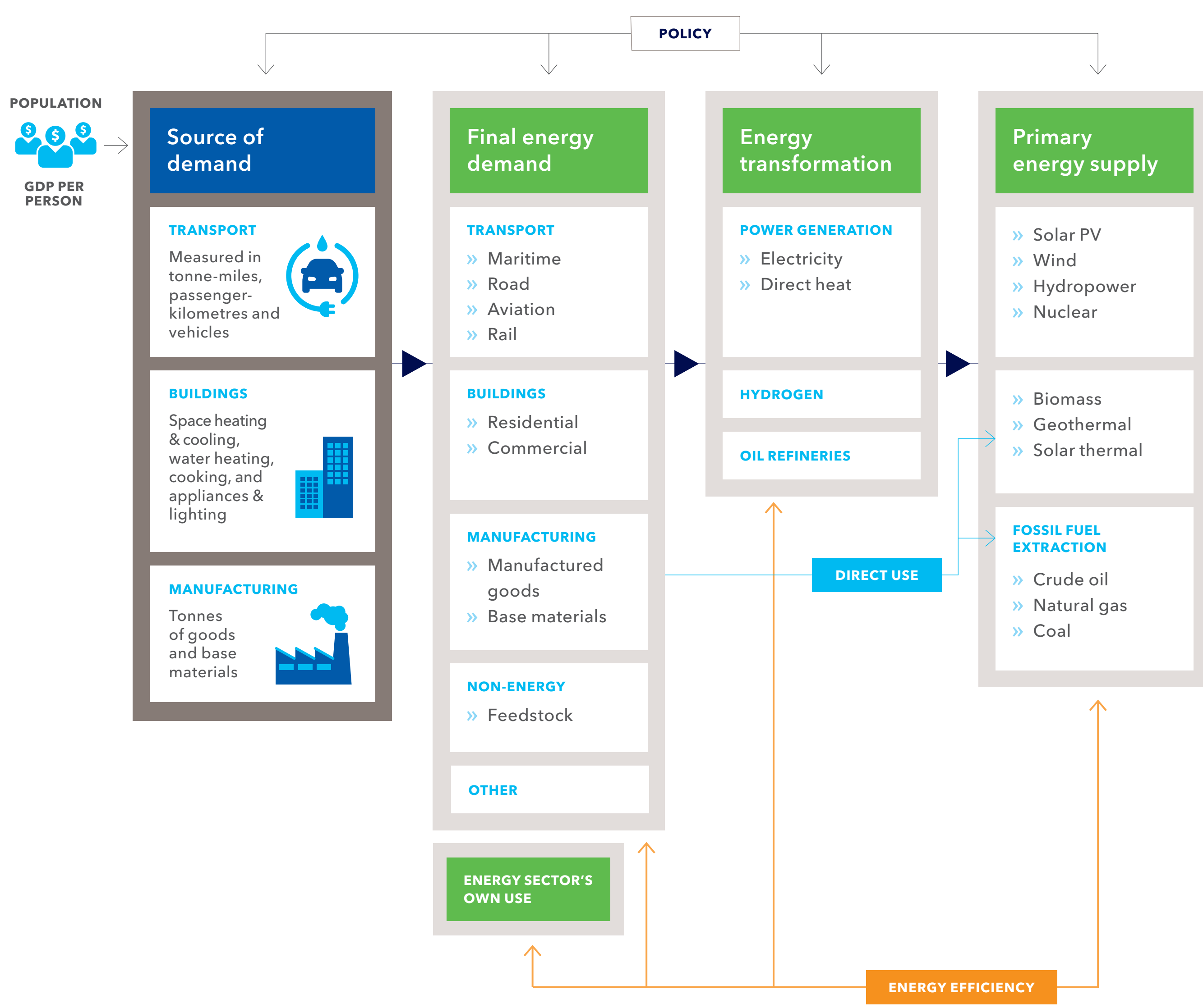
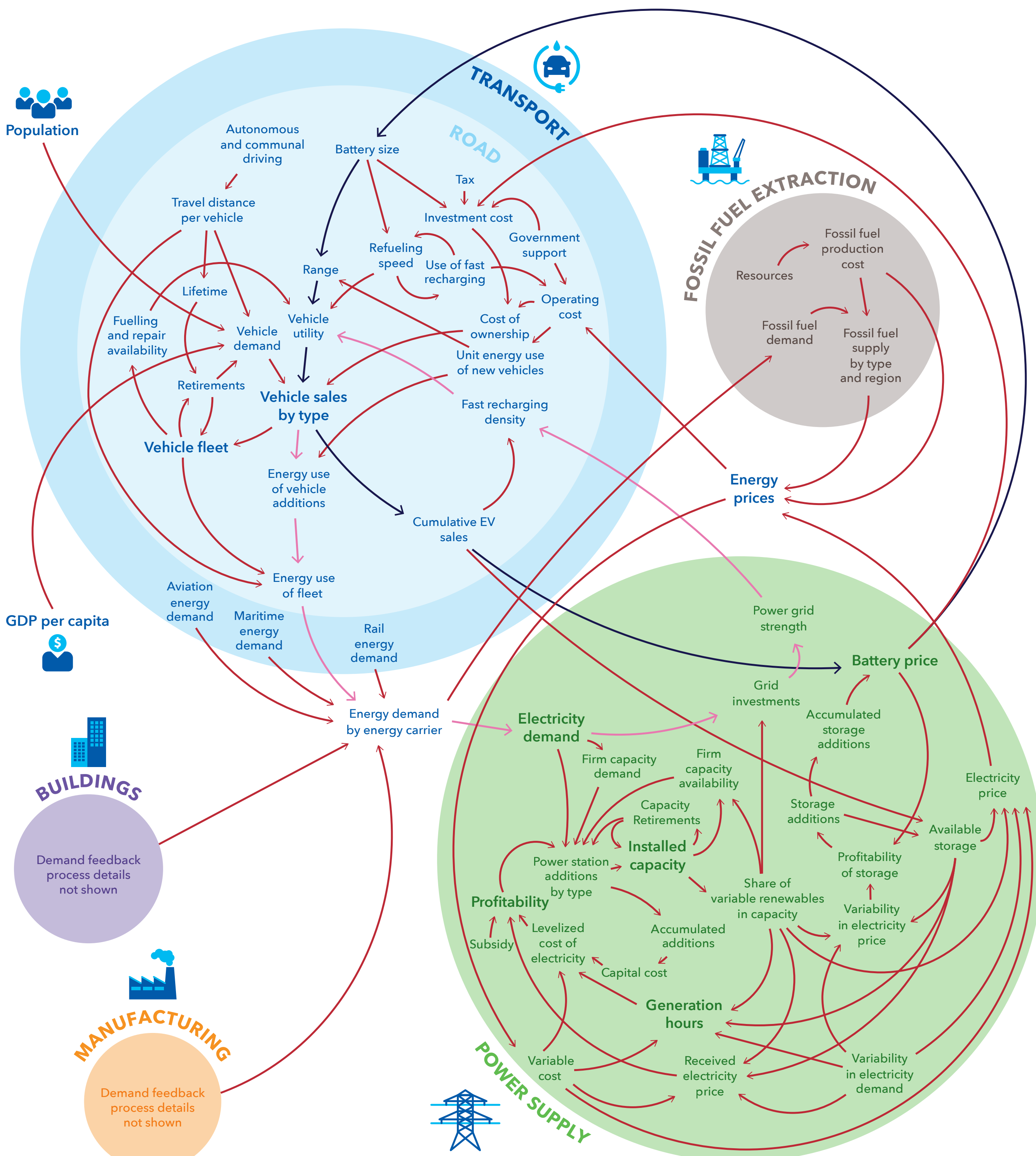
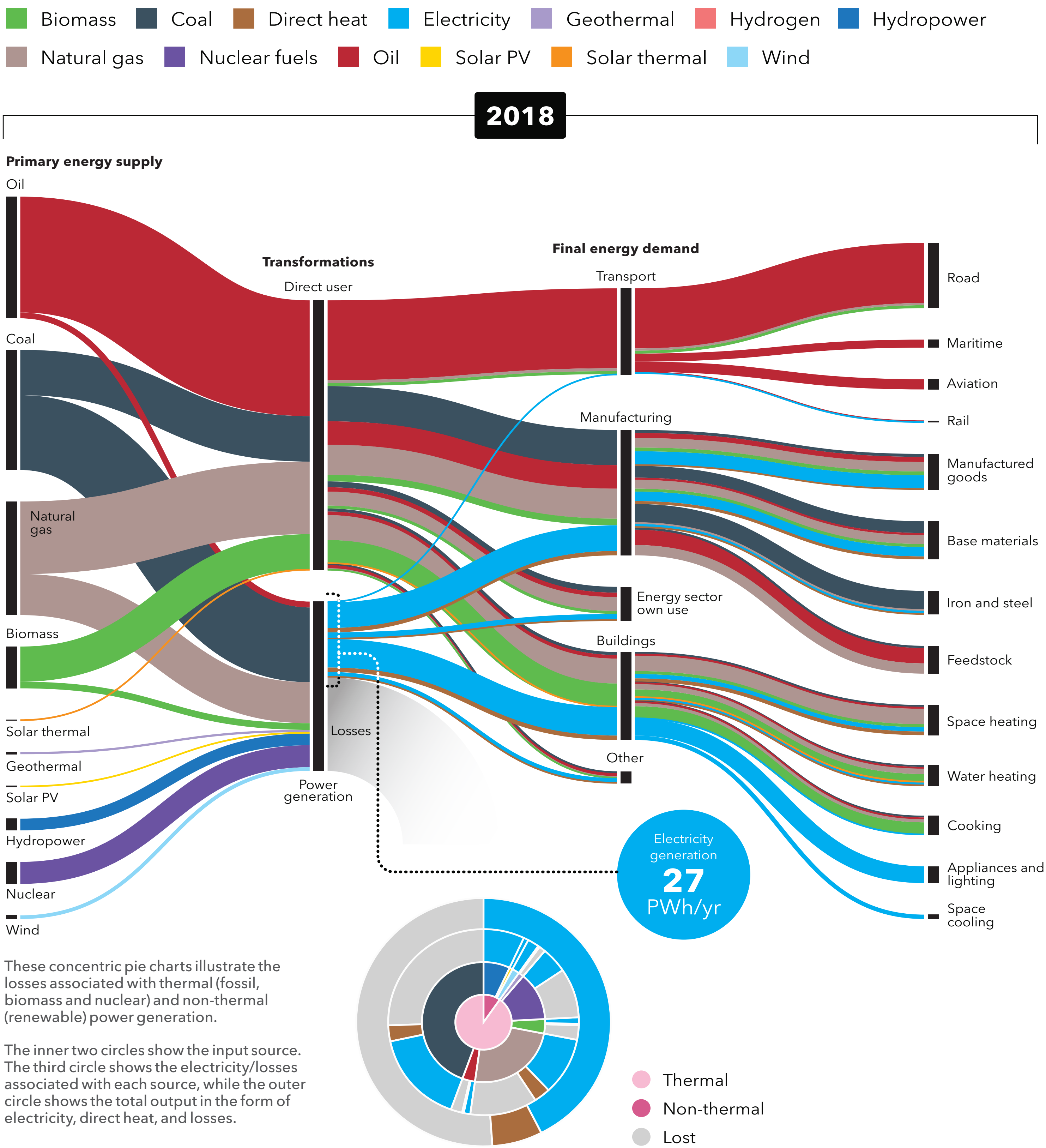


FIGURE 20

Selected and simplified feedback loops in the power-supply and road-transport sectors



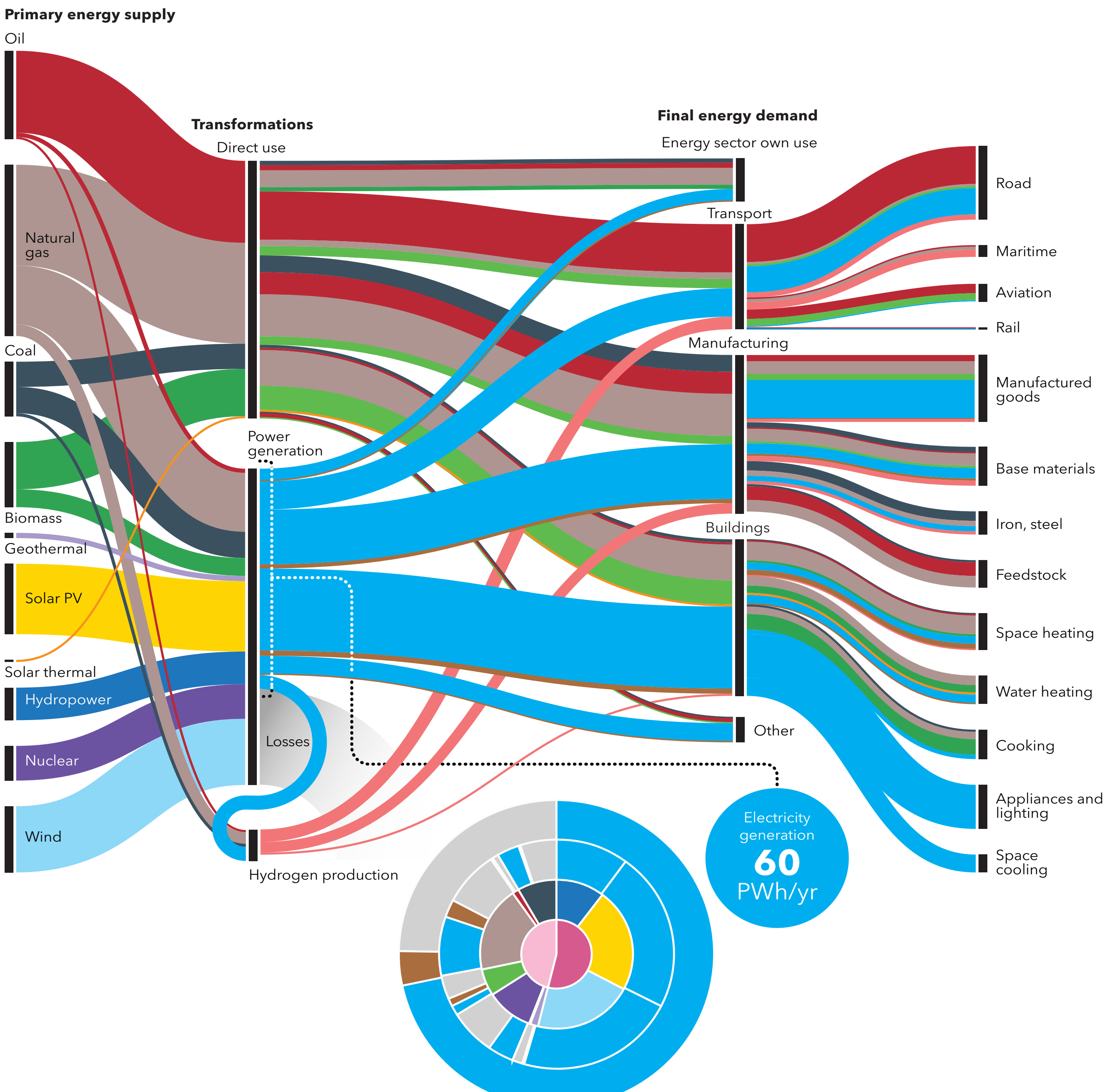
COMPARISON OF ENERGY FLOWS: 2018 AND 2050



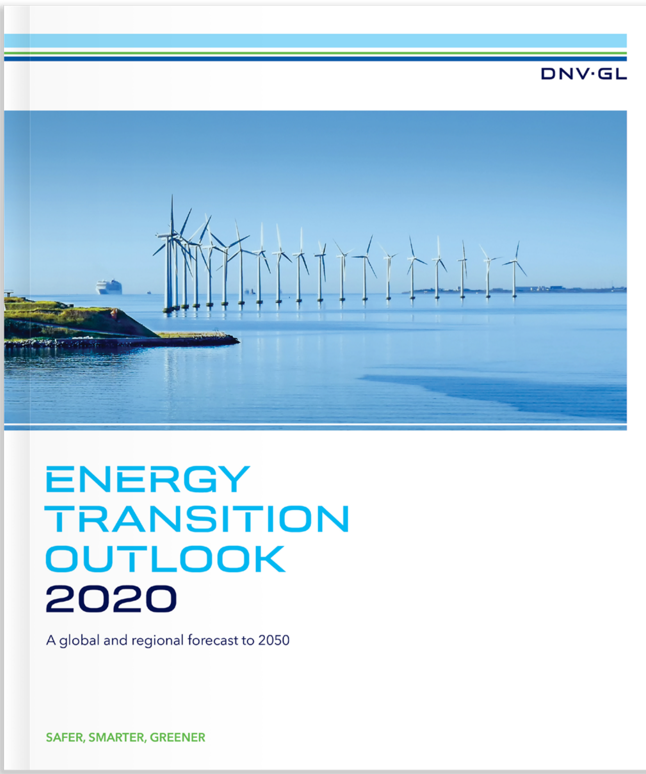
These concentric pie charts illustrate the losses associated with thermal (fossil, biomass and nuclear) and non-thermal (renewable) power generation.

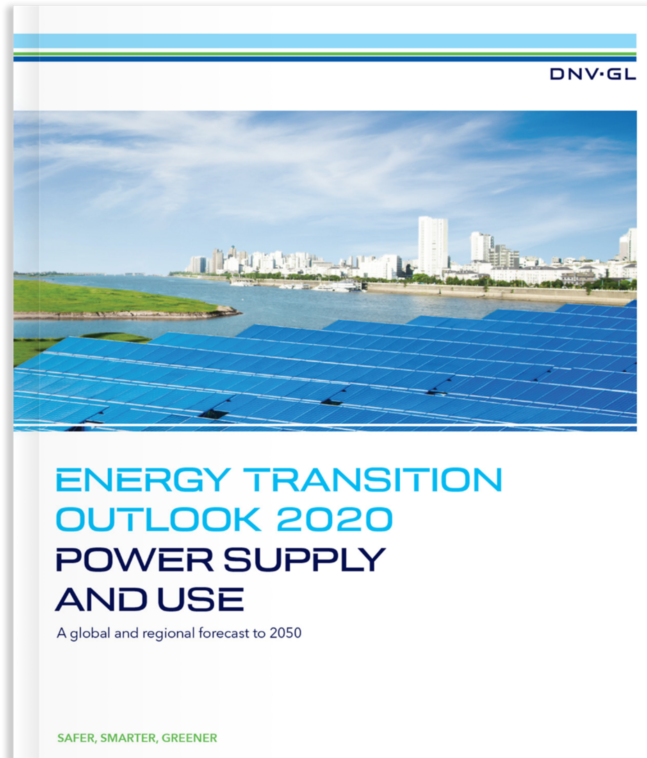
The inner two circles show the input source. The third circle shows the electricity/losses associated with each source, while the outer circle shows the total output in the form of electricity, direct heat, and losses.

2050


Primary energy supply
Oil
Natural gas
Coal
Biomass
Geothermal
Solar PV
Solar thermal
Hydropower
Nuclear
Wind
Transformations
Direct use
Power generation
Losses
Hydrogen production
Final energy demand
Energy sector own use
Transport
Manufacturing
Buildings
Other
Road
Maritime
Aviation
Rail
Manufactured goods
Base materials
Iron, steel
Feedstock
Space heating
Water heating
Cooking
Appliances and lighting
Space cooling
Electricity generation
60
PWh/yr

ENERGY TRANSITION OUTLOOK 2020 REPORTS OVERVIEW





ENERGY TRANSITION OUTLOOK

Our main publication details our model-based forecast of the world's energy system through to 2050. It gives our independent view of what we consider to be the most likely trajectory of the coming energy transition, and covers:

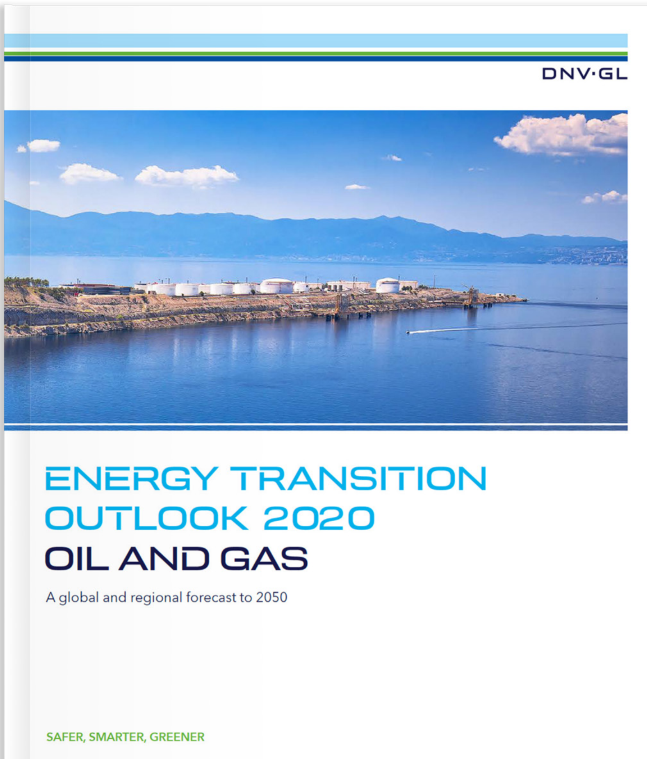
- The global energy demand for transport, buildings, and manufacturing
- The changing energy supply mix, energy efficiency, and expenditures
- Detailed energy outlooks for 10 world regions
- The climate implications of our forecast, and solutions for closing the gap to well below 2°C.

We also provide background details on the workings of our model and on our main assumptions (including population, GDP, technology costs and government policy). Our 2020 Outlook also details the impact of COVID-19 on the energy transition.

POWER SUPPLY AND USE

This report presents the implications of our energy forecast to 2050 for key stakeholders involved in electricity generation, electricity transmission and distribution, and energy use. Electricity use is increasing rapidly, and production becoming dominated by renewables; our report details the important industry implications of this evolution, including:

- Substantial opportunities for those parties involved in solar and wind generation
- Massive expansion, reinforcement and upgrading of transmission and distribution networks
- Further need for implementation of energy-efficiency measures
- Acceleration of the EV revolution
- Digitalization enabling process improvements and smarter operations
- The energy transition is fast, but not fast enough to meet the goals of the Paris Agreement.



OIL AND GAS

This report provides the demand, supply, and investment forecast for hydrocarbons to 2050, with a commentary on key trends:

- The world is moving from more oil to cheapest oil, as demand declines
- LNG is set to thrive in a strong gas market
- We forecast multiple energy transitions: from coal and oil to natural gas, and from fossil fuels to renewables and decarbonized gas.
  Further, we focus on decarbonizing the oil and gas industry:
- Pressure is mounting as emissions are set to remain stubbornly high until mid-2030s
- Decarbonization is on the agenda of industry and government, but not at the pace or depth to meet the Paris Agreement
- Hydrogen and CCS have the potential to transform the industry.

MARITIME

This year's Maritime Forecast aims to enhance the decision-making of shipowners as they navigate the technological, regulatory and market uncertainties surrounding decarbonization:

- A library of 30 scenarios has been developed that projects future fleet composition, energy use, fuel mix, and CO_2 emissions to 2050.
  Each of our scenarios belongs to one of three distinct decarbonization pathways.
- We model 16 different fuel types and 10 fuel technology systems. We analyse how particular fuel-technology alternatives perform commercially in a new Panamax bulk carrier as a case study.

Managing decarbonization risks is critical to protect the future value, profitability, and competitiveness of a vessel. Picking the wrong fuel solution today can lead to a significant competitive disadvantage.

VERACITY – EXPLORE OUR FORECAST DATA

DNV GL's Energy Transition Outlook aims to inform and assist those in energy supply chains assessing their future strategic options. All the forecast data from our Outlook reports and further details from our model are offered on Veracity: Our digital platform provides interactive access to our assumptions and results, and can be used by stakeholders in projects and business planning.

eto.dnvgl.com/forecast-data

ETO TEAM AND CONTACT

This report has been prepared by DNV GL as a cross-disciplinary exercise between the DNV GL Group and our business areas of Oil & Gas, Energy, and Maritime across 15 countries. The core model development and research have been conducted by a dedicated team in our Energy Transition research programme, part of the Group Technology and Research unit, based in Oslo, Norway. In addition, we have been greatly assisted by the external Energy Transition Outlook Collaboration Network.

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Historical data
This work is partially based on the World Energy Balances database developed by the International Energy Agency, © OECD/IEA 2019 but the resulting work has been prepared by DNV GL and does not necessarily reflect the views of the International Energy Agency. For energy related charts, historical (up to and including 2018) numerical data is mainly based on IEA data from World Energy Balances © OECD/ IEA 2019, www.iea.org/statistics, License: www.iea. org/t&c; as modified by DNV GL.

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ABOUT DNV GL
We are the independent expert in risk management and quality assurance. Driven by our purpose, to safeguard life, property and the environment, we empower our customers and their stakeholders with facts and reliable insights so that critical decisions can be made with confidence. As a trusted voice for many of the world's most successful organizations, we use our knowledge to advance safety and performance, set industry benchmarks, and inspire and invent solutions to tackle global transformations.

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