DNV·GL

ENERGY TRANSITION NORWAY 2020

A national forecast to 2050

Commissioned by:

Norsk Industri

CONTENTS

FOREWORD

Norway has ambitious goals to halve annual greenhouse gas emissions from their 1990 levels to about 26 million tons of carbon dioxide (CO_2) equivalents by 2030, and down to a maximum of 5 million tons by 2050. These ambitions are a highly appreciated contribution to the Paris Agreement and a cleaner future globally.

With its annual greenhouse gas emissions having remained largely the same since 1990, the key question is: Will Norway reach these ambitious targets by 2030?

Since 2017, DNV GL has released its annual Energy Transition Outlook report describing global energy trends, forecasting the energy mix and the energy demand and supply globally through to 2050. These reports have gained increased traction and international recognition. The Energy Transition Outlook 2020 was released September 9th, 2020, and divides the world into ten geographical regions. Europe is one such region. Unfortunately, Europe as a region does not provide a representative picture of Norway's expected energy transition. Norway has close to 100% renewable electricity production onshore, and consequently most of our CO_2 reductions need to be achieved within consumption. Further, Norway has the highest share of hydropower, the highest EV uptake, and is a large oil and gas exporter to Europe.

The Federation of Norwegian Industries (NI) has joined forces with DNV GL to develop Norway as a standalone region within the global energy model. By better understanding the energy transition in Norway with respect to demand, supply and energy mix, and the expected reduction in CO_2 emissions, adequate policies can be made. This report, Energy Transition Norway, clearly states that Norway will fall well short of the CO_2 emission reduction planned for 2030. The main contributors to the emissions are the transport sector and the oil & gas sector. Electrification is a key enabler for CO_2 reduction in the transport sector as well as for offshore oil & gas production. Hydrogen is likely to be developed for certain heavy vehicles in the transport sector. There is a domestic need for an additional 50 terawatt hours of electricity generation capacity by 2050 sourced mainly from hydropower and onshore wind power, while offshore wind will be developed mainly for export.

Not fulfilling the CO_2 emission targets is a challenge to our environment, but also an opportunity for Norwegian technology and Norwegian industry to find attractive products and sustainable solutions to close the gap.

The Federation of Norwegian Industries believes the forecast described in the Energy Transition Norway report will be instrumental to fertilizing political actions and industrial innovations to create an attractive home market for industry as a platform for export and competence building.

NILS KLIPPENBERG

CHAIRMAN ELECTRO AND ENERGY FEDERATION OF NORWEGIAN INDUSTRIES

EXECUTIVE SUMMARY

HIGHLIGHTS

1. **Norway has ambitious emission reduction targets – but is not on track to meet them**
2. **Norway's energy system will remain unique compared with those of other countries**
3. **Norway is well positioned for technology leadership in the green shift**
4. **Political decisiveness is crucial to meet targets and to unleash opportunities**

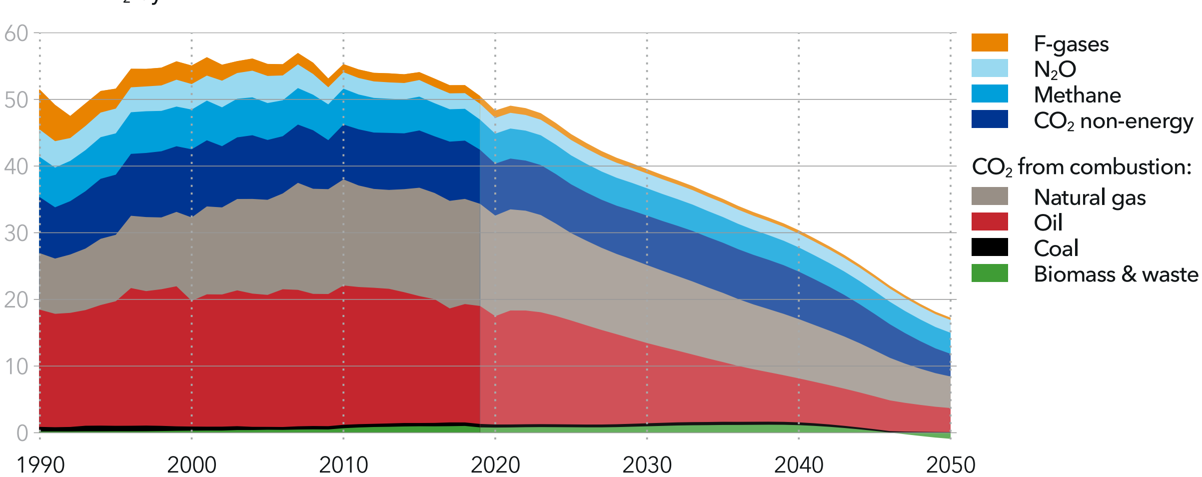
All national energy transitions are unfolding within regional transitions shaped in turn by global trends. This country analysis is noteworthy as it is the first time Norway's energy transition has been systematically analysed by connecting it to a globally recognized energy transition forecast – the DNV GL Energy Transition Outlook (ETO).

Despite its particularities and peripheral location in Europe, Norway's energy system is tightly coupled to the global and European energy systems. The linkages include grids, pipelines, shipping, technology, economic ties and policy development. We have therefore run our ETO model of the global energy system through to 2050 with Norway treated as a region within the ETO's Europe region.

FIGURE 1

Norway greenhouse gas emissions from combustion and non-energy related activities

Units: $MtCO_2e/yr$



F-gases include: HFC, PFC and SF6. Historical data source: SSB (2020)

This Energy Transition Norway report describes DNV GL's view of the most likely development of Norway's energy future, and details the dynamics, challenges and opportunities ahead. We believe this provides valuable insight for the Federation of Norwegian Industries, Norwegian politicians and decision makers, and all stakeholders in the energy system.

Norway has ambitious emission reduction targets – but is not on track to meet them
Norway's energy use already has low carbon-intensity due to its hydropower-dominated electricity system. Thus, it will be challenging to achieve its enhanced nationally determined contribution (NDC) under the Paris Agreement, as announced in February 2020. This NDC targets greenhouse gas (GHG) emission reductions of at least 50%, and towards 55%, by 2030 compared with 1990 levels. Our forecast shows Norway most likely achieving only a 23% reduction by 2030 (Figure 1). Note that the DNV GL model quantifies only energy-related CO_2 emissions; projections for other GHG emissions are made outside the model.

Norway is also unlikely to meet other stated targets. Instead of halving transport emissions by 2030 compared with 2005, the reduction will likely be 41%. By 2025, electric vehicles (EVs) will be about 82% of new passenger vehicle sales, instead of the targeted 100%.

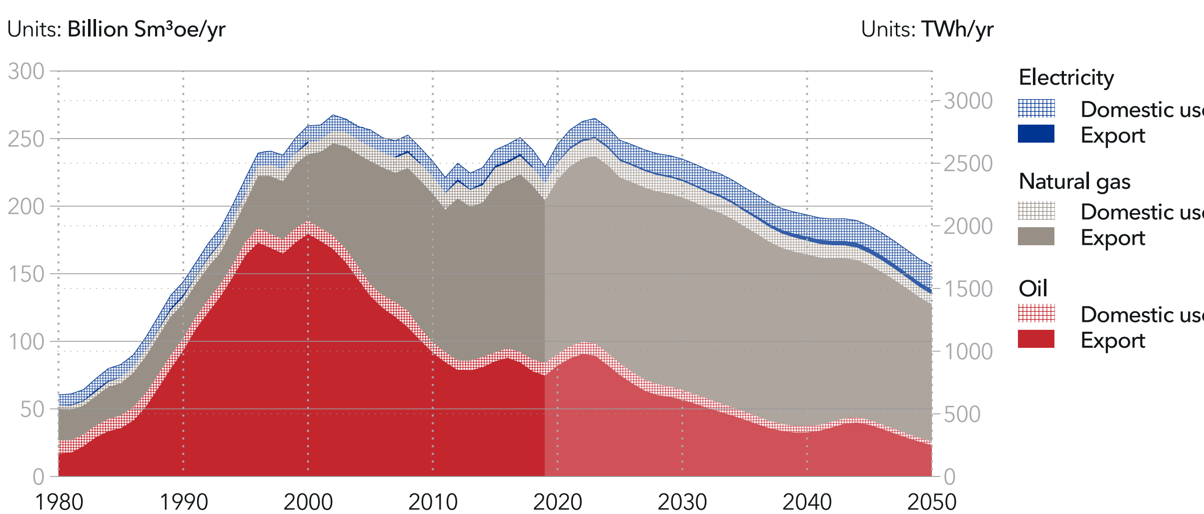
Our modelling through to mid-century shows Norway's 2050 GHG emissions then being 68% less than in 1990, while the Norwegian government's stated ambition is to reduce emissions by 90-95% by mid-century.

Norway's energy system will remain unique compared with those of other countries
Norway's energy system differs from most other countries' in several ways. It has abundant natural energy resources and a relatively small population; a large energy export; and a power sector already among the most decarbonized globally.

Norway is the world's fourth largest gas exporter, the eleventh largest oil exporter, and almost 90% of its petroleum production is exported (Figure 2). We see its gas production remaining at present

FIGURE 2

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs. Historical data source: NPD (2019), IEA WEB (2019) levels until around 2040 then declining gradually. Norwegian oil production declines after 2025 due to reduced global demand for oil, to run at half today's level in the 2040s. In 2050, the majority of energy exports will still be gas and oil; Without an aggressive expansion policy, electricity export will amount to less than one tenth of annual oil and gas export revenue by the end of the forecast period.

The current 45% share of electricity in Norway's energy demand is among the highest in the world, and will grow to 61% by 2050. Norway's electricity comes almost entirely from hydropower. Even with growing electricity demand, hydropower's share of Norwegian electricity supply is likely to remain well above 70% through to 2050, with additional renewable sources, mainly onshore wind, supplying the rest. Electricity generation from floating offshore wind (FOW) will grow, particularly after 2030 (Figure 3). Unlike hydropower and onshore wind, offshore wind power will mainly be exported.

At just over 10%, the EV share of Norway's passenger vehicle fleet is the highest in the world, with 2020 year-to-date EV sales accounting for 50% of new vehicle sales (Figure 4). With current policies we predict this will rise to 82% in 2025 and 91% in 2030. Electrification of commercial vehicle segments will follow rapidly, reaching 60% of the sales of such vehicles by 2030. We forecast that 13% of commercial vehicles sold in 2050 will be hydrogen-fuelled, but hydrogen fuel cells will remain negligible in the passenger vehicle segment.

Norway is well positioned for technology leadership in the green shift

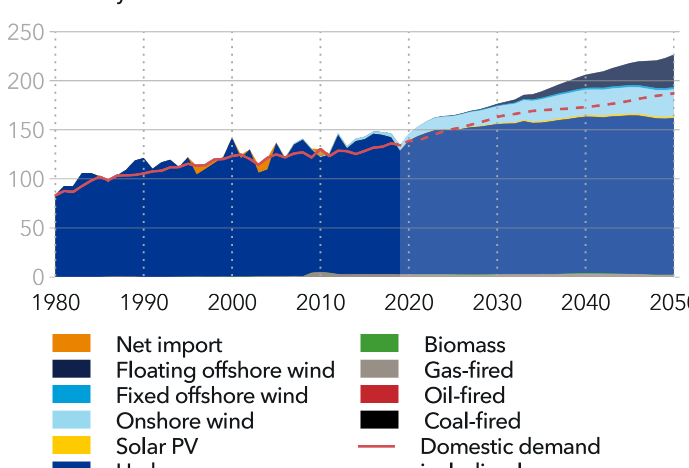
While Norwegian production of gas and oil is forecast to continue, there are also strong growth markets where Norwegian industry and energy players have unique opportunities to play leading roles.

Decarbonizing natural gas will be hugely important to secure the value of Norwegian gas and its industrial base. Our analysis finds that 42% of natural gas used in Europe in 2050 will likely be decarbonized, either as hydrogen or via post-combustion carbon capture and storage

FIGURE 3

Norway electricity supply by power stations and net imports

Units: TWh/yr

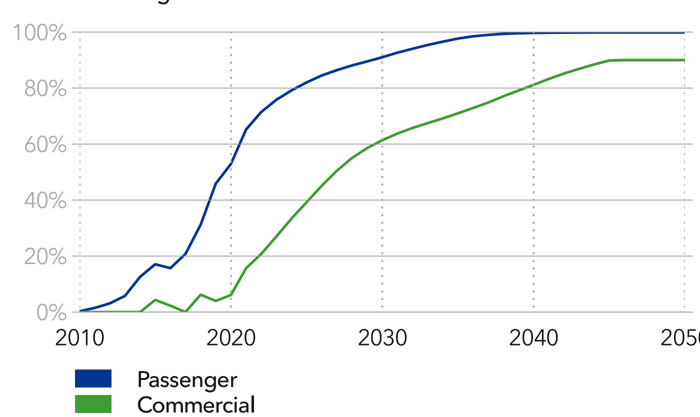


Historical data source: SSB (2020), IEA WEB (2019)

FIGURE 4

Norway market share of electric vehicles in new sales

Units: Percentages



Historical data source: SSB (2020)

(CCS) in power and industrial plants. More than 90% of Norway's gas is exported to Europe. It can either be decarbonized at the final point of use, or on the Norwegian Continental Shelf (NCS) for subsequent export in a decarbonized form such as hydrogen. Conversely, Norway is well positioned to receive CO_2 captured by European industry or power plants and store it in reservoirs under the seabed.

Norway plays an important, global role in maritime transport and innovation. Shipping is a hard-to-abate sector where direct electrification is expected to play only a minor role beyond the short-sea segment. The International Maritime Organization (IMO) and the shipping industry are initiating a massive R&D effort to decarbonize maritime fuels. Norway has extensive experience and a lead in LNG, batteries, and hydrogen for domestic short-sea shipping. Extending this leadership into research and piloting and development of low- and zero-carbon fuels and related infrastructures for deep-sea shipping is a promising opportunity.

Norway is also well positioned for a leading role in FOW power production. Hywind Tampen in the North Sea will be the world's largest FOW development when it is commissioned in 2022. DNV GL forecasts that by 2050, the world will install 250 gigawatts (GW) of FOW – corresponding to 3,000 Hywind Tampen fields – of which 7 GW will likely be in Norwegian waters. With its offshore gas and oil experience, Norway has competence in subsea, anchoring, floaters and much of what is needed to take part in developing and scaling FOW. However, it will remain important to have an attractive domestic market to demonstrate technology and capabilities, and to develop the local supply chain.

Political decisiveness is crucial to meet targets and to unleash opportunities

Technological progress enables decarbonization. However, step-changes tend to rely on decisive policy intervention. Individual behavioural change is happening due to the COVID-19 pandemic, but will have limited long-term impact unless further incentivized or forced. Even in combination, technology advances, finance sector support, and pandemic-related behavioural shifts are insufficient to achieve Norway's decarbonization targets. Policy will continue to be pivotal in setting the direction and route of change and to send clear signals to energy-sector stakeholders. Targeted policies and their effective implementation will be decisive for reaching emissions-reduction targets. This toolbox includes public investments for additional R&D, and funding for real-world projects to trigger technology readiness and scale-up.

Policy measures advancing the energy transition come in many forms including economic signals – e.g. incentives, fees and taxes – and efficiency standards, mandates, restrictions and bans. Norway can meet its ambitious emission targets only by strengthening policy measures across sectors and ensuring that these are stable and predictable. Such measures will likely have to include instruments that may prove unpopular, or which can only be settled by ballot.

Industrial development policies will also be instrumental for unleashing industry opportunities in the green shift. For example, to lead in offshore wind, Norway will need to run ahead of 'normal' business development reliant on global shifts in finance and advances in technology. Building a domestic industry will require opening up the policy toolbox to decide how best to support technologies at various stages of maturity, and to stimulate market and supply-chain creation through projects that enjoy the enthusiastic buy-in of local communities.

1 INTRODUCTION

1.1 ABOUT THIS FORECAST

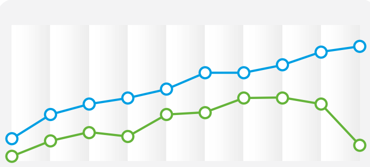
This Energy Transition Norway (ET Norway) report describes the energy future of Norway through to 2050. The analysis, the model framework behind it, the methodology, the assumptions, and hence also the results lean heavily on DNV GL's global forecast, Energy Transition Outlook 2020 (DNV GL, 2020a) and Energy Transition Outlook (ETO) model. This is necessary since Norway is part of the global energy system, and if we alter parts of the Norwegian energy system, the global system will be influenced. In linking our global forecast to Norway's energy system, we have had to make several adjustments. Not all global, or even regional, dynamics are equally valid when we apply them at country level. The ET Norway analysis produces a single 'best-estimate' forecast of the likely energy future, taking into account expected developments in policies, technologies and associated costs, as well as some behavioural changes.

The forecast also provides a basis for assessing whether Norway is likely to meet its energy and climate-related targets. A high-level summary of DNV GL's approach is shown below.

In this report we do not repeat all the details on methodology and assumptions from the Energy Transition Outlook 2020 (DNV GL, 2020a), but refer to that open report for further details.

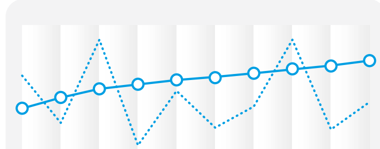
We are also mindful that this analysis has been prepared in the midst of the COVID-19 pandemic, which adds uncertainty to several parameters of relevance to the energy transition, including GDP, policy interventions and behavioural changes.

The basis for our forecast is DNV GL's ETO model, which provides a forecast on the global energy system and for 10 world regions. The model is an independently developed integrated system-dynamics simulation. It incorporates the entire energy system and reflects relationships

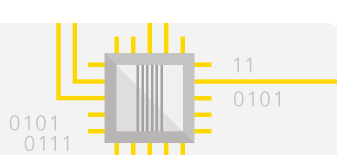


Our **best estimate**, not the future we want

A single forecast, not scenarios

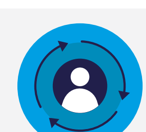


Long term dynamics, not short-term imbalances



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 between demand and supply – from source to end use and trade of energy – simulating how components interact. Model results cover the period from 1980 to 2050. A more complete description of the model is given in Energy Transition Outlook 2020 (DNV GL, 2020a).

To tailor the model for this project, we added Norway as a standalone region by splitting region Europe into two regions: 'Norway' and 'Europe-without-Norway'. In this way, we derive separate forecast results for Norway along with the other 10 regions.

For this project we have also added a module to the model to accommodate power trade. In the global model, only oil, gas and coal are traded between the regions, as cross-regional trade in power is assumed to be low. However, such trade is more common at the country level and within regions. A module calculating exchange between Norway and Europe has been added because import and export of power is an important dynamic in Norway's energy system.

1.2 ASSUMPTIONS AND POLICIES

Key input assumptions in the ETO model are in the areas of population, economic development, technology development and policy.

Population
We use the research and results from Wittgenstein Centre for Demography and Global Human Capital in Austria, rather than UN population data and projections, as the Wittgenstein Centre places more emphasis on future education levels influencing fertility. Female education and urbanization are together driving down fertility rates. Norway's population is forecast to grow from 5.4 million people today to reach 6.4 million in 2050, 3% less than the UN median estimate of 6.6 million.

Economic development
GDP per capita is a measure of the standard of living in a country, and is a major driver of energy consumption in our model.

DNV GL has developed its own GDP forecast model, basing our GDP per capita growth forecast on the inverse relationship between GDP per capita level and its growth rate. This relationship is a result of sectoral transitions that an economy experiences as it becomes more affluent.

At infrequent intervals extraordinary events cause a notably different GDP and productivity change. The present COVID-19 pandemic will cause such a change, with negative growth figures. Our model is not suited for deriving big changes for the next few years to come. We have therefore chosen to deviate from our model and instead use economic growth figures from the Confederation of Norwegian Enterprise (NHO). The GDP change for Norway is therefore assumed to be -2.5% in 2020, and +3.2% in 2021, thereafter returning to the growth rates given by the DNV GL GDP model.

For Norway, 2019 GDP was USD 382bn, while in 2050 it will be at USD 563bn. This implies a CAGR of 1.3% per year, including the effect of COVID-19. Productivity increases from USD 71,000 to USD 88,000 per person in the same period, measured in USD-denominated 2017 purchasing power parity (PPP) terms.

Technology development
DNV GL bases its forecast on the continued development of proven technologies in terms of costs and technical feasibility, not uncertain breakthroughs. During the period covered by this forecast, technologies we currently consider most promising might shift owing to changes in levels of support and varying cost reductions. Other technologies may achieve a breakthrough, such that they become cost competitive.

With technology learning curves, the cost of a technology typically decreases by a constant fraction with every doubling of installed capacity. This 'cost learning rate' (CLR) dynamic occurs because ongoing market deployment brings greater experience, expertise and industrial efficiencies, as well as further R&D. Technology learning is global, and it is the global installed capacity that is used in CLR calculations.

CLRs cannot easily be established for technologies with low uptake and which are still in their early stages of development. In such cases, calculations rely instead on insights from similar more mature technologies. CCS (other than that used in enhanced oil recovery) and next generation electrolysis are examples of this. Solar PV, batteries, and wind turbines are proven technologies with significant grounds for establishing CLRs with more confidence. Further down the experience spectrum are oil and gas extraction technologies where unit production costs and accumulated production levels are high and easy to establish. However, hydrocarbons face pressures from the structural decline in oil demand in tandem with rising extraction costs and carbon prices. It is virtually impossible to disentangle these two effects using costs and volumes alone; we therefore use historical datasets to separately estimate CLR and depletion effects.

For all technologies, it is necessary to separate out the cost of the core technology, for example solar photovoltaic (PV) panels, from supporting technologies, i.e. control systems and installation kits. Typically, the latter have a lower CLR. For PV, core technologies have CLR of 28%, while balance of supply has only 9%. For some technologies, like batteries, the core technology is almost all there is, and so the highest CLR dominates. For other technologies, like unconventional gas fracking, other cost components dominate.

Core technology CLRs that we have used through to 2050 in our forecast include 19% for batteries, 16% for wind and 28% for solar PV, falling to 18% later in the period. Oil and gas development has a CLR of 10-20%, but the annual cost reduction is minor because it can take decades for the cumulative installed capacity to double.

Policy

A wide range of policy objectives – such as climate goals, air quality, health, job creation and energy security – will drive changes in policies, in turn effecting change in the energy system.

In our global model, country-level data on expected policy impacts are weighted and aggregated to produce regional figures for inclusion in our calculations. In our model, we incorporate existing and likely future policy factors for Norway.

It is not a given that energy or climate ambitions and targets will be met, either on a national, regional, or global level. As such, our forecast does not assume that Norway will accomplish its latest (February 2020) NDC submission raising the country's emissions reduction ambition to at least 50% and towards 55% compared with 1990 levels by 2030. Instead, the degree of achievement of this target is a result of our forecast.

Targets and ambition levels may or may not be translated into real policy – and in the Norwegian context, there are numerous examples of goals and targets not being met. On the other hand, ambitious targets are often followed by specific policy measures that translate ambitions to reality which influence the emissions trajectory.

From the main ETO report (DNV GL, 2020a) we have a comprehensive list of the policy factors influencing the forecast. The same policy factors are incorporated in this analysis with the following adjustments for Norway:

1. Renewable power support

– Floating offshore wind projects will obtain financial support to supply Norwegian energy demand and establish a home market of projects. As cost declines and the share of electricity produced is increasingly exported to Europe with higher profitability, financial support declines towards 2050.

2. Zero-emission vehicle support

– The support schemes for passenger EVs are continued in present form until 2025 and then gradually removed.
– The support schemes for EVs in the commercial vehicle segment will continue as today and then grow slowly from the late 2020s, until reaching 13% of total cost of ownership in 2040.
– The support scheme for hydrogen vehicles will help uptake of fuel cell electric vehicles (FCEVs) based on hydrogen from the early 2030s as production of hydrogen becomes viable, to reach a final share of 13% in the commercial vehicle segment by 2050.

3. Carbon capture and storage

- The Langskip project with CCS from Brevik is included with phase-in from 2024/2025. Also included is CCS at Klemetsrud with phase-in from 2026/2027.
- The CCS operations at the Sleipner and Snøhvit fields on the NCS are expected to be phased out. The carbon captured at Sleipner is not expected to be replaced by an alternative operation. However, we expect that CO_2 will need to be removed at LNG liquefaction installations, thus replacing CO_2 captured at Snøhvit, where operations will be phased out in the late 2030s.
- All other CCS will be developed on a commercial basis.

4. Carbon price

- Carbon prices are reflected as costs for fossil fuels in the power and manufacturing sectors. In these areas Norway is part of the EU emissions trading scheme (ETS), and carbon prices equivalent to rest of Europe (reaching USD 80/t CO_2 in 2050) are used.
- In other areas of the model, e.g. transportation and buildings, carbon price is not used directly, and taxation of fuels, energy, and carbon is incorporated.

5. Fuel tax

- Fossil fuel tax increases at a quarter of the carbon-price growth rate.

6. Power capacity limitations

- Norway is unlikely to add large capacity additions for onshore wind, hydropower or solar PV for export – even if profitable.
- For offshore wind (bottom-fixed and floating), we do not expect any similar power capacity limitations, and capacity will be added when profitable, also for export.
- Norway is expected to add generating capacity to support increasing demand for domestic energy use. Since hydropower and wind production varies annually, Norway will accept the need to add capacity to maintain a surplus of 10% above average demand levels.
- For exporting electricity, we expect a planned 2.8 GW expansion of transmission capacity to Europe to be installed by 2021. Further transmission capacity of 3.5 GW is assumed to be gradually introduced in the latter part of 2030s.

2 ENERGY DEMAND

Energy consumption is dependent on a supply and demand balance, but Norway has enough energy resources to supply domestic energy demand and also export to other regions. This chapter describes the domestic demand for energy within transport, buildings, manufacturing, feedstock and other sectors.

Historically, energy demand has grown in lock-step with population growth and improvements in standards of living. Norway's population growth will slow, but still reaches 6.4 million people in 2050. Economic growth will average 1.3% per year from 2019 to 2050, when the size of the Norwegian economy will be 47% higher than today's USD 382bn.

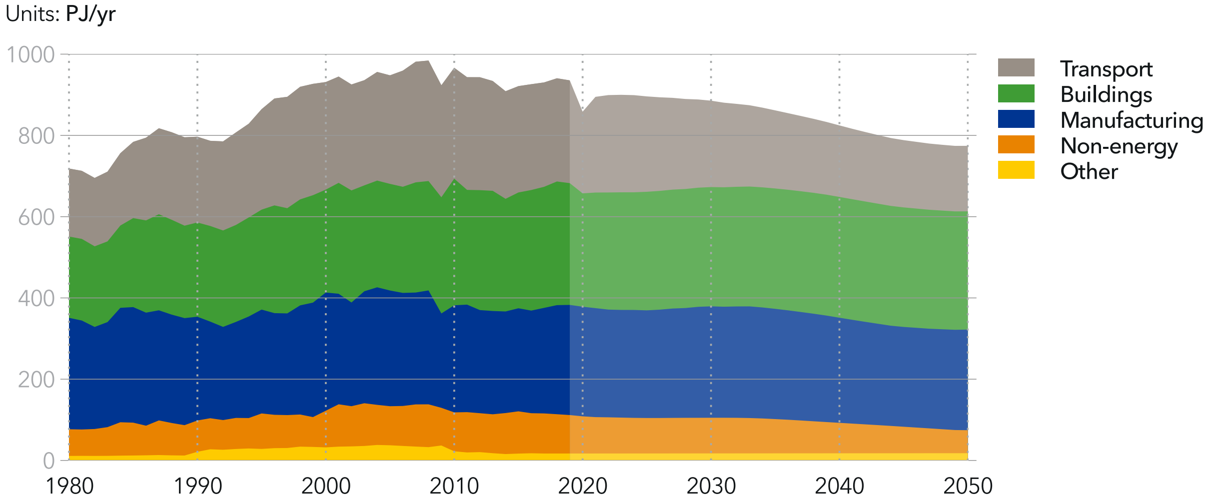
More people requiring more energy services for transportation, heating, lighting or consumer goods typically means increased energy demand. This held true until around 2008. Up to that point demand grew despite impressive developments in energy efficiency, achieved by, for example, advances in lighting and heat-pump technologies.

After 2008, the growth/energy dynamic changed, and this will characterize the coming decades too. We forecast that efficiency gains – largely enabled by accelerated electrification – will continue to outpace economic growth. A major drop in energy

FIGURE 2.1

Norway final energy demand by sector

Units: PJ/yr



Historical data source: IEA WEB (2019), SSB (2020) demand in 2020 due to the COVID-19 pandemic will be followed by a slight pick-up in 2021. However, energy demand will gradually drift downwards to 2050. This is illustrated in Figure 2.1, where the COVID-19 effect on energy demand can be clearly seen, strongest in transport and least in manufacturing energy use.

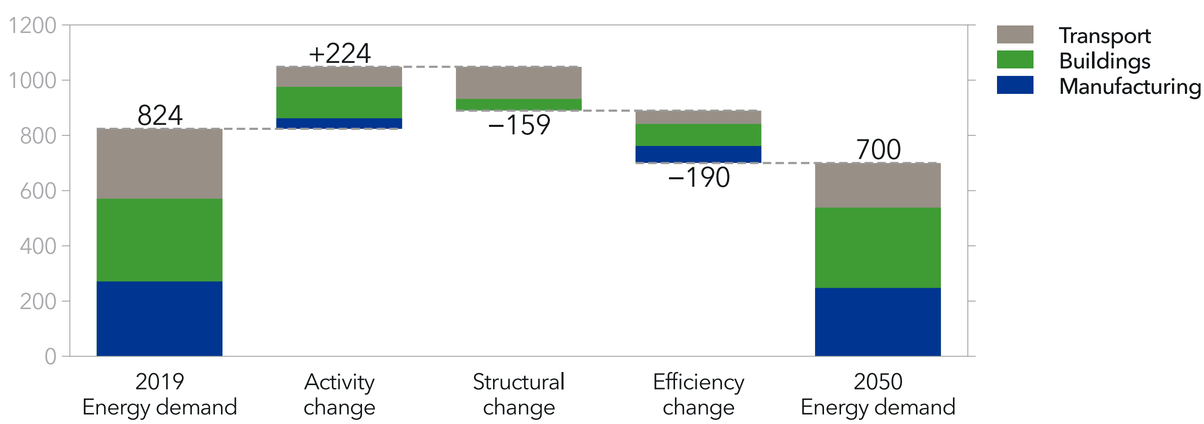
Energy efficiency is the key driver of the transition over our forecast period. It is also usually the most cost-effective measure to reduce emissions and should be at the top of the list when authorities and companies consider emission mitigation options. For many countries, the main drivers of energy-efficiency improvements include the electrification of the energy system, and the rapidly growing share of renewables in electricity generation, eliminating enormous heat losses. Because hydropower supplies much of Norway's electricity, such gains are limited, but electrifying gas and oil production will improve efficiencies. Efficiencies come not only in the supply of energy, but also in how it is used. Electrifying end-use demand, such as already seen with the uptake of EVs in the passenger vehicle segment, yields further efficiency gains. The biggest improvement is expected in road transport where EVs will continue to edge out less-efficient ICE vehicles. Other measures raising efficiency in demand sectors include appliance switching, increasing insulation through improved building standards, and uptake of heat pumps for both residential buildings and low-heat manufacturing processes.

Figure 2.2 shows how Norway's energy demand in 2050 is significantly influenced by efficiency gains and expected structural changes. All sectors will experience activity change that increases demand, where population and economic activities require delivery of greater energy services. The net effect of structural changes – particularly the electrification of road transport – is a considerable reduction in energy demand. On top of this comes efficiency changes, such as insulation, meaning that 2050 energy demand for the three main sectors will be slightly lower compared with present energy demand levels.

FIGURE 2.2

Norway energy-efficiency developments in the main demand sectors

Units: PJ/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, e.g. heat pumps (buildings)
Efficiency changes include: battery and ICE efficiency gains (transport); equipment efficiency improvements (buildings); more efficient processes (manufacturing)

2.1 TRANSPORT

The transport sector has seen significant pandemic-associated reductions in energy demand during 2020. Transport – including road, rail, aviation and maritime – accounted for 27% of Norwegian final energy demand in 2019, mainly in the form of oil as fuel (82%). We forecast that overall energy demand will decline almost 36% from 253 petajoules (PJ) in 2019 to 161 PJ by 2050 (Figure 2.3).

Passenger and commercial vehicles together are the largest source of energy demand, consuming 54% of total energy demand in 2019. With road transport set to be largely electrified by 2050, its share in energy demand reduces to 46%. Overall, the transport sector's transformation will include oil's share in its fuel mix dropping from 82% today to 29% in 2050 as electricity and low-carbon fuels come to dominate. The other three transport subsectors modelled are not improving efficiency to the same degree.

Road

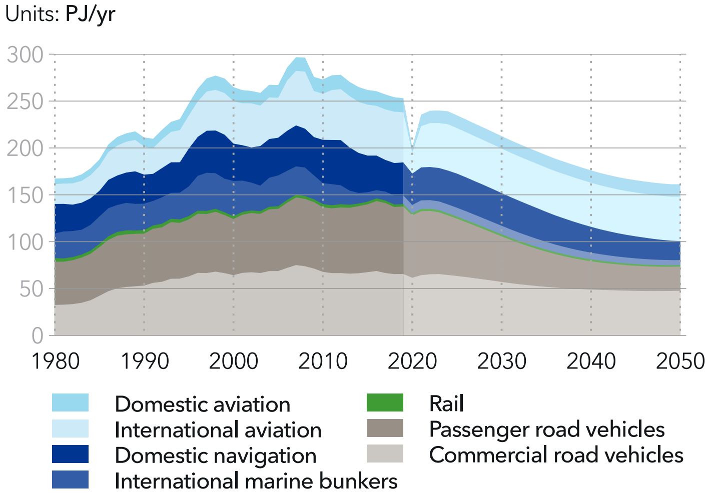
We envisage policy targeting emissions reduction from road traffic to continue with significant incentives (purchase and operation) to companies and private individuals encouraging switching from ICE vehicles to EVs. Over time, battery cost-learning rates will render such policies superfluous – at least in the road sector. Vehicle manufacturers are increasingly overhauling their strategies to cope with the looming market dominance of battery EVs in the passenger segment, driving uptake and further lowering cost. For most uses, EVs will soon become more cost effective than ICEVs; EVs typically consume less than a third of the energy that ICEVs do, and cost much less to maintain.

However, battery electric vehicles (BEVs) uptake hinges in the near term on continued policy support, and the forecast includes a significant level of such support – with exclusion from Norwegian value added tax (VAT), and other benefits, continuing at present levels until 2025,

FIGURE 2.3

Norway transport sector energy demand by subsector

Units: PJ/yr

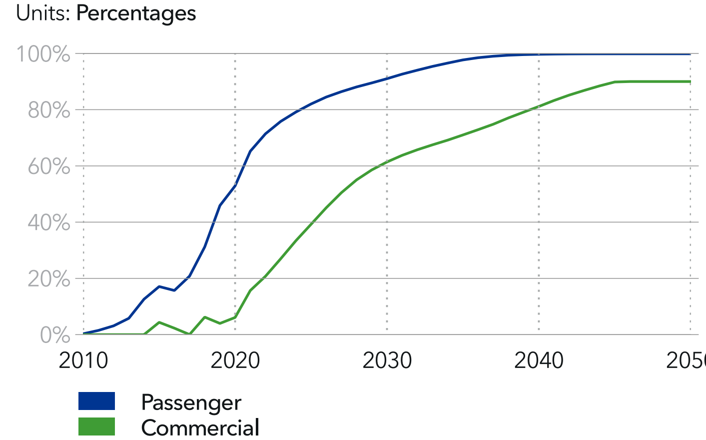


Historical data source: IEA WEB (2019), SSB (2020)

FIGURE 2.4

Norway market share of electric vehicles in new sales

Units: Percentages



Does not include hybrids and plug-in hybrids. Historical data source: SSB (2020) then gradually being halved by 2030. EVs will account for 82% of new passenger vehicle sales in Norway in 2025, and 91% by 2030 (Figure 2.4). EV uptake will be somewhat slower for commercial vehicles, which includes everything from smaller trucks and utility vehicles to municipal buses and long-haul heavy road transport. Battery cost and driving range are the key determinants in the competition between batteries and ICEs, and hence on the electrification opportunities of various vehicle segments. We expect 10% of commercial vehicles to continue to use a mix of fossil- and bio-based fuels in 2050.

Norway leads the world in electrifying passenger-vehicle transport, and we forecast a 50:50 split between EVs and passenger ICEVs on the road by 2030. This split is not achieved for commercial vehicles until the late 2030s (Figure 2.5). It is also noteworthy that we do not see the total number of vehicles in Norway growing significantly between now and 2030. By the mid-2030s, car-sharing and automation will start to make an impact and will slowly reduce the total number of vehicles to about 3 million by 2050, 10% less than today.

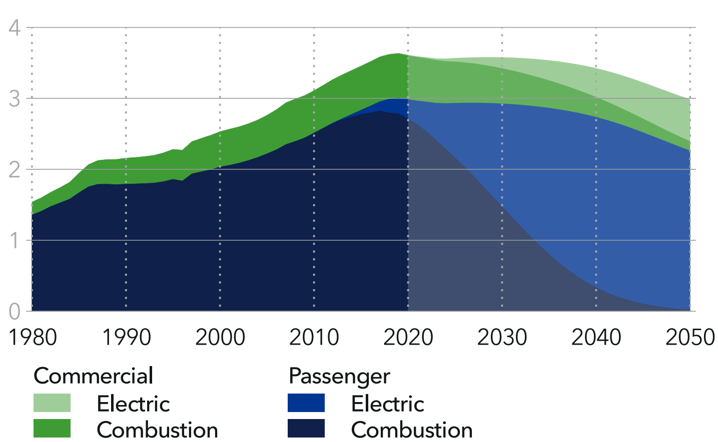
While the number of vehicles will decline, their utilization will be higher, so neither the related energy services required, nor the total number of kilometres travelled will necessarily reduce. Total kilometrage will increase 20% by mid-century. A similar dynamic is anticipated for commercial vehicles, but the number of vehicles in this segment will expand by about 15% towards 2050. However, even with this uptick in vehicle growth and the overall demand for vehicle-kilometres driven rising, Norway will not experience a similar growth in energy demand.

Figure 2.6 shows road transport energy demand declining 46% from 138 PJ in 2019 to 74 PJ in 2050, mainly because of the shift from ICEs to electric drivetrains. The subsector's energy demand for oil declines 87% while demand for

FIGURE 2.5

Norway number of road vehicles by type and drivetrain

Units: Million vehicles

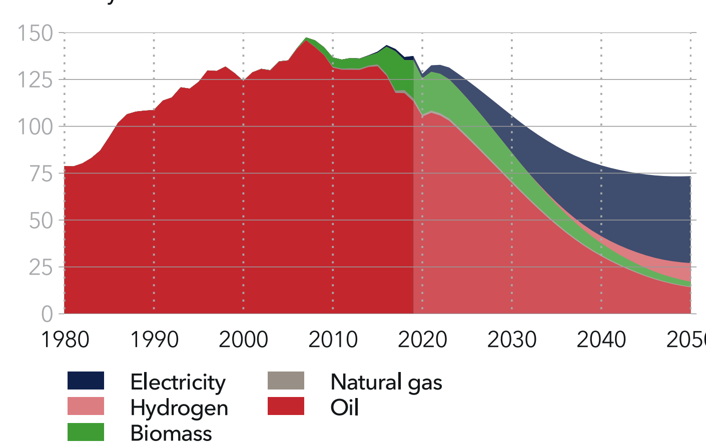


Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs. Historical data source: SSB (2020)

FIGURE 2.6

Norway road subsector energy demand by carrier

Units: PJ/yr



Natural gas includes LPG. Historical data source: IEA WEB (2019), SSB (2020)

energy from electricity grows almost 20-fold. Note how, in 2050, electricity supplies transport services way above its two-thirds weight as an energy carrier.

Aviation

Aviation has grown strongly in recent decades but levelled off since 2010. A dramatic reduction in air travel due to COVID-19 will see the subsector's energy demand fall by more than 60% in 2020. Longer term, the number of air trips is forecast to increase compared with 2019. However, fuel use will remain virtually flat due to energy-efficiency gains from higher load factors and developments in engines and aerodynamics. About 80% of the subsector's energy demand in Norway is for international aviation, which we expect to continue using traditional combustion engine technology. The remaining 20% is for Norwegian domestic aviation, and part of that is well suited for electrification, and could be a front-runner globally in the electrification of short-haul flights.That said, we forecast that sustainable aviation fuels (SAF), particularly biofuel blends, will be the main contributor to aviation emission reductions, especially for international and long-haul flights. Which low-carbon or zero-carbon solution, or mix of fuel solutions, will dominate is not yet known. By 2050, half (31 PJ in energy terms) of Norwegian aviation's fuel mix will still depend on oil, but the share of biofuels will increase to 31% (19 PJ) and electric aviation will account for 18% (11 PJ) as Figure 2.7 shows.

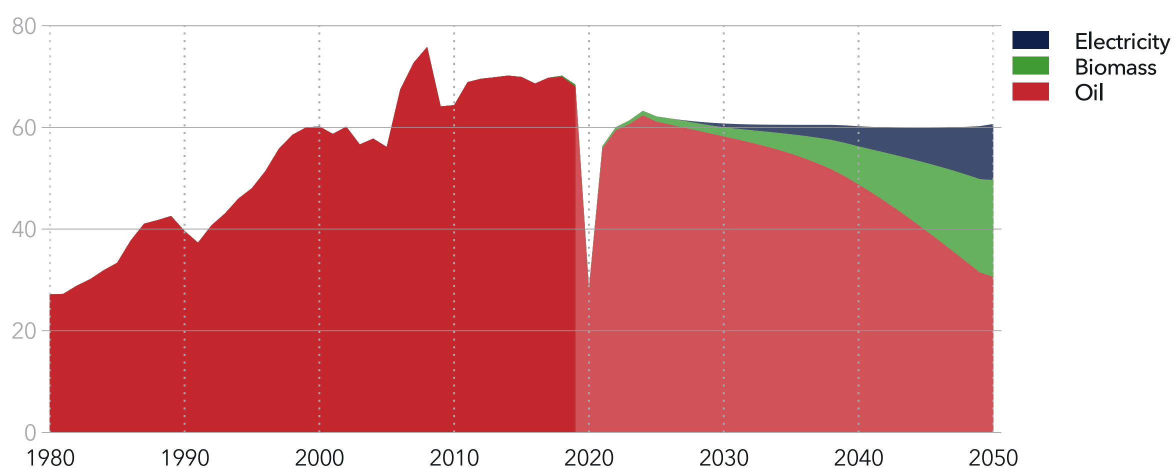
Maritime

Maritime transport is by far the most energy-efficient mode of transport in terms of energy/tonne-kilometre. Almost 3% of the world's final-energy demand, including 8% of the world's oil, is consumed by ships today, mainly international cargo shipping. Norwegian energy demand from maritime activities consists of domestic shipping demand as well as energy demand from international ships bunkering in Norwegian ports. In 2019, the total demand was

FIGURE 2.7

Norway aviation subsector energy demand by carrier

Units: PJ/yr



Natural gas includes LPG. Historical data source: IEA WEB (2019), SSB (2020)

44 PJ with 80% domestic use. The COVID-19 pandemic is not expected to affect maritime transport significantly, apart from exposed segments like passenger and cruise traffic. After a slight dip in 2020, there will be a quick recovery, but the long-term trend will be a decline in energy demand of 42% resulting in demand of 26 PJ in 2050.

The IMO regulation on global shipping targets a 50% reduction in CO_2 emissions from 2008 to 2050. Our forecast is that a mixture of improved utilization and energy efficiencies, combined with massive fuel decarbonization, and including conversion from oil to gas and ammonia and other low- and/or zero carbon fuels, will enable this goal to be met. Some short-sea shipping and local ferries will use a combination of electric shore power as well as electric propulsion thus increasing the energy demand for electricity, but it will initially be gas and later other low-carbon fuels that contribute as main fuel sources for shipping (Figure 2.8).

Rail

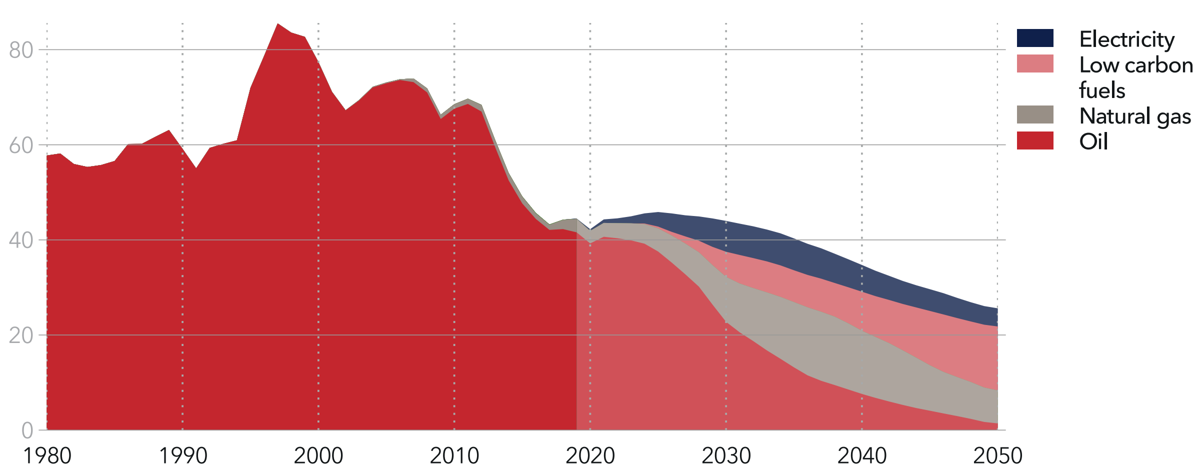
The Norwegian rail subsector consists of all rail-using transportation including urban rail transport, such as subways and trams. Presently, 1% (2.6 PJ) of Norway's total transport energy demand is for rail, of which almost 80% is based on electricity and 20% on oil. Towards 2050, rail will still account for 1% of total transport energy demand, but electricity will rise to 85% of the subsector's energy mix.

> "Norwegian domestic aviation is well suited for short-haul electrification, and could be a front-runner globally

FIGURE 2.8

Norway maritime subsector energy demand by carrier

Units: PJ/yr



Natural gas includes LPG. Historical data source: IEA WEB (2019), SSB (2020)

2.2 BUILDINGS

In 2019, about 32% of Norway's energy was consumed in buildings, making it the largest energy demand sector. Most this energy is used for heating (Figure 2.9), and 57% of the total energy consumption is in residential buildings. 80% of building energy demand is supplied by electricity with the rest covered by equal shares of oil, biomass and direct heat. This mix will not change significantly towards 2050. We estimate final energy demand for five end-uses: appliances and lighting, cooking, space cooling, space heating, and water heating.

Floor area is one of the most important drivers of energy demand in buildings. While an increasing population with higher GDP per capita will push energy demand in the buildings sector upwards, that will be counteracted by increased efficiencies in appliances and heating.

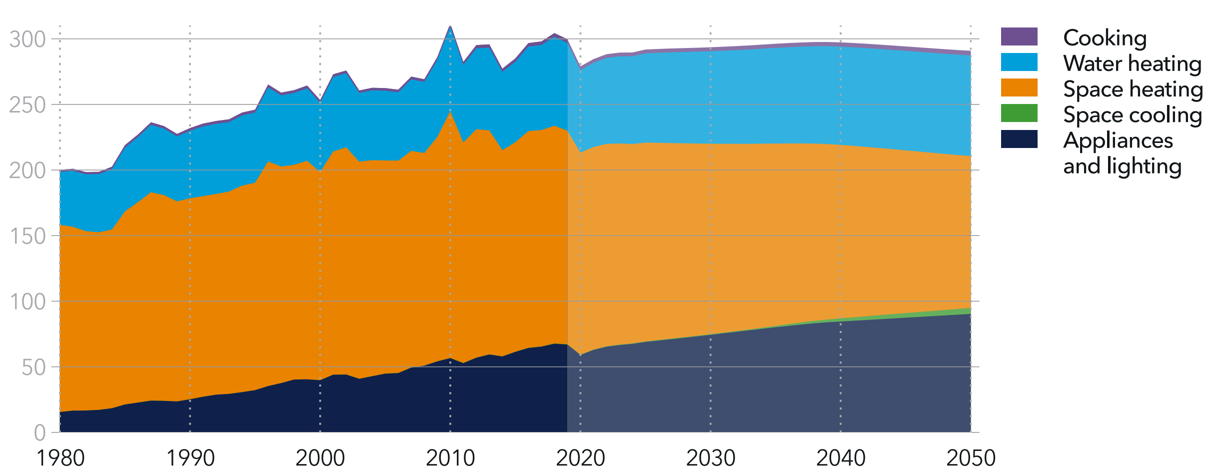
The residential appliances and lighting segment includes everything from reading lights, phone chargers, and computers, to refrigerators, washing machines, and dryers. Despite improvements in energy efficiency for these purposes, historical evidence suggests that, as GDP per capita increases, the electricity use for appliances and lighting per person also rises. Norway is at the high end of this relationship, and high-income levels manifest themselves, for example, in home entertainment systems, second refrigerators or keeping indoor- and outdoor lights on all night. We forecast that energy demand for appliances and lighting for both residential and commercial buildings will grow 34% between 2019 and 2050 (Figure 2.9).

Space heating accounts for 54% of all energy demand and is the segment with biggest expectation of efficiency gains. Buildings heat energy demand will decline 29% from 163 PJ in 2019 to end at 116 PJ in 2050, even while heating a growing number of buildings. A combination of measures will enable this transformation. These include increased insulation, mandatory energy performance certificates and connections to district heating systems, improved automation through digitalization, and greater heating efficiency by phasing out oil-fired heating and widespread use of heat pumps.

FIGURE 2.9

Norway buildings sector energy demand by end use

Units: PJ/yr



Historical data source: SSB (2020), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2019)

2.3 MANUFACTURING

The manufacturing sector consists of all activities from the extraction of raw materials to the conversion into finished goods. However, we do not consider fuel extraction and its conversion to energy as part of this sector. In this forecast, manufacturing covers three separate subsectors based on their energy footprint and demand drivers in the production process – from finished goods to provision of raw materials.

Manufactured goods – includes general consumer goods; food and tobacco; electronics, appliances, and machinery; textiles and leather; paper, pulp, and print; and vehicles and other transport equipment.

Base materials – includes non-metallic minerals (including conversion into cement), chemicals and petrochemicals; non-ferrous materials, including aluminium; and wood and its products. This category also includes energy used in the mining and construction sector.

Iron and steel – includes the production of iron and steel as well as the energy required for the conversion and use of energy for coke ovens and furnaces used in the steel manufacturing process.

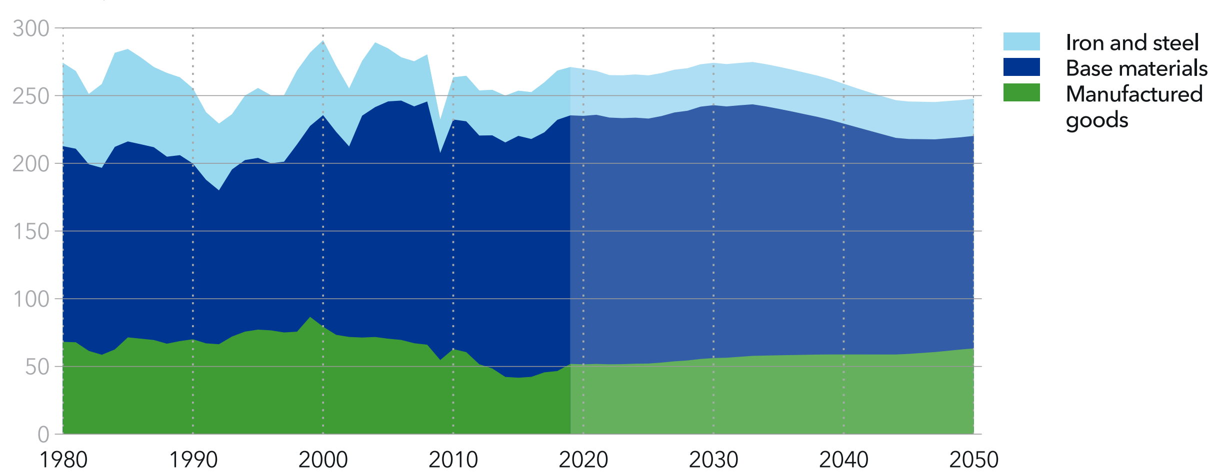
The demand for manufactured goods is assumed to be proportional to each region's GDP. The global supply of manufactured goods is then balanced in our model to match each region's capacity to produce the required manufactured goods, based on the size of the region's secondary (industrial) sector. In our analysis, we have mapped the share of the secondary sector of the economy from historical records and then extrapolated that trend into the future. A detailed description of the global demand and supply model of manufactured goods and associated demand for raw materials can be found in ETO 2020 (DNV GL, 2020a).

Norway's manufacturing sector consumed 270 PJ in 2019, 29% of the country's final energy demand. Base materials represented 67% of total manufacturing energy demand (Figure 2.10).

FIGURE 2.10

Norway manufacturing energy demand by subsector

Units: PJ/yr



Historical data source: SSB (2020), IEA WEB (2019)

Energy demand for the manufactured goods subsector is expected to grow towards 2050, due to growing overall goods demand driven by GDP growth. A large share (68%) of the final energy here is used for heat. Most of the remaining 32% is to operate machines, motors and appliances (MMA). Driven by automation and digitalization, energy demand for MMA in the manufactured goods subsector will also grow towards 2050 (Figure 2.11).

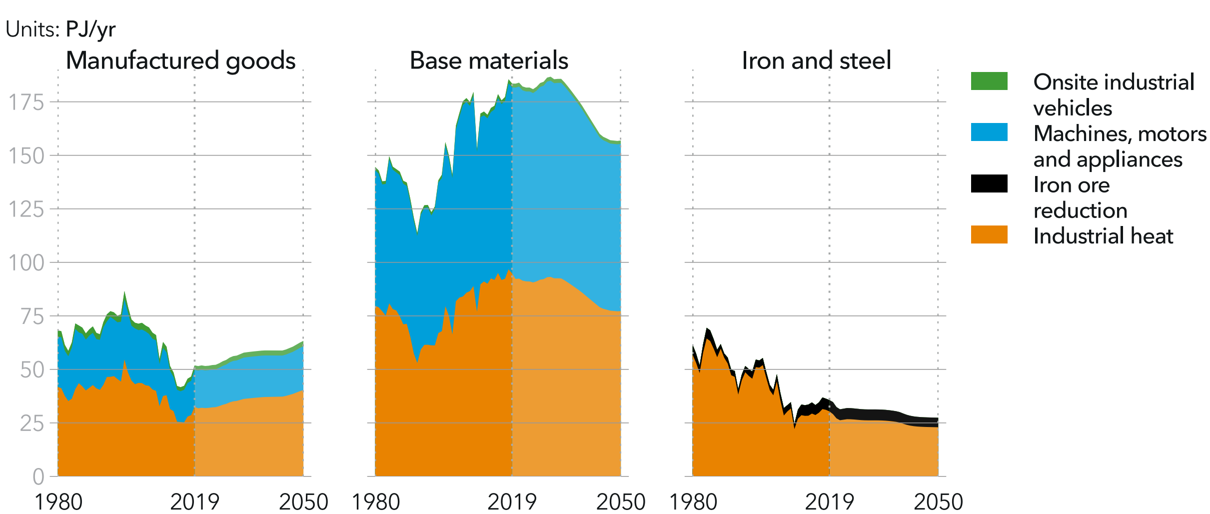
Energy demand for the base materials subsector was 184 PJ in 2019. It is energy intensive in its conversion of raw materials into feedstock for other industries. Much of the energy use is more or less evenly divided between industrial high-heat processes (52%) and operating MMA (Figure 2.11). COVID-19 appears to be having a limited effect on the subsector's energy demand in 2020. Demand is expected to remain around similar levels to today before growing to a peak in 2030 then steadily declining to 160 PJ in 2050. This reduction of 15% compared to today's level is driven by increasing efficiencies in heating and from reuse of already-processed materials rather than extracting and processing virgin raw materials; secondary-production processes require much less high-grade heat. Aluminium made from recycled material requires 95% less energy than producing it from bauxite (Hydro, 2020), for example.

85% of the Norwegian iron and steel sector's current energy demand is for heat, the rest being for reduction agent or additive during steel production. Increasing shares globally of recycled steel in steel production will reduce the need for new virgin iron ore. When combined with stagnating growth in developing countries triggering a plateau in global steel demand, these effects will reduce energy demand from iron and steel production (Figure 2.11).

Change in the Norwegian manufacturing energy mix is dependent on technological innovation, resources availability, and on policies and

FIGURE 2.11

Norway manufacturing subsectors energy demand by end use



Historical data source: SSB (2020), IEA WEB (2019)

incentives. With 63% of the sector already electrified, further electrification offers only limited efficiency gains, so change between now and 2050 in sourcing energy is likeliest in high-heat processes. From the late 2030s, we expect 'green' hydrogen produced by electrolysis to replace coal and natural gas as energy carriers for manufacturing processes, and to grow rapidly from 2% of the energy mix in 2040 to 13% in 2050. However, electricity will still dominate through to 2050, when it will have a 69% share in the manufacturing energy mix (Figure 2.12).

2.4 NON-ENERGY

In 2019, 15% or 95 PJ of primary fossil-fuel consumption was used for non-energy purposes. This category represents the use of coal, oil, and natural gas as feedstock. Much of the energy in the form of natural gas goes to petrochemicals as the largest consumer (67%) of feedstock, and the rest is oil used in construction and for producing non-metallic minerals (Figure 2.13).

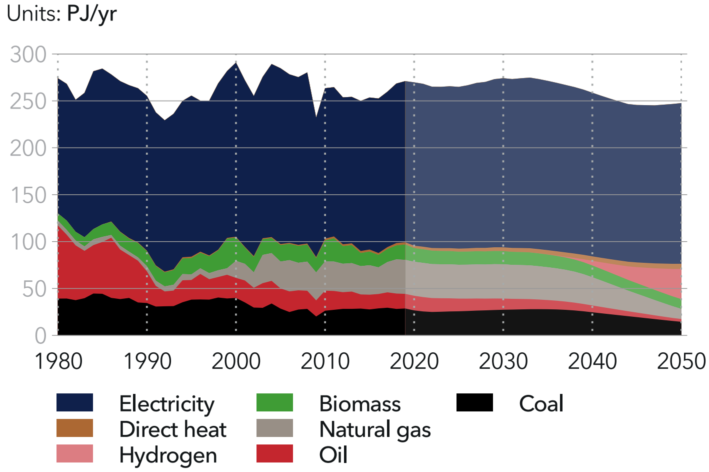
Half of the sector's natural gas consumption was used to produce plastics in 2019, with the rest going to making fertilizers, paints, and other chemicals. We expect plastics to account for about 60% of petrochemical feedstock demand globally by 2050. While demand for plastic continues to grow between now and 2050, recycling grows more rapidly. We estimate Norway's rate of plastic recycling will improve from 25% in 2019 to 74% in 2050. It will be boosted by more efficient (and potentially circular) chemical recycling methods supplementing or replacing traditional, mechanical recycling.

> "For high-heat processes, we expect green hydrogen produced by electrolysis to replace coal and natural gas from the late 2030s

FIGURE 2.12

Norway manufacturing sector energy demand by carrier

Units: PJ/yr

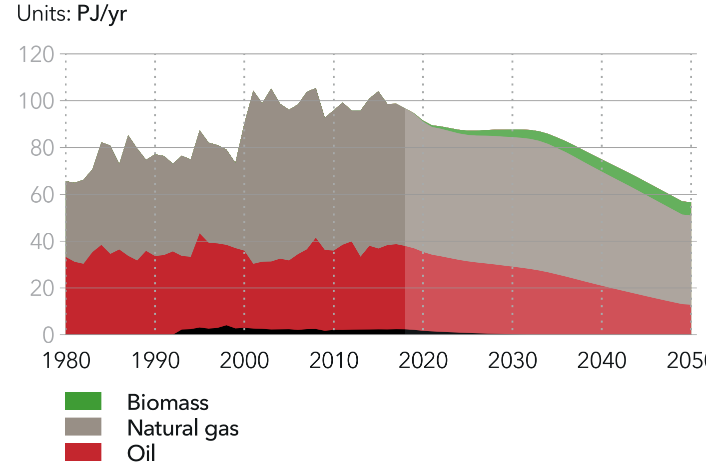


Historical data source: SSB (2020), IEA WEB (2019)

FIGURE 2.13

Norway feedstock demand for energy carriers

Units: PJ/yr



Historical data source: IEA WEB (2019)

2.5 TOTAL DEMAND FOR ENERGY CARRIERS

By combining the energy demand of each of the sectors covered, we forecast Norway's final energy demand by energy carrier, as Figure 2.14 illustrates. 'Final' energy here means the energy delivered to end-use sectors. It excludes energy losses and the energy sector's own use in power stations, oil and gas fields, refineries, pipelines, and in similar ways.

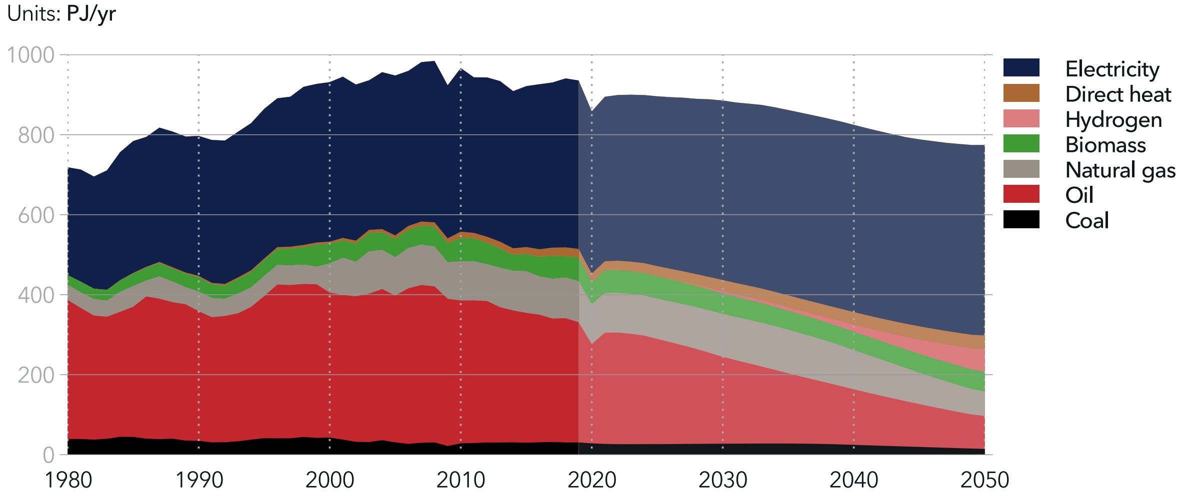
Even for Norway, with one of the world's most renewable energy-based power systems, the ongoing transition will further increase the share of electricity in final energy demand. In 2019, electricity represented 45% (421 PJ/yr) of Norway's final energy use. In 2050, it will account for 61% (476 PJ/yr). Cheaper non-hydro renewables, technological advances, and policy are together driving the steady electrification of Norway's energy demand. A combination of onshore wind, solar PV (on a limited scale), and (eventually) floating offshore wind backed by policy, will support growth in demand for electricity for use in Norway, and for export, which will account for a growing share of the demand.

Electric systems have smaller energy losses than fossil- and biomass-fuelled systems. When technological progress makes electricity available and viable for use in ever-more subsectors and new applications, users will increasingly make the switch. For Norway, the transition to higher shares of electricity in the energy system is driven by decarbonization ambitions in the transport sector, and in gas and oil production. As total energy demand starts to drop, electricity will increasingly replace coal, oil, and (later) gas in the final energy-demand mix. Replacing these sources as energy carriers and feedstock will increase demand for electricity, also amplified by new demand for electricity for electrolysis-based hydrogen production, and in combination this will raise electricity's share in the final-energy demand mix. Total demand and supply of Norwegian energy resources is discussed in subsequent chapters.

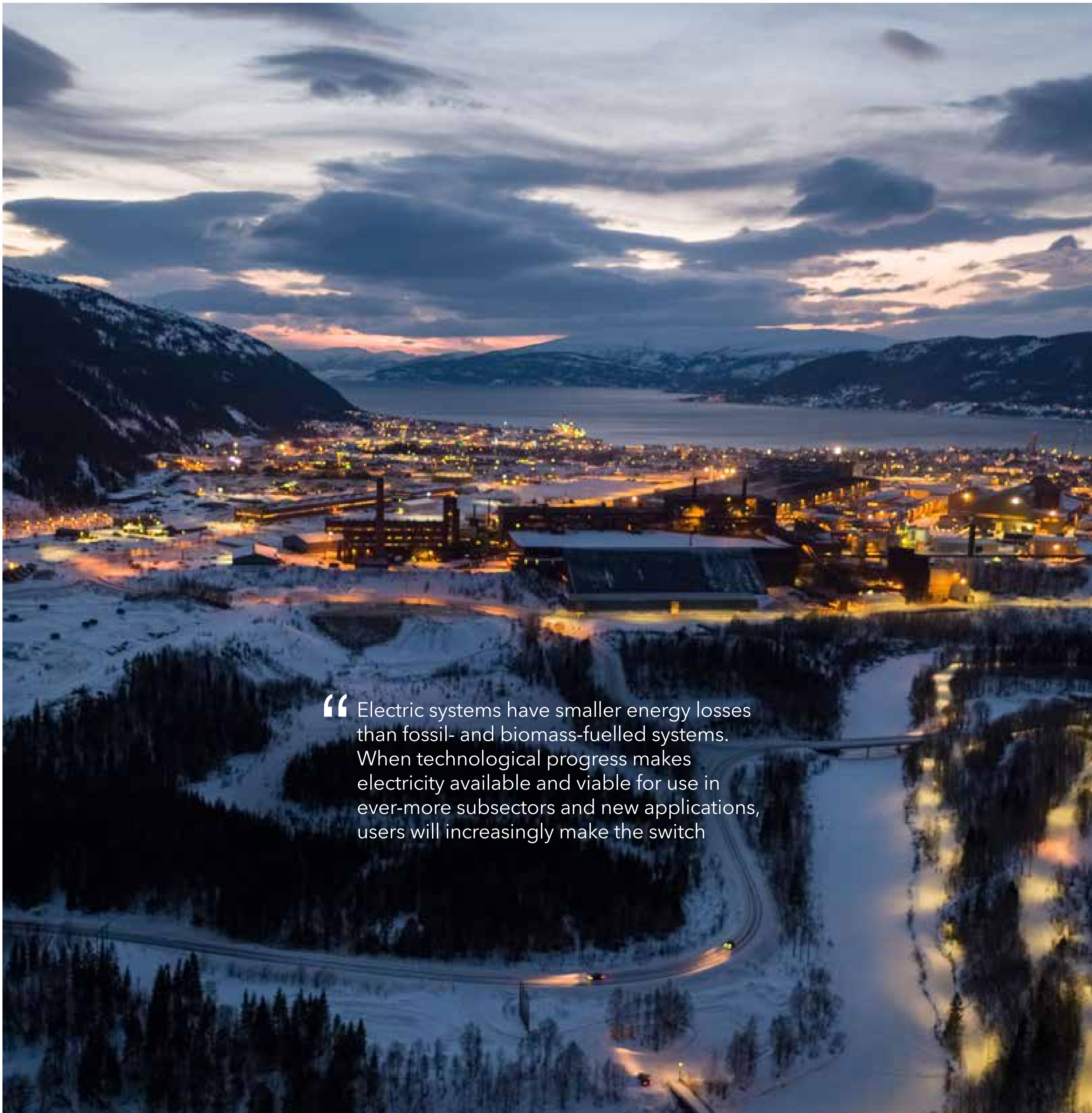
FIGURE 2.14

Norway final energy demand by carrier

Units: PJ/yr

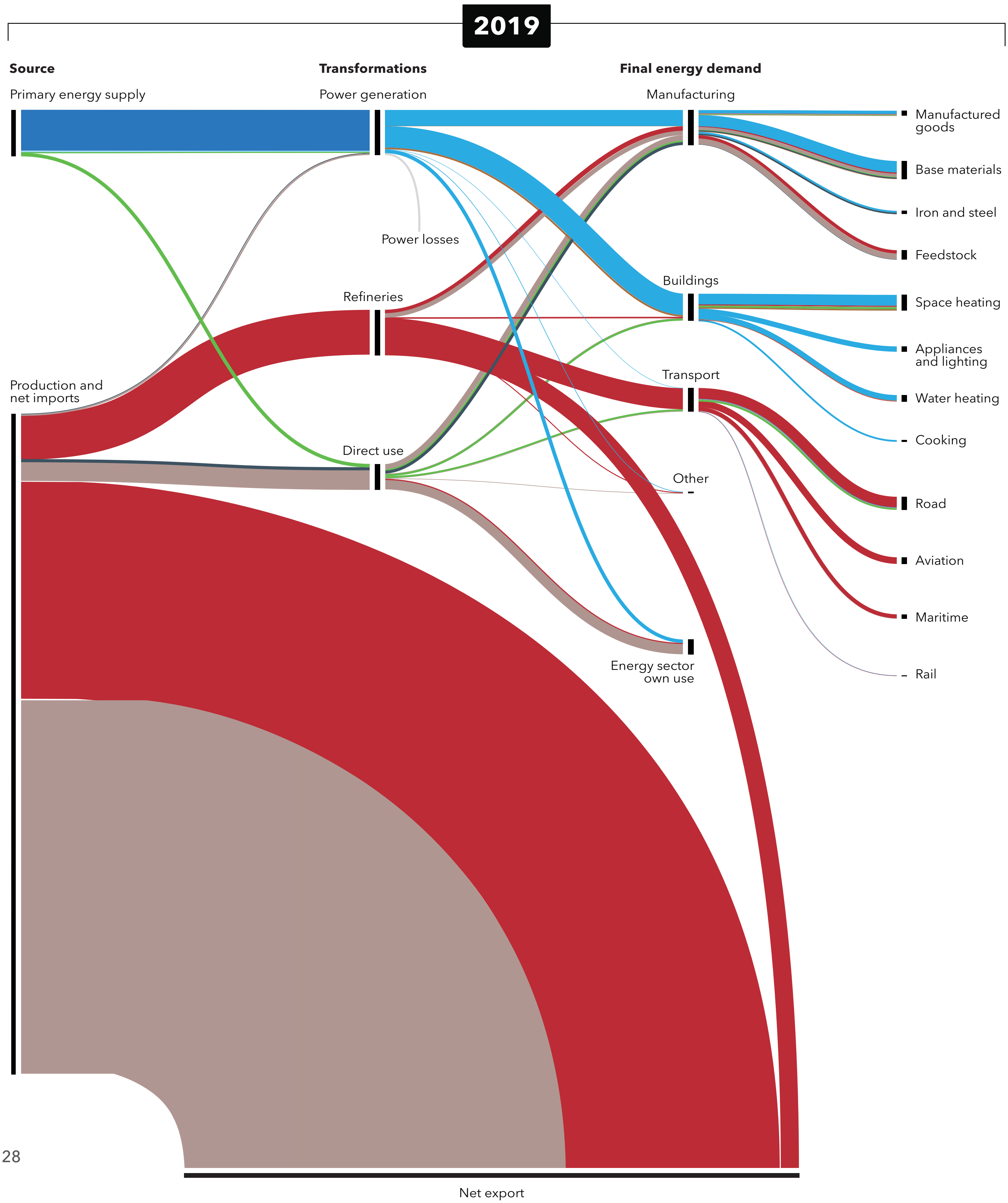


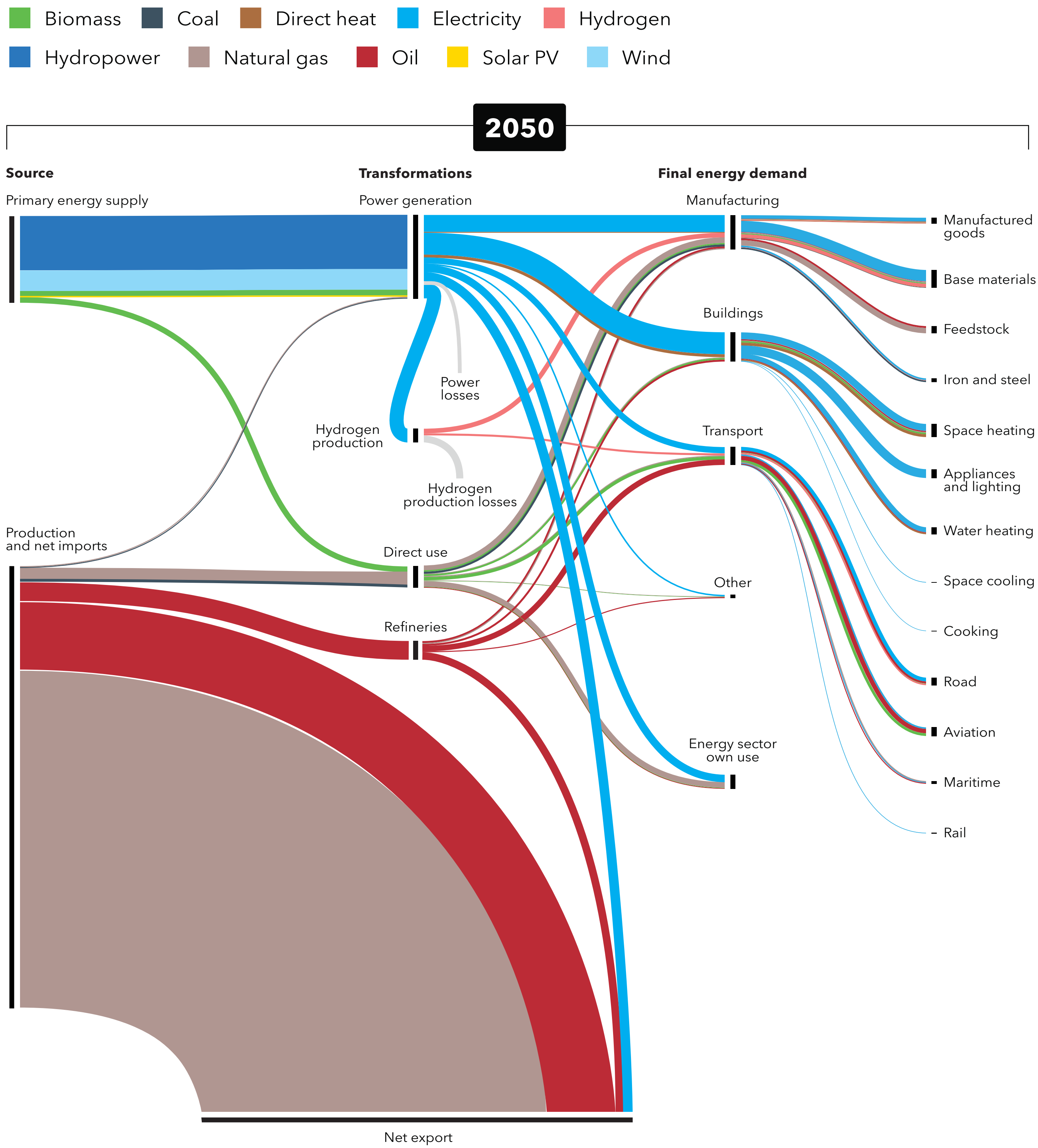
Historical data source: IEA WEB (2019)



> “Electric systems have smaller energy losses than fossil- and biomass-fuelled systems. When technological progress makes electricity available and viable for use in ever-more subsectors and new applications, users will increasingly make the switch

COMPARISON OF NORWAY'S ENERGY FLOWS: 2019 AND 2050





Biomass
Coal
Direct heat
Electricity
Hydrogen
Hydropower
Natural gas
Oil
Solar PV
Wind
2050
Source
Primary energy supply
Production and net imports
Transformations
Power generation
Power losses
Hydrogen production
Hydrogen production losses
Direct use
Refineries
Net export
Final energy demand
Manufacturing
Buildings
Transport
Other
Energy sector own use
Manufactured goods
Base materials
Feedstock
Iron and steel
Space heating
Appliances and lighting
Water heating
Space cooling
Cooking
Road
Aviation
Maritime
Rail

3 ENERGY SUPPLY

We are approaching a future in which the world will need less energy, even as the global population increases and the economy continues to grow. The global energy mix is also changing rapidly. For Norway, this creates challenges for fossil-energy export, but opens opportunities to supply low-carbon electricity to Europe, mainly through existing hydropower and the future expansion of onshore or offshore wind.

Primary-energy supply is the total amount of energy needed to meet energy demand. There are several ways in which to measure primary energy (DNV GL, 2020a). In this analysis, we use the Physical Energy Content Method.

Norway's historical and forecast energy consumption, derived from various primary-energy sources, is shown in Figure 3.1. We forecast that the country's primary-energy consumption will continue to fall through the forecast period, to a level 30% lower than in 2019. The pandemic reduces demand by some 5% in 2020, but consumption will recover in 2021, rising in the early part of this decade before it continues to fall.

In addition to its domestic consumption, Norway exports large amounts of energy, mainly oil and gas, as described in Chapter 4 of this report.

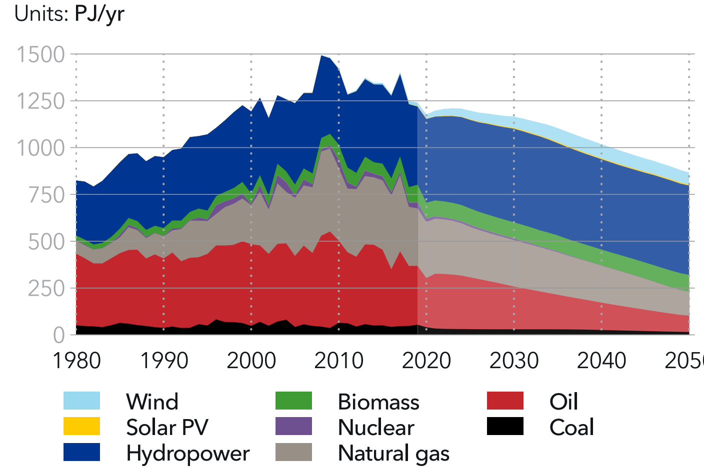
Norway also exports and imports some electricity on a daily and seasonal basis. Apart from exceptionally dry years, the annual balance is a net export, which will only grow in the future with increased interconnector-cables and production capacity. The flow to and from Norway, which is included in Figure 3.1, will thus impact the Norwegian grid mix and includes electricity production from nuclear, for example, as part of the European grid mix.

The domestic energy mix today is mostly electricity- and oil-based, whereas natural gas is mainly used offshore. In our forecast, we see fossil fuels being replaced by renewables, mainly wind and hydropower. By 2050, renewable primary-energy consumption will represent 73% of the domestic energy mix, up from 43% today.

FIGURE 3.1

Norway primary energy consumption by source

Units: PJ/yr



Adjusted for gross electricity trade, using average European electricity mix.
Historical data source: SSB (2020), IEA WEB (2019)

3.1 OIL

For the last 40 years, Norway's domestic oil demand has been on a bumpy ride. Demand declined between 1980 and 2019, from 350 PJ to 310 PJ, with spikes and troughs in between. Historical highs were up to 410 PJ in 2008 and historical lows down to 305 PJ (1983). As Figure 3.2 shows, towards mid-century we forecast a 70% drop in domestic oil demand with a decrease to about 87 PJ. This is similar to developments projected for Europe, where we forecast a reduction of 83% compared with 2019. On a global scale we forecast oil demand to decline gradually to almost half the current consumption level by 2050.

Three quarters of Norway's oil demand is used in transport; the rest is split between non-energy use, particularly as petrochemical feedstock, and other energy use. The transport sector's share of oil demand increased in recent decades from less than 50% in 1980 up to 74% in 2014 when it started to decline. In 2019, half of the transport sector's 223 PJ oil demand was from road vehicles.

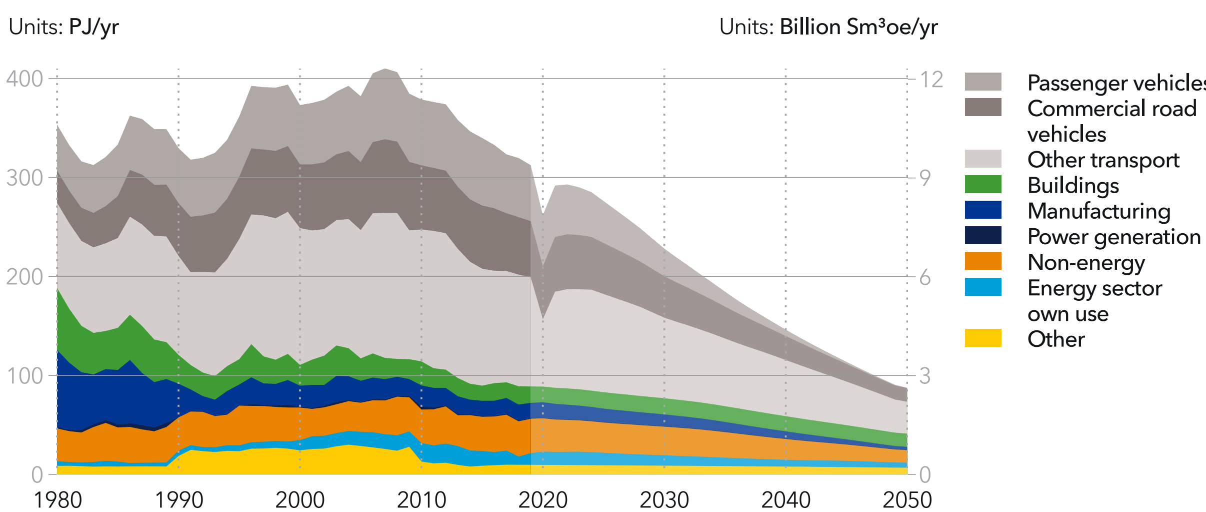
Going forward, passenger vehicles will experience the most extensive conversion to electricity with Norway as a frontrunner in electric mobility. The decline in oil demand from commercial vehicles will be slower. By 2050, the road subsector's oil demand will have reduced by almost 90% compared with 2019, which is a development similar to that in Europe.

Maritime will see an even faster reduction, with less than 4% of current oil demand by 2050. Combined with less overall maritime energy demand, strong growth of alternative fuels for shipping – such as electricity, natural gas, and low-and/or zero-carbon fuels – will drive the reduction. Aviation will be dependent on oil for longer, reducing to 55% of current consumption by 2050. In aviation, synthetic fuels, biofuels, and other low- and zero-carbon fuels, rather than electrification, will drive decarbonization.

Oil demand from buildings, at 5% of total oil demand in 2019, is expected to decline 20% by 2050 due to ongoing electrification of space and water heating.

FIGURE 3.2

Norway oil demand by sector



Historical data source: SSB (2020), IEA WEB (2019)

A very similar outcome is expected in manufacturing. Here, the current 5% share will decline to about 3% by 2050. The main driver here is less oil use in manufactured goods production, especially in industrial heat processes where oil is replaced by electricity.

Norway's offshore oil production has plateaued since 2010 after a decade of strong decline, but will increase slightly through to 2025 (Figure 3.3). Towards mid-century, offshore oil production will decrease as several oil fields are approaching their end-of-life phase (e.g. Ekofisk, Statfjord, Gullfaks, Sleipner Vest, Draugen). Increased global competition in a shrinking market will place downward pressure on oil prices, and relatively few new discoveries are expected to be developed. Reduced oil demand will make it less attractive for the industry to expand production into challenging environments, such as deep water and/or Arctic locations. Globally, as oil fields are depleted faster than global demand for oil declines, continued investment in new capacity is expected, with investments increasingly targeting low-cost production. Thus, incoming capacity will not replace the capacity being shut down. That said, oil production in Norway in 2050, at about 0.5 Mbpd, is still much higher than domestic demand of about 0.07 Mbpd.

As to the effects of the COVID-19 pandemic, we expect a 14% reduction in global crude oil demand in 2020, mainly as a result of impacts on the transport sector (e.g. a major drop in fuel demand in aviation). Our forecast is that global oil demand has already reached a plateau, peaking in 2019, and will never again return to pre-pandemic levels. DNV GL's ETO (DNV GL, 2020a) provides more details on the global dynamics behind this.

3.2 GAS

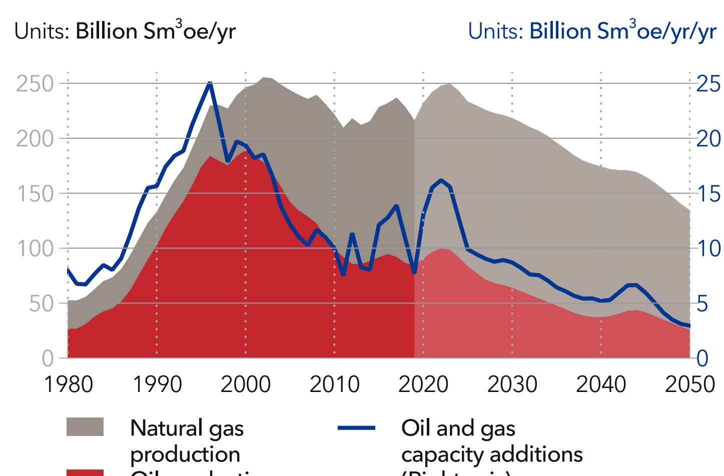
On a global scale, we forecast that world natural gas demand will grow until 2035, surpassing oil to become the largest primary energy source in 2026. Natural gas will retain its status as the largest primary energy source throughout our forecast period, even as demand gently tapers off towards 2050. In Europe, which receives almost all of Norway's gas export, consumption will gradually decline to 60% of the current level in 2050.

Overall natural gas demand in Norway will halve towards mid-century. The main natural gas use in Norway is for the energy sector's own use. Here, consumption peaked in 2015 at 200 PJ. Since then, natural gas consumption has declined and will continue to do so until 2050, reaching 56 PJ. This decline is linked to significant electrification of the NCS, mainly through power-from-shore, but also through wind power (e.g. Hywind Tampen) replacing gas turbines on offshore installations.

The second biggest use of natural gas is as petrochemical feedstock. In Figure 3.4, we show that only 9% of all gas use in 2050 will be for power generation; the manufacturing and buildings sectors will account for about 8% and 3% respectively – somewhat contrary to the

FIGURE 3.3

Norway oil and gas production and capacity additions



Oil includes crude oil and condensates, natural gas includes NGLs.
Capacity additions are based on asset lifetime of 20 years.
Historical data source: NPD (2019), IEA WEB (2019)

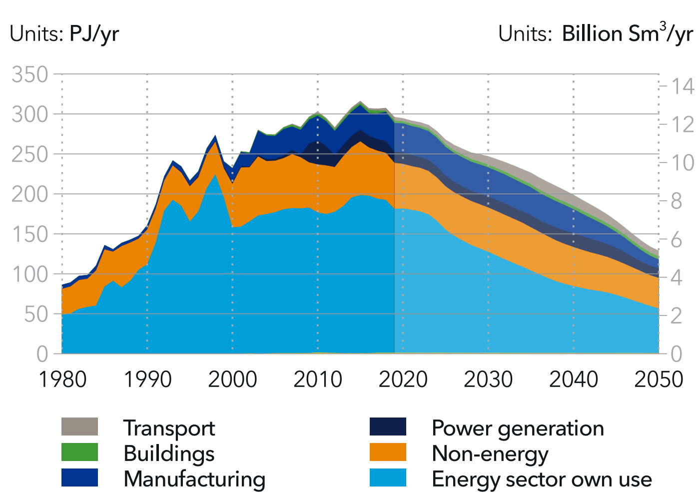
situation in Europe where natural gas is predominantly used in buildings and power stations. This is explained by Norway's unique hydropower-dominated power system. The Norwegian transport sector is the only sector where natural gas use is poised to grow in the coming decades due to the increasing use of natural gas in maritime as a bridge fuel to other low- and/or zero-carbon fuel alternatives.

On a global scale, one can summarize that gas production will increase and move to new locations around the world. In terms of absolute output, the three dominant players at present, North East Eurasia, North America, and the Middle East and North Africa, will maintain their current levels of production throughout the forecast period. Norway's natural gas production, currently at about 140 Gm³, is forecast to increase in this decade, and then to decline 25% by 2050 (Figure 3.3). Throughout this time span, Norway will maintain an export share of around 95%. We forecast that Norway's LNG liquefaction capacity, currently at 4 Mt per year, will double during the 2030s. LNG will still only account for less than 10% of Norway's gas export, way below the global average. Should the European market choose to limit Norwegian gas purchases, the LNG share could increase dramatically. In our view, however, Europe's gas demand is likely to continue.

Electrification of oil and gas production on the NCS started as early as 1996 with Troll East (A) connecting to the mainland electricity grid. With ongoing electrification of the NCS, natural gas use, as part of oil and gas extraction processes, will decrease almost 70% as gas-fired onsite power production on offshore installations is replaced by electricity from the mainland or from offshore wind. In 2019, emissions from the oil and gas industry's own use of energy accounted for almost a third of Norway's total GHG emissions, making the industry the largest contributor to the Norwegian carbon footprint. It is expected that previous single cable connections between mainland and offshore units will become multi-user electricity grids on the NCS. Towards mid-century, we forecast a 50% share of electricity in the supply of NCS energy needs (Figure 3.5).

FIGURE 3.4

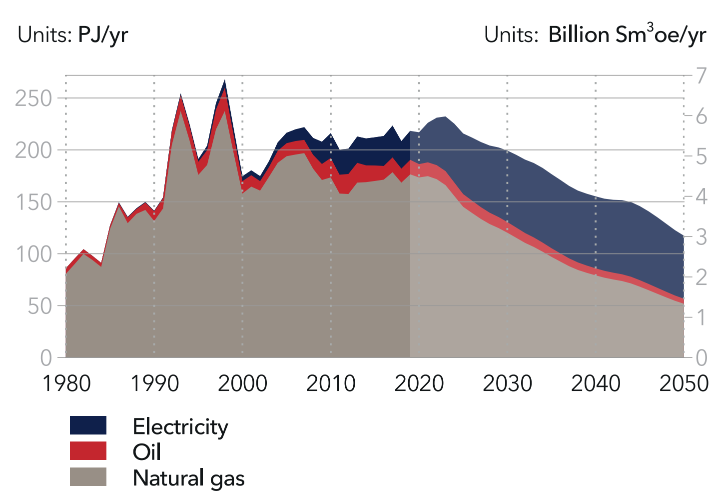
Norway natural gas demand by sector



Includes natural gas liquids. Historical data source: SSB (2020), IEA WEB (2019)

FIGURE 3.5

Norwegian continental shelf energy demand by carrier



Historical data source: SSB (2020), IEA WEB (2019)

3.3 ELECTRICITY

Electricity demand

With 23.5 MWh annual consumption per person, Norway is second only to Iceland in having the highest electricity consumption per inhabitant in the world. This is due to Norway's electricity-intensive industries such as aluminium production, high penetration of electricity use in heating of residential and commercial buildings and in powering its oil and gas extraction industry, and its leading role in electrification of road and marine transportation.

As Figure 3.6 shows, after a small reduction in 2020 due to COVID-19, total national electricity consumption will grow 37% from 132 TWh/yr in 2019 to 181 TWh/yr in 2050. Three sectors will spur this growth: transport, hydrogen production and oil and gas production. We will see electrification of all transport segments, but first and foremost road vehicles, with 13 TWh/yr consumed by 2.2 million passenger and 530 000 commercial BEVs in 2050. Electric short-haul flights will consume 3 TWh in 2050. As hydrogen and e-fuels start to replace gas in manufacturing and marine gas oil from the late 2020s, electricity consumption from electrolysis plants will grow significantly, reaching 6 TWh/yr in 2040 and 20 TWh/yr in 2050. The energy sector's own use, for oil and gas production, will continue to grow as both new and some existing fields are electrified.

Total electricity use in buildings will be mostly flat, but there will be shifts within the sector. More efficient heat pumps, better insulation and a warming climate will reduce electricity use for heating purposes. Meanwhile, the appliances and lighting segment will grow in line with building expansion and increasingly tech-heavy lifestyles. Space heating currently has the highest seasonality between winter and summer months, but this will start to even out as less electricity is used for heating, and more power is consumed by appliances. A more even distribution of load across the year will reduce the ratio of peak load to the annual average.

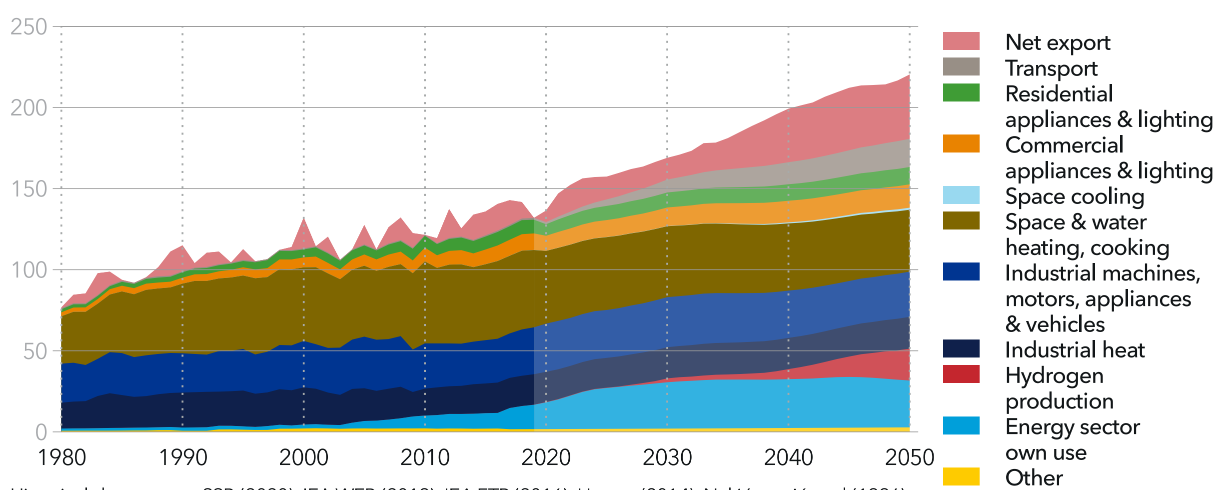
Electricity supply

Historically, Norway's electricity supply has been dominated by hydropower (Figure 3.7), and through to 2006, over 99% of domestic electricity was supplied by this source. At that point, other technologies started to make inroads, such that in 2019 non-hydro electricity generation was 6.4%:

FIGURE 3.6

Norway electricity demand by sector

Units: TWh/yr



Historical data source: SSB (2020), IEA WEB (2019), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996)

4.1% from wind, 1.7% from gas, 0.3% from biomass, and 0.1% each from solar PV and coal.

In the future, we foresee an even more diverse production mix. Electricity demand will grow 37% to 2050, but annual average hydropower generation will only grow by 15% in the same period. The remainder of the gap will be closed mostly by wind. Onshore wind will continue to grow until 2040, but more slowly than with recent growth due to public opposition and increased environmental concerns. From the 2030s, offshore wind, particularly floating, will grow rapidly, driven by reducing costs, sustained government support and increasing opportunities for electricity trade. 2050 electricity generation will include 1% solar PV, 1% gas, 12% onshore wind and 16% offshore wind, with the latter mostly exported. The remaining 70% will be hydropower-based.

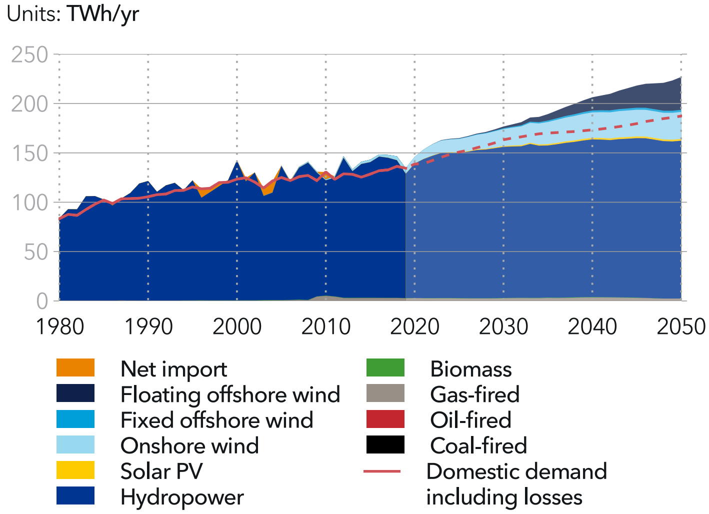
Electricity generation

Although it is possible to control how much power to generate from hydropower stations, their operations are impacted by the water levels in the reservoirs. For that reason, we categorize hydropower as dispatchable generation with storage constraints. As Figure 3.7 shows, hydropower generation fluctuates from year to year due to variations in rainfall. In our modelling, we use an average year to forecast the future quantities of water inflow to the reservoirs, since it is impossible to predict the variations due to natural factors. As average precipitation is likely to increase (NVE, 2019), we include an increase in the average capacity factor of hydropower power stations from 49% to 50.4% towards 2050.

FIGURE 3.7

Norway electricity supply by power stations and net imports

Units: TWh/yr



Historical data source: SSB (2020), IEA WEB (2019)

Wind and solar PV are non-dispatchable because only limited control is possible over how much electricity these technologies provide. We have used normalized deterministic profiles for their generation patterns. We account for the differences in onshore and offshore wind profiles, where offshore has higher capacity factors and a steadier profile. The generation profiles vary over years, representing technological improvements and geographical distribution of the wind turbines and solar panels.

Our forecast also accounts for the impacts of cross-border electricity trade and energy storage, namely pumped hydro storage, battery storage and the storage provided by EVs through vehicle-to-grid systems. We assume that 10% of battery capacity of all EVs will be available to the grid to provide flexibility. Electricity trade with the rest of Europe is based on the wholesale price differences between Norway and Europe. The operations of storage technologies are modelled by a heuristic algorithm that aims to utilize the storage in the most suitable way to exploit price arbitrage opportunities.

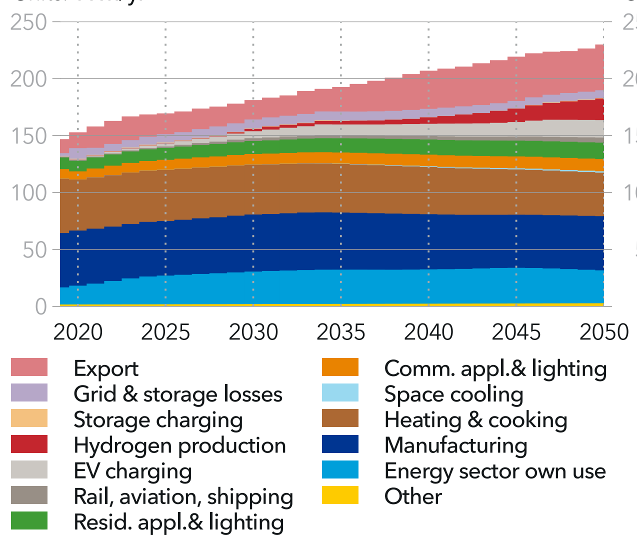
Our power market operates on an hourly scale and finds the market equilibrium at each hour by adding up the potential supply and demand at different prices and calculating the price at which total supply equals total demand. The graphic overleaf summarizes how our model's power-market module operates. Our hourly model ignores any grid constraints, meaning that, within the model, any demand can be met by any generator in the country or the region, regardless of location. For Norway, we do not distinguish between the bidding zones and treat the whole country as a single market.

HOW OUR MODEL'S POWER SECTOR OPERATES ON DIFFERENT TIME SCALES

Here, we illustrate how our model determines the operating hours of power stations. Annual electricity demand by sector use comes from the corresponding parts of the model.

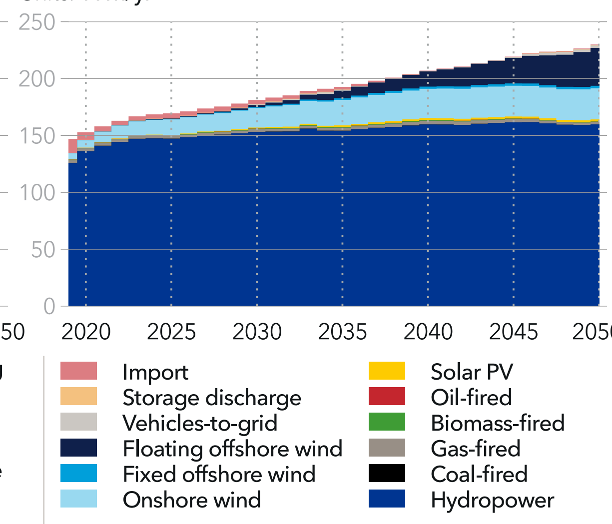
Norway electricity demand by segment; 2019-2050

Units: TWh/yr



Norway electricity supply by source; 2019-2050

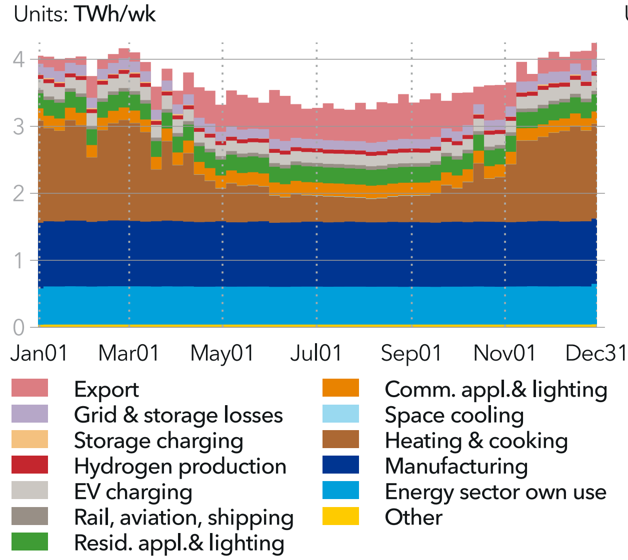
Units: TWh/yr



We expand the year 2034 over 52 weeks. All profiles are aggregated over Norway. Electricity trade flows are determined by wholesale price differences in Norway and the rest of Europe.

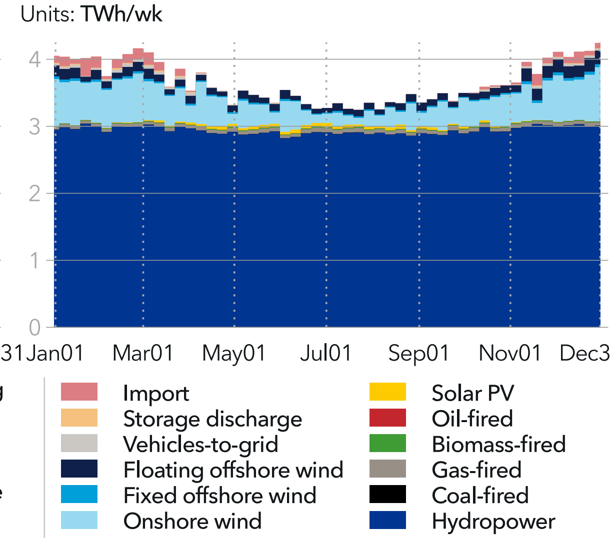
Norway electricity demand by segment; 2034

Units: TWh/wk



Norway electricity supply by source; 2034

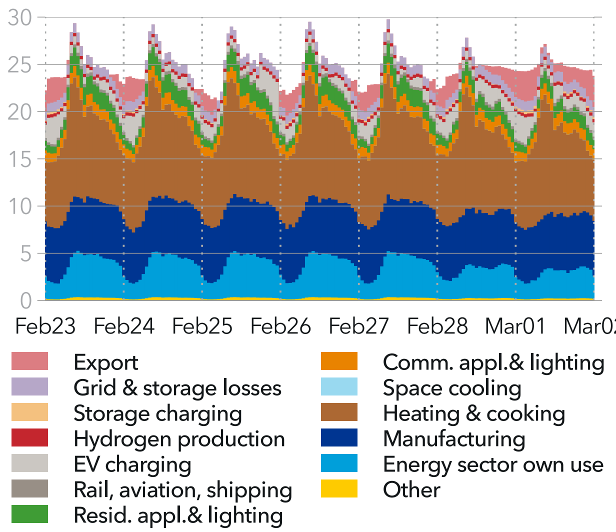
Units: TWh/wk



This next chart zooms in on week 9. How storage and hydrogen production plant operators behave is based on price signals. Thus, they tend to store energy when wind output is ample and to release energy when it is not. However, as many operators compete, the result is not optimal with respect to reducing variability.

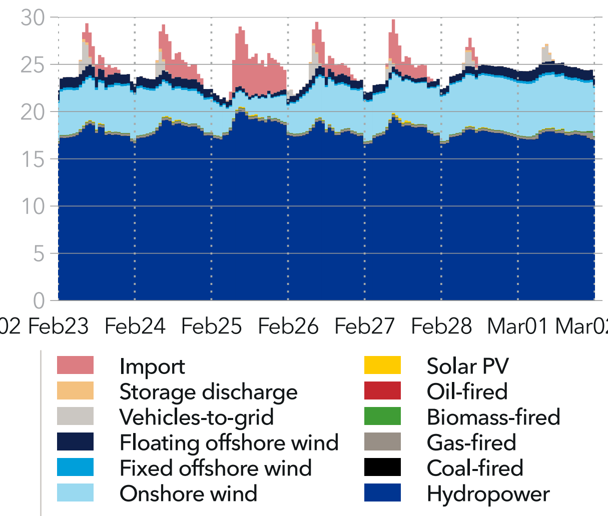
Norway electricity demand by segment; week 9; 2034

Units: GWh/h



Norway electricity supply by source; week 9; 2034

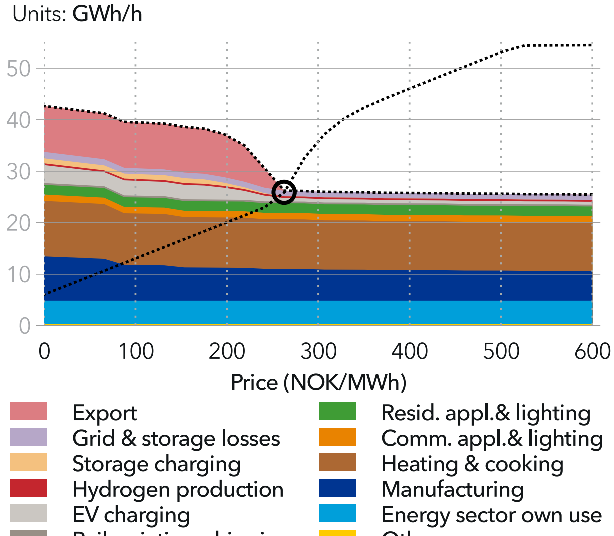
Units: GWh/h



At each hour, the model establishes demand and supply curves, as shown below, demonstrating national supply and demand at each possible price. The point at which supply and demand curves cross indicates the realized supply, demand, and price.

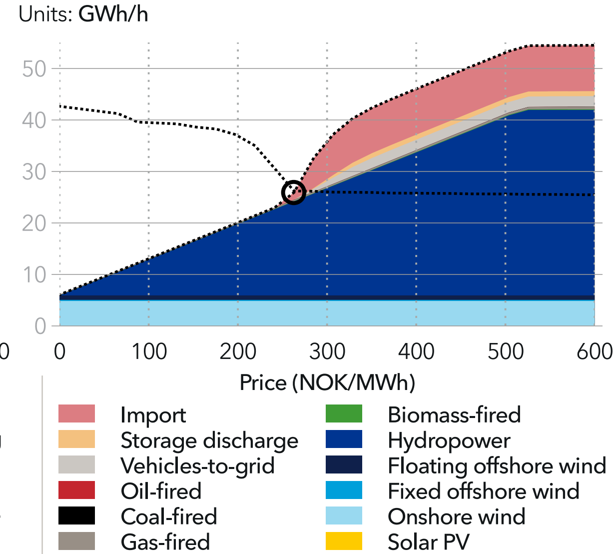
Norway electricity demand curve; 26 February 2034; 13:00-14:00

Units: GWh/h



Norway electricity supply curve; 26 February 2034; 13:00-14:00

Units: GWh/h



Capacity developments
In markets with large amounts of variable renewables – solar and wind – in their power mix, one major obstacle for continued investment in these resources will be reduction in revenues compared with conventional generation sources. The number of hours in a year in which solar and wind combined will adequately meet the load will increase. In these hours, the price of electricity will drop to zero. As a result, the 'capture price' of variable renewables (vRES) – i.e. average price weighted by their generation volume over the year – will decline. Since solar and wind will remain relatively small in Norway's electricity mix, the levelized cost of energy – the cost of producing one MWh of electricity including the annualized capital costs – will continue to determine the mix of new capacity investments, along with government support levels.

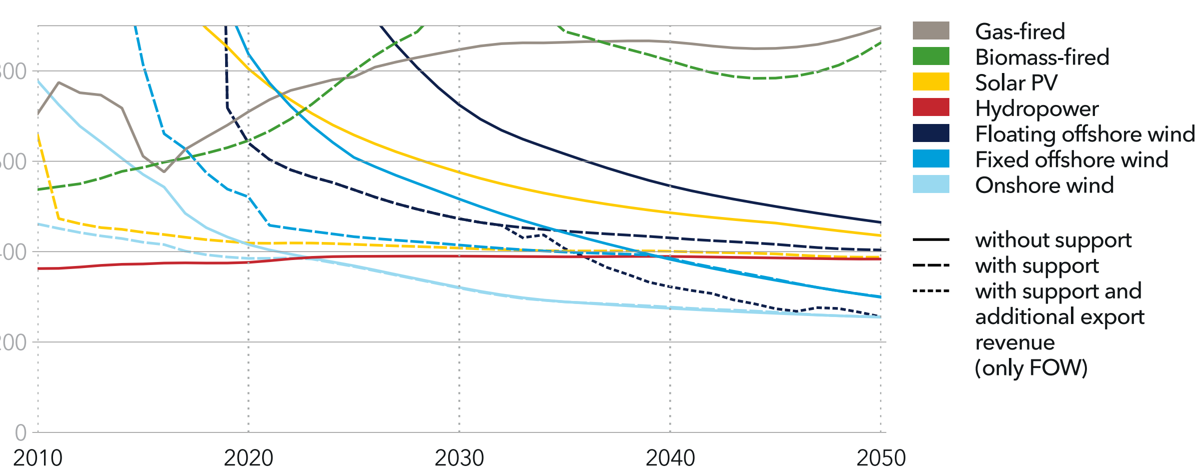
Figure 3.8 shows our estimates for the recent and future developments of the national average levelized cost of electricity. For biomass, solar PV and wind, two versions are presented: with and without government support. Government support is assumed to close a fraction of the gap between the cost of these technologies and the cheapest competing conventional technology, i.e. hydropower. After 2022, onshore wind becomes cheaper than hydropower, making it unnecessary to continue government support. The same happens with fixed offshore wind after 2040.

Floating offshore wind (FOW) remains more expensive than hydropower until 2050, even with continued modest government support. However, we assess FOW to have a unique advantage in being able to provide cheap electricity to the rest of Europe through growing undersea interconnections, without the public opposition faced by onshore wind and hydropower. Our hourly comparative analysis of Norwegian and European power systems indicates that up to 90% of annual output from Norwegian FOW can be sold to Europe. This additional revenue stream will bring the levelized cost of floating offshore wind down to the levels of onshore wind after 2040.

FIGURE 3.8

Norway average levelized cost of electricity by power station type and support level

Units: NOK/MWh



Support includes all forms of government incentives, including tax cuts, subsidies and PPAs.

TABLE 3.1
Installed capacity and the annual average capacity factor

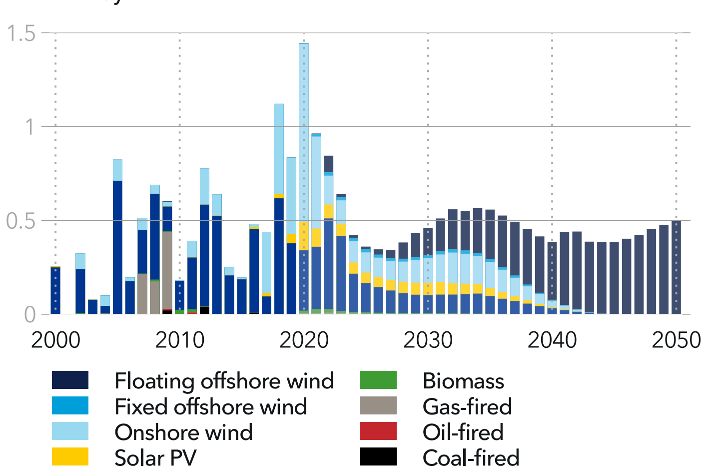
	Installed capacity (GW) by the end of year				Capacity factor			
	2020	2030	2040	2050	2020	2030	2040	2050
Hydropower	33.2	35.6	36.6	36.7	47%	49%	50%	50%
Onshore wind	3.0	4.9	6.6	6.7	25%	40%	45%	47%
Floating offshore wind	0.0	0.5	3.0	7.0	42%	38%	51%	54%
Fixed offshore wind	0.0	0.2	0.4	0.4	-	45%	55%	58%
Solar PV	0.3	1.1	1.7	1.8	5%	10%	11%	12%
Thermal	1.1	1.2	1.1	1.0	32%	29%	41%	29%

There are certain overlaps in the cost of new developments, as well as many geographical and political factors, that may result in not only the lowest-cost technology being built. Hence, we get a distribution based on price and other factors. Figure 3.9 illustrates historical and future annual power capacity additions by power station type, estimated using this logic.

FIGURE 3.9

Norway capacity additions by power station type

Units: GW/yr



Historical data: Platts (2018), GlobalData (2020), IRENA (2020)

Capacity additions in the near future include new capacity under construction. After these power stations come online, investments will slow down in the mid-2020s. The 2030s will be the last decade with significant hydropower, onshore wind and solar PV capacity additions. After 2040, we foresee almost all new capacity to be in the form of floating offshore wind, where export-driven capacity additions will be sufficient to also cover the anticipated increase in domestic electricity demand.

Table 3.1 shows developments within installed capacity through to mid-century and the average annual capacity factor of the installed capacity. In addition, we forecast 730 MW of pumped hydro storage and 190 MW of utility-scale Li-ion battery storage to support the Norwegian electricity grid in 2050.

Hydropower

With more than 1600 plants (Platts, 2018), hydropower is the backbone of the Norwegian electricity system. Unlike hydropower capacity in relatively flat countries with limited dams, Norwegian hydropower system is supported by a very strong reservoir storage capacity, with a total of 86.5 TWh across the country (Energifaktanorge, 2020). This capacity acts as a buffer against fluctuations in demand, as well as irregularities in the water flow to the reservoirs. It also has the potential to act as a battery for electricity systems in Europe. Over the last 30 years, the average capacity factor of Norwegian hydropower plants has been between 42% and 58% with a mean value of 49%. This year-to-year irregularity resulted in some years closing with a net import of electricity, but average generation capacity has been above average domestic demand, allowing Norway to be a net electricity exporter over the years.

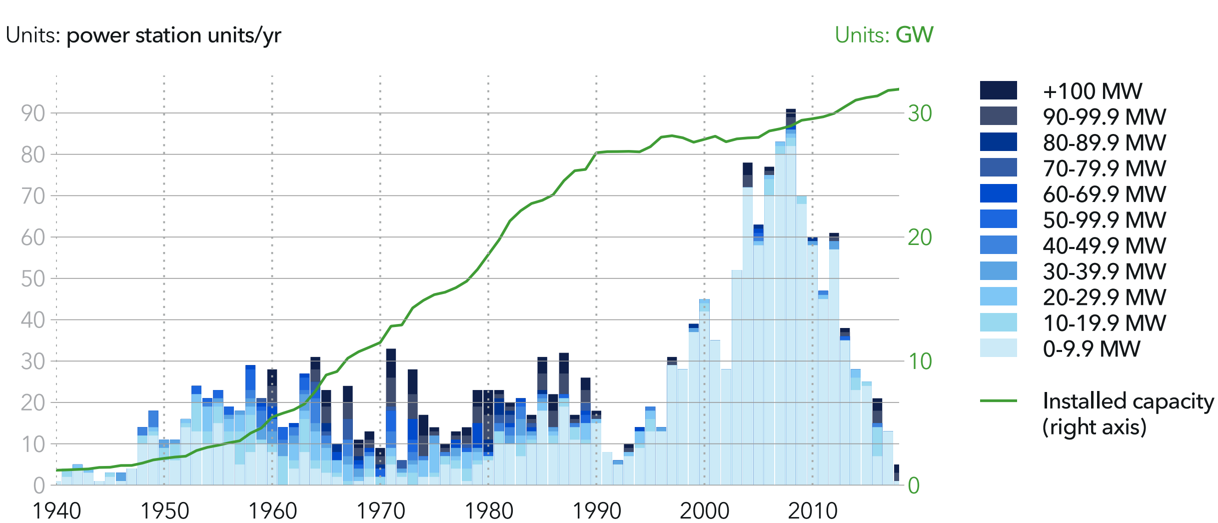
Norway's installed hydropower has been growing ever since the 1890s (Figure 3.10). During the period from 1960 to 1990, hydropower experienced an average 5.4% annual growth in capacity, driven by many large-scale projects. From 1990 to the early 2000s, new capacity additions slowed significantly. The start of the electricity certificate scheme in 2002 boosted smaller hydropower investments, many of them being less than 10 MW. The current scheme grants renewable electricity certificates to power plants that start operation until the end of 2021.

Hydropower will continue to play a central role in Norway's electricity system. The existing 33 GW installed capacity will expand only slightly until 2040, at 37 GW. Although the technical potential for Norwegian hydropower is estimated to be around 46 GW (NVE, 2011; Cutler & Morris, 2013), we predict capacity additions to stop well before that owing to factors related to preservation, licences, regulation, cost, and competition. With an increase in annual rainfall as a result of climate change, annual generation is expected to reach 160 TWh in 2050.

With increased variability on the supply side of the electricity system with a growing share of wind, hydropower will need to respond to fluctuations not only in demand, but also in generation. Adoption of new technologies that allow hydropower plants to ramp up and down more quickly will be instrumental in the integration of hydropower and wind. With new interconnections to UK, Germany and the rest of Scandinavia, Norwegian hydropower will expand its balancing role in the larger European power system.

FIGURE 3.10

Norway hydropower additions by size



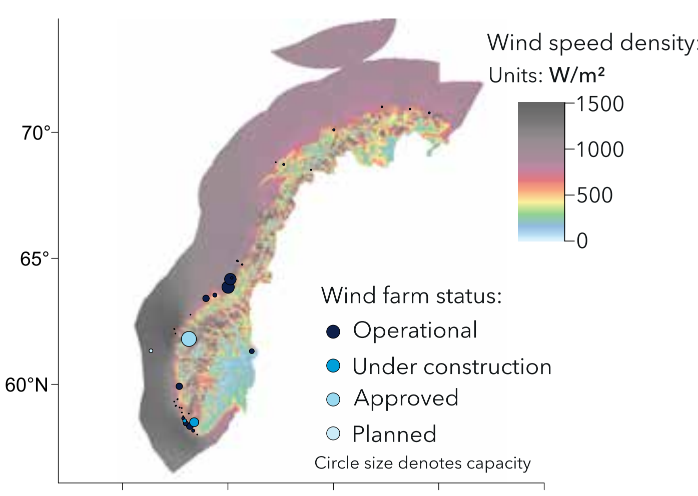
Shows the year of becoming operational. Historical data source: Platts (2018)

Wind

Norway's wind industry has grown steadily since its first installation in 1993. At the end of 2019, total installed capacity reached 2.1 GW, almost all onshore with a handful of exceptions like the 2.3 MW Hywind Demo floating offshore project installed in 2009 off Karmøy. But as Figure 3.11 shows, most onshore wind turbines are on the southwest, west and north shores. Favourable wind conditions exceeding 1000 W/m² wind speed density in some locations, proximity to the grid, and large areas with relatively sparse population makes the Norwegian west coast advantageous for wind developments. However, future onshore installations are likely to be delayed and/or scaled down by public concerns like noise, impact on birds, recreation and a desire to preserve untouched landscape and wilderness. Unlike many Western countries with significant fossil shares in their power mix and where wind investments are regarded as essential for decarbonizing and lowering the cost of electricity generation, the Norwegian wind industry enjoys less public support. The public is also wary of arguments for building excess wind capacity for export to the European continent, fearing that may cause domestic electricity prices to increase.

FIGURE 3.11

Mean wind power density and distribution of wind farms



Data source: Global Wind Atlas 3.0, Technical University of Denmark, 2020, Global Power Plant Database 1.2.0, GEO, Google, KTH, Enipedia, WRI. 2019

Given the tussle between climate goals and natural habitat preservation, we predict that growth in Norway's wind capacity will be mostly offshore, constituting 56% of 63 TWh wind-based generation in 2050. Cost is the first factor contributing to growth. Figure 3.12 shows how levelized cost of three categories of wind declines in Norway until 2050, as a result of global and local developments in various cost components. For onshore wind, about half of the 39% cost reduction over 30 years will come from reductions in unit turbine cost. The impact of ever-growing turbine size and hub height is part of this. The offshore wind segment will experience large reductions in non-turbine fixed costs and operating & maintenance costs, as the 31-fold increase in global installed capacity will lead to massive accumulation of learning and economies of scale. However, the fact that the North Sea deepens quickly off Norway's west coast will limit the share of bottom-fixed offshore turbines. As shown in Figure 3.8, government subsidies will not be needed for onshore wind starting from the mid 2020s, and for offshore wind from the late 2030s.

The second driver of the uptake of wind in Norway is the increase in domestic electricity demand, as presented earlier in Figure 3.6. Due to the limited growth possibilities of hydropower, wind is in prime position to fill the gap between demand and available supply.

Electrification of offshore oil and gas production will be a third driver for offshore wind. With the electricity consumed by offshore platforms increasing by 8.3 TWh in the coming 30 years, floating offshore wind turbines located near the platforms will be a natural choice for supplying the required power.

Finally, new interconnections to the UK and Germany, combined with the higher flexibility needs in Europe, will mean that export revenues for Norwegian floating offshore wind operators will be twice as high as the revenues from domestic market. Thanks to these additional revenues from exports, total government subsidies required to support floating offshore wind until 2050 will amount to USD 3 billion, instead of USD 11 billion.

Solar PV

Solar PV will remain a niche technology in Norway. We predict installed capacity to increase from 120 MW in 2019 to 1.75 GW in 2040 and remain flat thereafter. The main disadvantage of solar PV is low solar irradiation in Norway. This leads to an annual capacity factor of around 10% on average. Even worse, as Figure 3.13 demonstrates, solar PV generation is at its lowest when electricity demand is at its highest.

Hydrogen

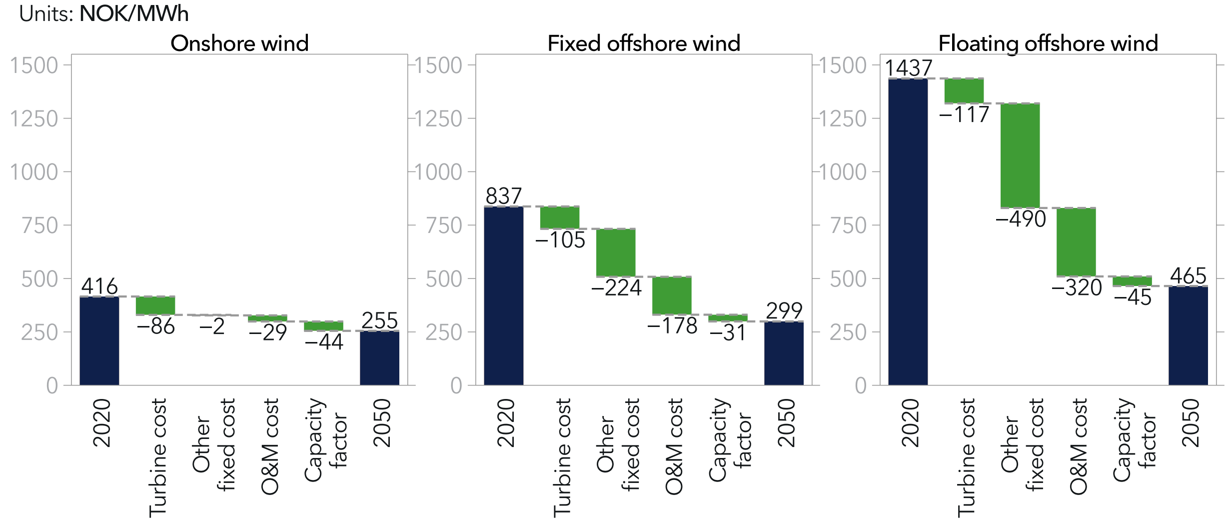
Hydrogen's main strong point is that it emits only water when consumed for energy production. Only water and energy are needed to produce hydrogen as it does not occur naturally as a gas on earth. However, producing hydrogen with electrical current requires costly electrolysis equipment and generates substantial energy losses. The main alternative production method via steam methane reforming (SMR), where hydrogen is derived from hydrocarbons, currently has lower overall costs due to low fossil-fuel prices. We forecast this gap to decrease with higher carbon prices and ongoing process improvements for electrolysis-based hydrogen production.

Hydrogen supplied via electrolysis is seen as one of many flexibility options to take advantage of low power prices when production from vRES is plentiful and demand is lacking. This will increasingly be the case. However, there are many other markets for such cheap electricity, e.g., demand response, pumped hydro, battery-electric vehicles (storage), and utility-scale batteries. It will be some time therefore before abundant vRES results in a steep increase in electrolysis-based hydrogen production in Norway. We forecast this will occur in the late 2030s. From 2030 onwards, Norway-based hydrogen production will be supplied exclusively

FIGURE 3.12

Drivers of change for levelized cost of wind in Norway between 2020 and 2050

Units: NOK/MWh



by electrolysis at around 6 PJ/yr, reaching almost 60 PJ/yr by mid-century.

We see hydrogen as a likely zero-emission energy carrier for heat applications in manufacturing (Figure 3.14). More specifically, hydrogen will start replacing natural gas as an energy carrier for industrial heat provision in the 2030s. This will be the major application of hydrogen in manufacturing (> 90%), with a minor share being used in the iron and steel sector.

For the transport sector, hydrogen can serve as an energy-storage medium, competing with battery storage in zero-emissions usage. Long-haul, heavy road transport that cannot rely as easily as passenger vehicles on batteries for main energy storage, will turn to fuel-cell solutions, despite these being only half as energy efficient as batteries and more complex and costly. Hydrogen use in Norway for road transport will pick up from 2035 onwards and reach 10 PJ by 2050.

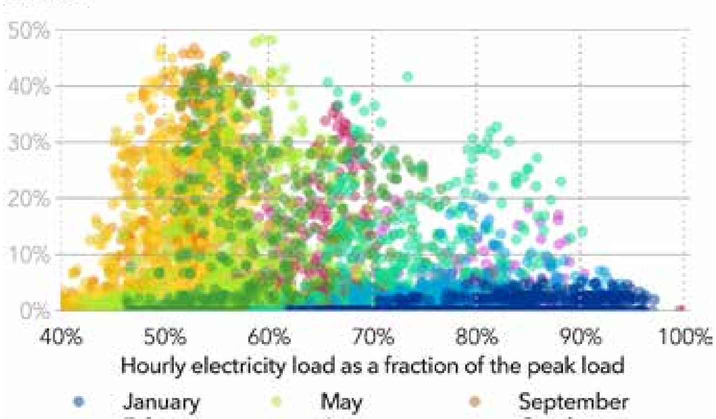
For maritime transport, we expect that low- and/or zero-carbon fuel alternatives – partly implemented in hybrid configurations with diesel and gas-fuelled propulsion – will have significant uptake and provide slightly more than 60% of the maritime fuel mix by 2050, most of which will be synthetic fuels. This forecast is covered thoroughly in DNV GL's ETO (DNV GL, 2020a) and in our Maritime companion report (DNV GL, 2020b), Note that we do not treat synthetic fuels as a separate category in this forecast but classify these under hydrogen because their production shares many similarities. We forecast that 13 PJ/yr of low-and/or zero-carbon fuels will be used in Norway's maritime sector by mid-century (Figure 3.14).

> "It will be some time before abundant variable renewables result in a steep increase in electrolysis-based hydrogen production in Norway

FIGURE 3.13

Norway solar PV capacity factor vs. normalized load

Unitless

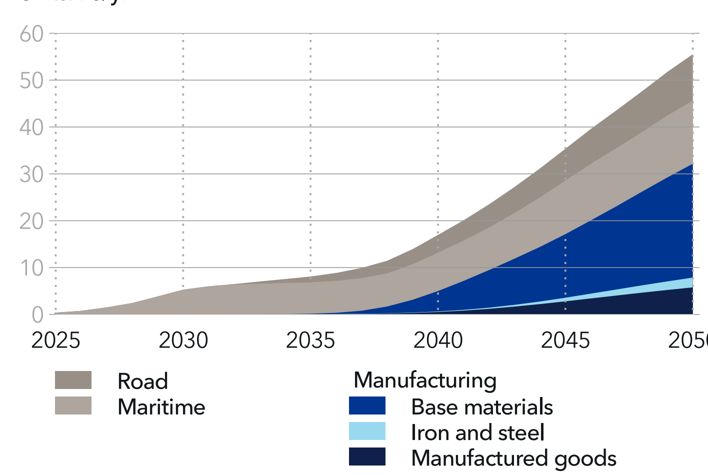


Each dot represent an hour.

FIGURE 3.14

Norway hydrogen demand by sector

Units: PJ/yr



Only includes hydrogen as energy carrier. Maritime sythetic fuels are counted as hydrogen.

4 ENERGY TRADE

Norway's profile as an energy exporter will continue throughout our forecast period, but electricity export will most likely only marginally compensate for falling oil and gas revenues.

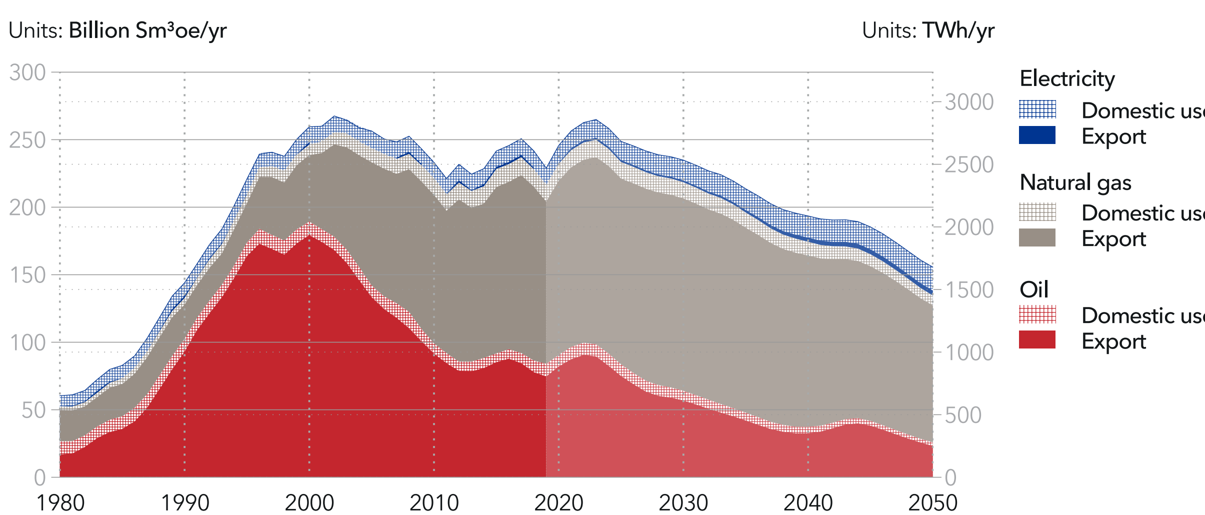
Norway is a huge net exporter of energy and will continue to be so over the next 30 years (Figure 4.1). Although new fields will boost oil and gas exports in the immediate future, they will not be enough to exceed the export peak in 2001 and the long-term trend of oil exports will show a steady decline. Total oil and gas exports in 2050 will be 36% lower than the 2019 level. Although electricity exports will continue to grow, volumes are comparatively minor, and electricity revenues will be unable to compensate for the lost revenue from oil and gas exports. The value of Norwegian oil and gas exports was NOK 424bn in 2019 (NPD, 2020a). Assuming constant prices, 36% reduction in oil and gas exports will result in lost revenue of NOK 153 billion/yr. However, 33 TWh/yr growth in net electricity exports by 2050 will only translate to an additional income NOK 20 billion/yr.

Oil and gas exports

Norway's production meets about 1.7% of the global oil demand. As Norwegian oil's competitiveness against cheaper oil will weaken in a world with reduced oil demand, its share of the global oil market will reduce gradually to around

FIGURE 4.1

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs. Historical data source: NPD (2019), IEA WEB (2019)

1% by 2050. As a result, total oil exports – including oil products – will reduce to 57 billion Sm³oe/yr in 2030, 33 billion Sm³oe/yr in 2040 and 23 billion Sm³oe/yr in 2050.

The outlook for gas is less bleak since natural gas will maintain its market position in the European energy system. Currently 24% of Europe's gas demand is supplied by Norway (BP, 2020). Since it is possible to deliver Norwegian gas to the rest of Europe cheaply through pipelines to Germany, the UK, Belgium and France, new gas producing fields in Norway will ensure its position in European gas supply. Thanks to relatively stable gas demand in Europe until the early 2030s, Norway's gas exports (including NGLs) will not drop below current levels before the early 2040s and will still be just above 100 billion m³/yr in 2050.

As of 2019, total LNG export from Norway is 6.6 billion m³/yr, while exports to non-European countries (Turkey, South America, China and India) constitute only 0.9 billion m³/yr, or about 1% of Norway's gas exports (BP, 2020). We forecast LNG export to rise after 2030 due to demand outside of Europe which will require a doubling of LNG liquefaction capacity to 8 Mt/yr in 2030s. Most exports will, however, still go via pipelines to Europe.

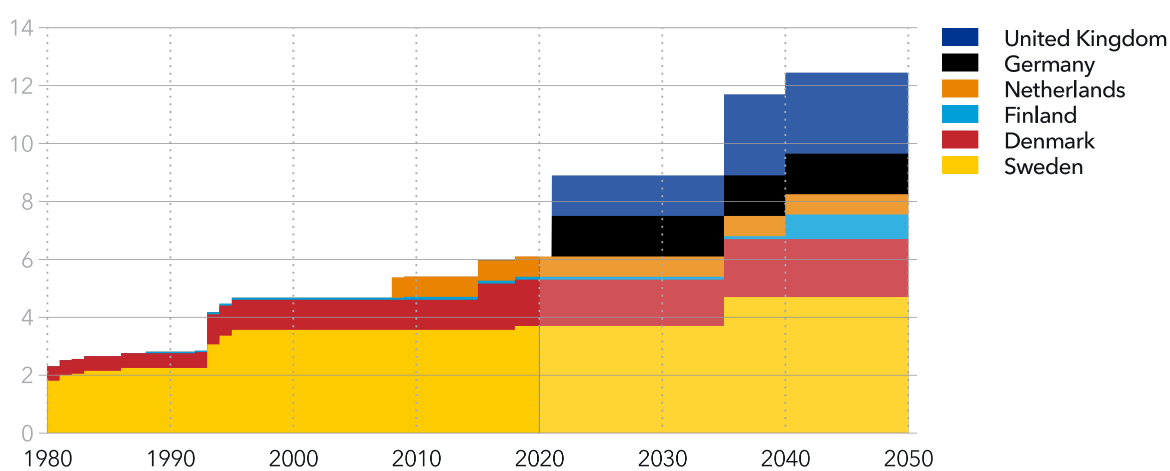
Electricity exports

Norway's total net transfer capacity to other countries is 6.1 GW of which 3.7 GW is to Sweden, 1.6 GW to Denmark, 0.7 GW to the Netherlands and 0.1 GW to Finland (ENTSO-E, 2020). As shown in Figure 4.2, the NordLink subsea cable to Germany and the North Sea Link to the UK are expected to become operational in 2021. To facilitate greater renewable generation, in the mid 2030s we foresee increases in cross-border capacity to Sweden and Denmark by another 1 GW and 0.4 GW, respectively. One more 1.4 GW interconnector between Norway and UK is expected and finally, we assume a 750 MW cable from Northern Norway to Finland to be built by 2040.

FIGURE 4.2

Norway net electricity transfer capacity

Units: GW



Historical data source: ENTSO-E (2020)

Norway's electricity grid is divided into five bidding zones. The actual cross-border electricity trade is very dependent on the supply and demand conditions in these bidding zones and the markets they trade with. Our model simplifies this structure by representing Norway and the rest of Europe as two electricity markets without any grid constraints within each market. This simplified model still operates at hourly intervals and calculates the trade between Norway and the rest of Europe, based on the price differentials in each market. By using this approach, we are able to replicate historical trade volumes reasonably well.

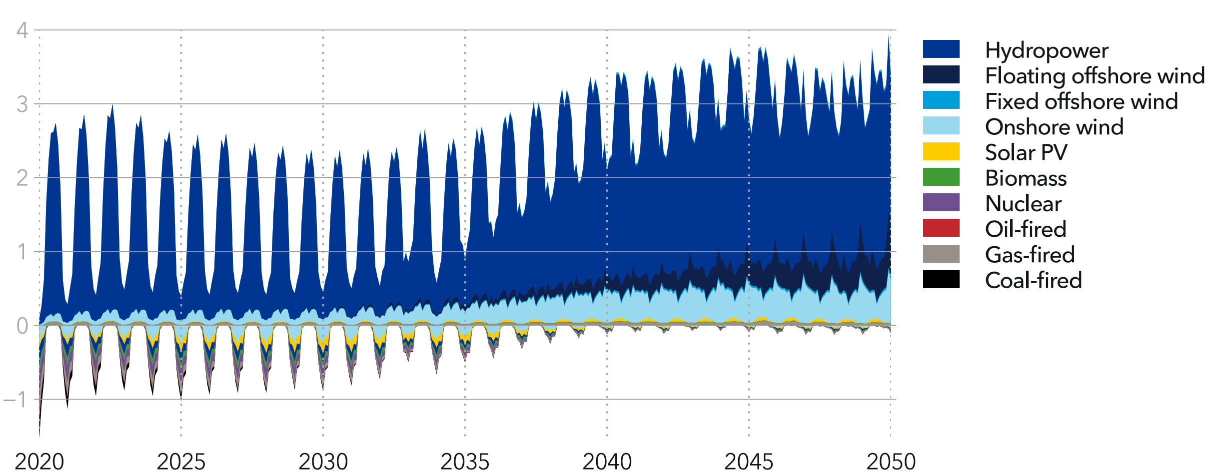
Figure 4.3 presents monthly electricity exports and imports of Norway until 2050, broken down by power station type of the exporting region in that month. The chart gives many clues about the future of Norwegian electricity exports. The annual total net exports increase significantly. In the last 20 years, Norway's average annual net electricity export has been 10 TWh. We foresee this increasing to above 30 TWh/yr in the 2040s and 40 TWh/yr by 2050. This increase is only partially linked to increase in net transfer capacity, because Norway's electricity exports in summer months – the time of year with the most exports and the period that would benefit from an increase in capacity if there was a bottleneck – only increases by about 50%. The real change happens in the winter months. As explained in the beginning of Section 3.3, there will be a shift from space heating electricity demand to other load segments, resulting in a more homogenous distribution of domestic electricity load, and ample generation capacity especially from new wind investments, will allow Norway to become a net electricity exporter, also during winter months.

We have assumed that new floating offshore wind capacity will not only be driven by domestic demand and the revenue from Norway's own electricity market, but also by increasing European electricity demand and opportunities for high export revenue. We see this happening in a self-reinforcing process, where year-round

FIGURE 4.3

Norway monthly electricity export and import by power station type of source

Units: TWh/month



Positive values show exports, negative values show imports.

export opportunity will trigger new floating offshore wind investments, and availability of this sufficient capacity allows up to 90% of floating offshore wind's annual generation to be exported.

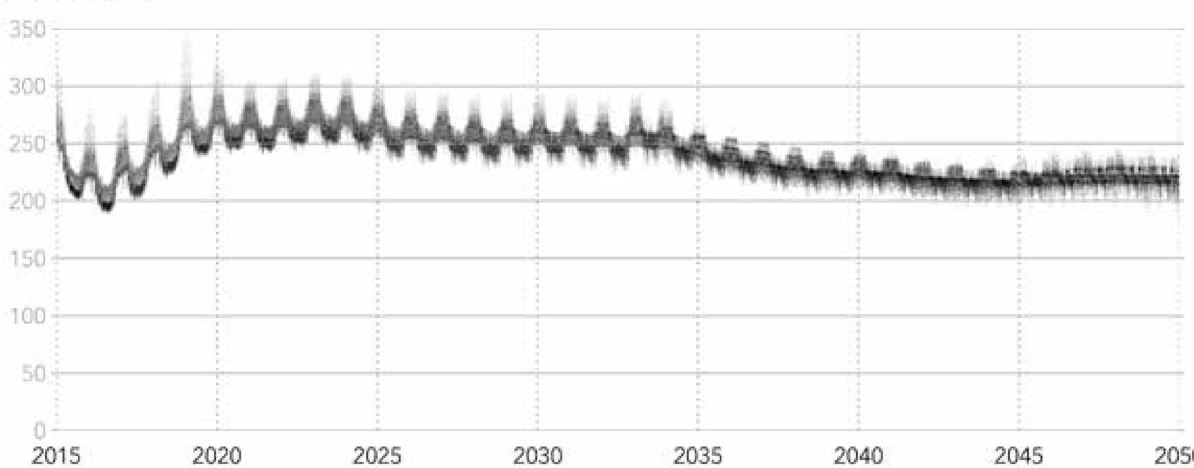
One important dimension of increasing electricity exports is its effect on the domestic electricity prices. Our analysis (Figure 4.4) shows that not only will average electricity prices remain stable, but price fluctuations within the year will reduce. The price stability is linked to increased flexibility resources in the power system, brought by new interconnections, availability of EV batteries through vehicle-to-grid systems, new utility-scale storage capacities and better demand response afforded by widespread adoption of smart grids. One limitation not accounted for is that our model is not designed to reflect grid constraints. As each specific bidding zone will be constrained by its local supply and demand as well as its interconnection capacity, the actual variation in the price may be higher than our model's predictions.

"One important dimension of increasing electricity exports is its effect on the domestic electricity prices. Our analysis shows that not only will average electricity prices remain stable, but price fluctuations within the year will reduce

FIGURE 4.4

Norway wholesale electricity price distribution

Units: NOK/MWh



Each dot represents the simulated wholesale electricity price at a particular hour.

5 EMISSIONS

The energy sector is the dominant source of anthropogenic greenhouse gas emissions, both globally and in Norway. CO_2 is the main contributor to these emissions and largely comes from the combustion of fossil fuels.

In this chapter, we describe how we estimate Norway's emissions by source and by sector. We begin with the estimated energy-related CO_2 emissions derived from our forecast, and then list the remaining GHGs and their origin. Since our modelling focuses mainly on the energy system, we make assumptions to determine future emission levels for the other, non-energy-related anthropogenic GHG emissions. We conclude with a discussion on developments surrounding the capturing and storing some of the emissions.

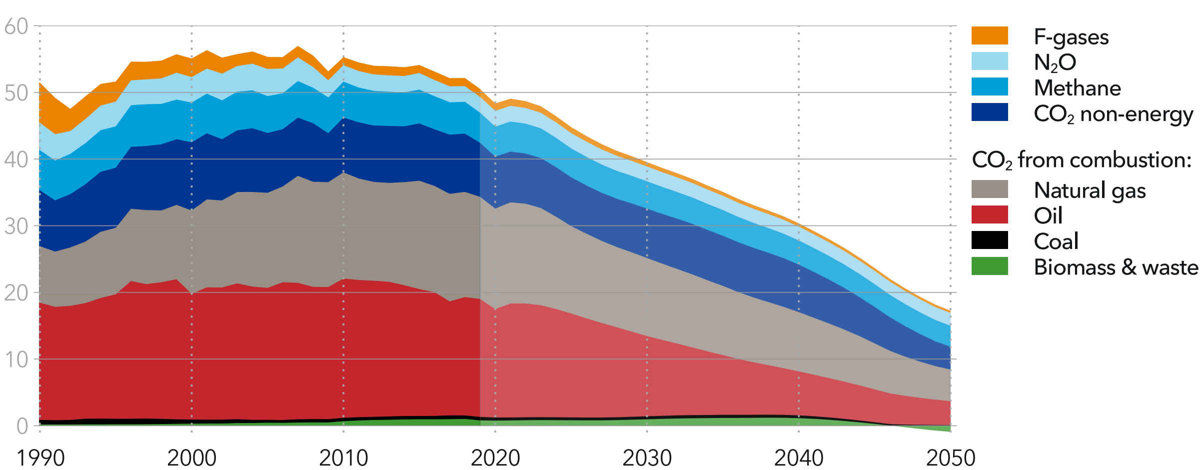
Emissions by source

Energy-related CO_2 emissions increased steadily in Norway for three decades, and it has only been in the last five years that a decline has been observed. In addition to CO_2 emissions from combustion of fossil fuels, a large share of Norwegian CO_2 emissions comes from non-energy related emissions. Much of these are from the use of fossil fuels as feedstock in the steel, aluminium and petrochemical industries. Non-energy emissions also come from the calcination process in cement production. Other GHGs included in the Norwegian footprint

FIGURE 5.1

Norway greenhouse gas emissions from combustion and non-energy related activities

Units: $MtCO_2e/yr$



F-gases include: HFC, PFC and SF6. Historical data source: SSB (2020) are methane, nitrous oxide and industrial flourinated gases (HFC, PFC and SF6). All these gases have a much more aggressive global warming potential than CO_2. In tonnage terms, these emissions are small compared with CO_2, but converted to CO_2 equivalents, they were 16% of the total GHG emissions in 2019 and grow to 33% in 2050.

Our forecast indicates that emissions will continue to decline over the entire forecast period. Emissions in 2019 are only slightly lower than in 1990, and by 2030 will have further declined 23% compared with 1990, far from Norwegian commitments. By 2050 we expect a decline of 68% compared with 1990 to 16 million tCO_2e (Figure 5.1).

Declining emissions are mainly linked to the electrification of road transport and the associated reduction in oil consumption. Other factors leading to lower emissions are significant electrification of the NCS, mainly through shore power or offshore wind, and changes in heat production processes in the manufacturing sector. As our energy transition model does not include non-CO_2 greenhouse gases or CO_2 from cement production, we have used current levels of emissions to extrapolate trends for each sub-source, or have have tied the emission source to an activity we model. For instance, methane emissions from oil and gas activities are tied to activity levels in oil and gas exploration, which we do have in the model.

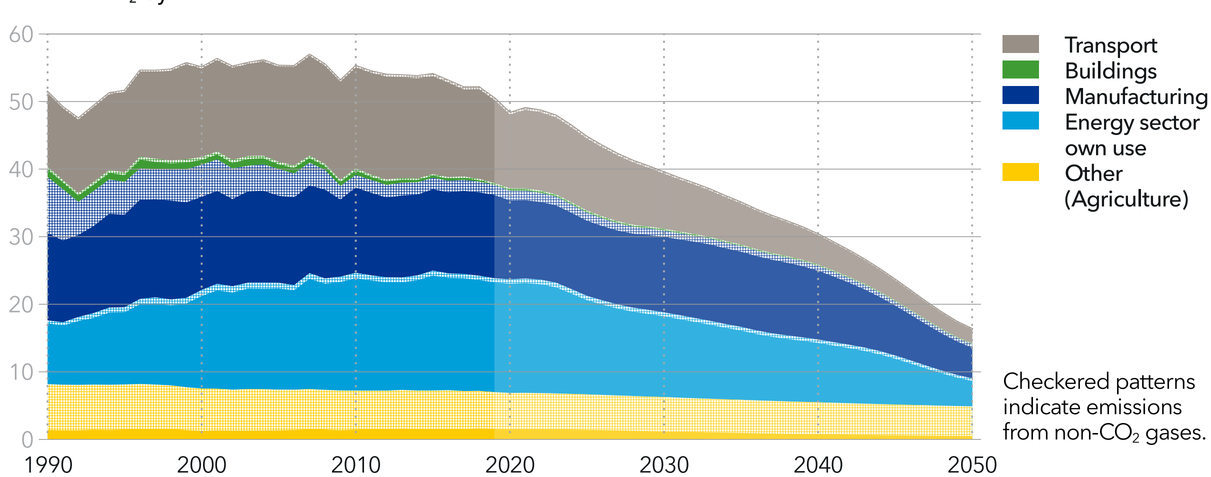
Emissions by sector

From a sectoral perspective all emissions have been associated with the main sectors described in our energy systems model. In all sectors apart from 'Other', which in this context equates mainly to agriculture and fishing, the emissions from CO_2 dominate. In the agricultural sector, emissions are largely methane from animal management through enteric fermentation and manure. Another major source in the 'Other' sector is methane from landfills. We do not expect Norwegian agriculture and animal management activities to decline significantly and thus assume a modest reduction of 10% between 2019 and 2050 for these non-CO_2 emissions.

FIGURE 5.2

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Emissions from power generation are allocated to end-use sectors. Historical data source: SSB (2020)

The sector with the highest emissions today (33%) is energy sector own use, being mainly oil and gas extraction and production. Most of these emissions are CO_2 from gas-turbines generating electricity on the NCS. As the NCS continues to electrify more of its production, emissions will decline gradually towards 2030 by about one third compared with 2019 levels. By 2050, the reduction will be 70% at 4 $MtCO_2$ due to declining activities and an electrification rate of over 50%.

The manufacturing sector currently emits 13.8 $MtCO_2e$. Most of these emissions (60%) are associated with non-energy related CO_2 activities in heavy industry, together with combustion emissions from fossil fuels. By 2030, these emissions will have declined by 12%. By 2050, emissions will be down to 5 $MtCO_2e$ due to the effect of plateauing growth in manufacturing output, a fuel switch to cleaner sources, and more CCS. Despite this 63% reduction, the manufacturing sector will have the highest share of emissions (31%) in Norway at the end of the forecast period.

In 2019, the transport sector was responsible for 25% (12.6 $MtCO_2e$) of total emissions. These emissions will drop significantly towards 2050, but are not on track to fulfil Norway's 2030 ambition of reducing transport emissions by 50% compared with 2005 levels. The road transport sector today emits 8.5 $MtCO_2e$ and by 2030 this will decline to 5.3 $MtCO_2e$, a reduction of 44% compared with 2005. The main contributor to the reductions is the electrification of the road sector, especially passenger vehicles, which just passes the 50% share of all passenger vehicles being electric in 2030.

Aviation, rail and maritime combustion emissions have been declining since 2005 and are currently 33% of Norwegian total transport emissions. However, these emissions will not decrease as fast as those from road transport. The overall GHG emissions from these non-road sectors are expected to decline by 38% from 2005 to 2030 and end up at almost 3 $MtCO_2e$. Longer term, the electrification of road transport as well as efficiency gains and fuel switching in the rest of the transport sector will cause emissions to decline markedly. By 2050, transport emissions will decline by 83% compared with today's levels to represent 13% of Norwegian emissions, leaving 2.1 $MtCO_2e$ to be removed to achieve a net zero ambition.

The building sector's energy use in Norway is largely linked to electric heating. Some fossil fuels are still used for space and water heating for commercial buildings. The rest of building emissions are in the form of methane from burning biomass for heating. Today, the buildings sector represents less than 1% of Norwegian emissions at about 250 $ktCO_2e$. Even with an expected increase in building mass and floor space, these emissions will decline further due to building-standard efficiencies, fuel switching, and the further introduction of heat-pump systems making electric heating even more prevalent. By 2050, emissions will have further declined by 50%.

Carbon capture and storage

CCS is currently almost solely applied in processes related to oil and gas extraction, where there is a viable business case or need to follow technical specifications. We forecast that the future large point sources of carbon, mainly in manufacturing, will increase the capture of carbon from their waste streams. However, the CCS developments we are aware of today and have modelled are not happening at sufficient scale to make a significant contribution to the emission reductions required by Norway's climate ambitions.

Today there are two CCS processes in Norway, both related to oil and gas activities. At the Sleipner field, some 850 $ktCO_2$/yr is removed from the gas and injected into an offshore sandstone reservoir (GCCSI, 2020). At the Melkøya LNG facility to prevent dry ice formation in the liquefaction process, an additional 700 ktCO_2/yr is captured and transported back to the Snøhvit field and stored in offshore reservoirs. The Sleipner field is expected to close by 2030 (Equinor, 2020) and Snøhvit by the late 2030s (Offshore, 2006). We do not anticipate the capture from Sleipner to be replaced by other activities, however there is a likelihood of the CCS activity at Melkøya being replaced by the capture of CO_2 associated with more gas shipped on keel.

Included in our modelling is the anticipated 400 ktCO_2/yr at Brevik. We add another 400 ktCO_2/yr from Klemetsrud with a higher degree of uncertainty. Both of these two capturing streams come online gradually from 2024 to 2027.

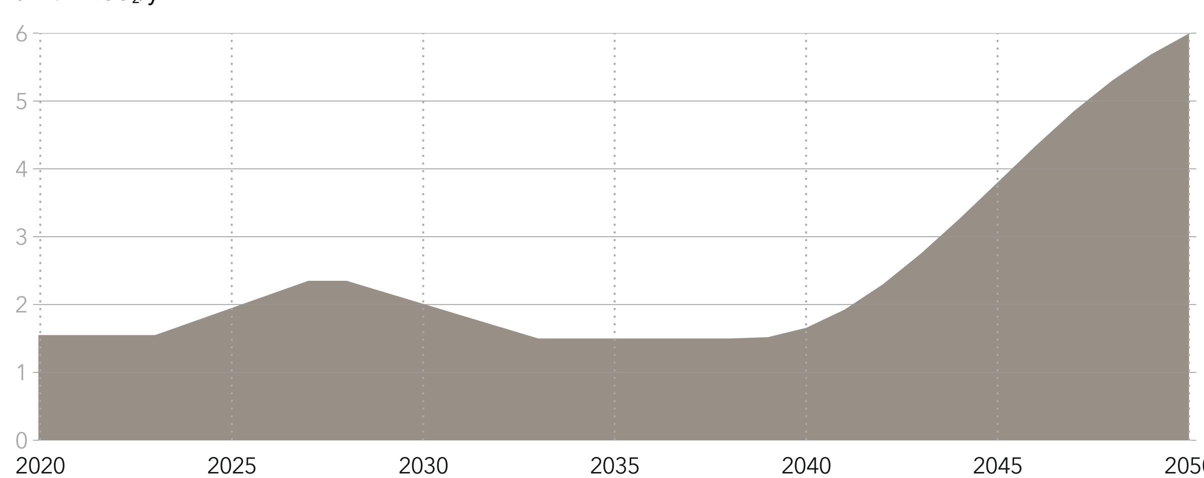
It is only in the 2040s, when carbon prices start to approach the cost of CCS, that uptake accelerates, and deployment begins at scale, but too late for carbon neutrality. By 2050, we expect emissions captured by CCS to be just below 6 Mt/yr, amounting to 35% of all Norwegian CO_2, leaving 11 MtCO_2 uncaptured in 2050. That level of capture is well below the potential for storing emissions in Norwegian reservoirs, which can also extend to the storage of international emissions (NPD, 2020b). The Northern Lights project illustrates this; it has ambitions to store 1.5 MtCO_2 of which 0.8 MtCO_2 can come from known Norwegian projects.

Putting CCS on a faster deployment track is dependent on policy spurring it to the point where technology learning will bring down CCS costs and make it competitive with carbon prices. Norway, however, cannot 'go at it alone' with initiatives to make further projects and the CCS value chain commercially viable. Global actions resulting in an additional policy push, for example higher carbon prices, will be needed to stimulate real-world experience. Another option is mandated CCS to force emissions down. This, however, has clear disadvantages for industries subject to international competition.

FIGURE 5.3

Norway CCS capacity

Units: MtCO_2/yr



Energy transition indicators

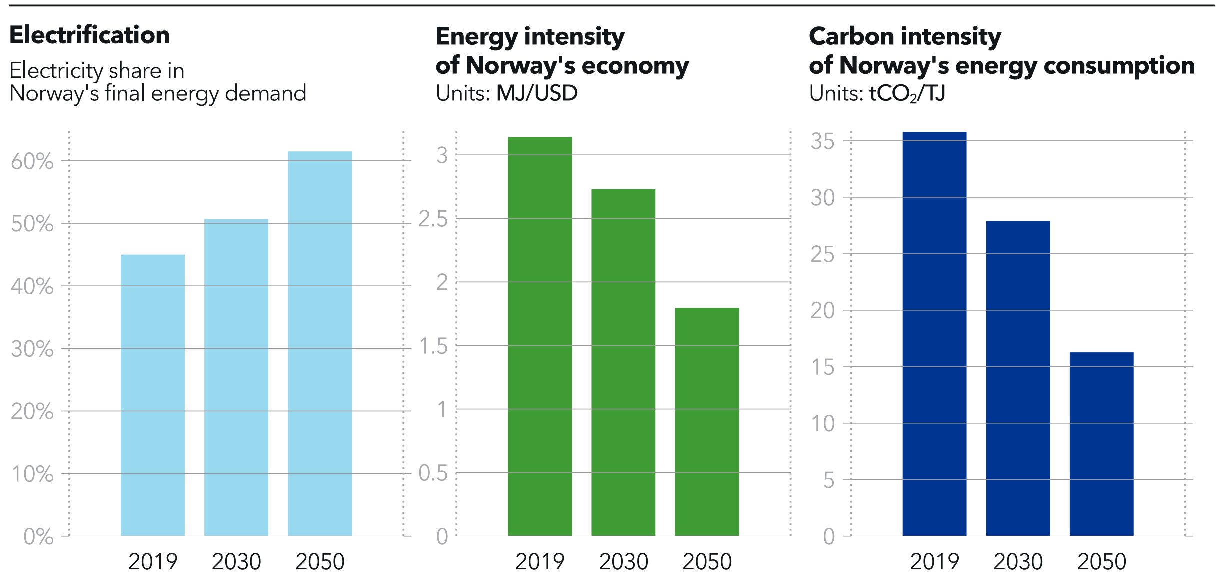
Figure 5.4 presents Norway's development against three main energy-transition indicators: electrification, energy-intensity improvements, and decarbonization. Norway's share of electricity in final energy demand will exceed 60% in 2050, far higher than any of the regions in our global Outlook. Energy intensity is almost halved to 1.8 MJ/USD, a level slightly above the rest of Europe which is expected to reach 1.5 MJ/USD in 2050. Carbon intensity also more than halves towards 2050, reaching a final value of 16 tCO_2/TJ. This is a level slightly higher than that in Europe, which declines 75% to 13.3 tCO_2/TJ.

Ambitions

In sum, we show that GHG emissions in Norway will fall by 23% by 2030, and by 68% by 2050 – including the effect of CCS developments. That is far from Norway's NDC ambition to more than halve emissions by 2030 and approach carbon neutrality by 2050. Technology can deliver these ambitions levels, but only within the context of reinforcing policy decisions and support.

> "Accelerating CCS is dependent on policy spurring it to the point where the technology learning has brought down CCS costs and makes it competitive with carbon prices

FIGURE 5.4



REFERENCES

BP (2020) *BP Statistical Review of World Energy 2020.*

Cutler & Morris (2013) Cleveland, Cutler J., and Christopher G. Morris. *Handbook of energy: diagrams, charts, and tables.* Vol. 1. Newnes, 2013.

DNV GL (2020a) *Energy Transition Outlook 2020 – a global and regional forecast to 2050.* Available at: eto.dnvgl.com

DNV GL (2020b) *Decarbonizing pathways for shipping - Energy Transition Outlook 2020*

EIA RECS (2015) *Residential Energy Consumption Survey. U.S. Energy Information Administration*

Energifaktanorge (2020) *Energy facts in Norway.* Available at: https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon

ENTSO-E (2020) *Transparency Platform.* Available at: https://transparency.entsoe.eu/

Equinor (2020) *Utbygging og drift av kraft fra land til Sleipner.* Available at: https://www.equinor.com/content/dam/statoil/documents/impact-assessment/sleipner-kraft-fra-land/equinor-vedlegg-1-re-pm712-00011-01-dokumentasjon-av-konsekvenser-ved-utbygging-og-drift-av-kraft-fra-land-til-sleipner.pdf

GCCSI (2020) *Global CCS facilities database.* Available at: https://co2re.co/FacilityData

GlobalData (2020) *GlobalData Power Database.* Available at: https://www.globaldata.com/industries-we-cover/power/

Global Energy Observatory, Google, KTH Royal Institute of Technology in Stockholm, Enipedia, World Resources Institute. (2019). *Global Power Plant Database.* Available at: http://resourcewatch.org/

Global Wind Atlas 3.0, Technical University of Denmark (DTU), World Bank Group, Vortex, Energy Sector Management Assistance Program (ESMAP). Available at: https://globalwindatlas.info

Harvey, L. D. (2014). *Global climate-oriented building energy use scenarios. Energy Policy,* 67, 473-487.

Hydro (2020) *Improve your resource efficiency.* Available at: https://www.hydro.com/en-NO/products-and-services/services/remelting-and-recycling/

IEA ETP (2016) *Energy Technology Perspectives.* International Energy Agency.

IEA WEB (2019) *World Energy Balances.* International Energy Agency. Available at: http://www.iea.org/statistics/relateddatabases/worldenergybalances.

IRENA (2020) *Renewable Electricity Capacity and Generation Statistics Query Tool.* Available at: https://www.irena.org/Statistics/Download-Data

Nakićenović et al. (1996) *Regional and global exergy and energy efficiencies.* Energy. Volume 21, Issue 3, March 1996, pp 223-237. https://doi.org/10.1016/0360-5442(96)00001-1

NPD (2019) *Historical and expected production in Norway*. Available at: https://www.norskpetroleum.no/en/production-and-exports/production-forecasts/

NPD (2020a) *Exports of oil and gas*. Available at: https://www.norskpetroleum.no/en/production-and-exports/exports-of-oil-and-gas/

NPD (2020b) *CO_2 ATLAS FOR THE NORWEGIAN CONTINENTAL SHELF*. Available at: https://www.npd.no/en/facts/publications/co2-atlases/co2-atlas-for-the-norwegian-continental-shelf/7-summary-storage-capacities-of-the-norwegian-continental-shelf/

NVE (2011) NVE. *Økt installasjon i eksisterende vannkraftverk*. 2011.

NVE (2019) *Krafproduksjon i Norden til 2040*, Oktober 2019, Nr. 43/19. Available at: http://publikasjoner.nve.no/rapport/2019/rapport2019_43.pdf

Offshore (2006) *Snøhvit development employs subsea-to-beach long-offset control system*. Available at: https://www.offshore-mag.com/subsea/article/16754525/snhvit-development-employs-subseatobeach-longoffset-control-system

Platts (2018) *World Electric Power Plants Database March 2018*. Available at: https://www.spglobal.com/platts/en/products-services/electric-power/world-electric-power-plants-database

SSB (2020) *Statistisk sentralbyrå Statistikkbanken*. Available at: https://www.ssb.no/statbank

Wittgenstein Centre for Demography and Global Human Capital (2018) *Data Explorer Version 2.0* (Beta). Available at: http://www.wittgensteincentre.org/dataexplorer

THE PROJECT TEAM

This report has been prepared by DNV GL as a cross-disciplinary exercise between the Group Technology and Research unit and our business areas.

CORE CONTRIBUTORS FROM DNV GL:

Project responsible: Sverre Alvik

Project manager: Mats Rinaldo

Modelling responsible: Onur Özgün

Core modelling- and research team and contributing authors: Gudmund Bartnes, Thomas Horschig, Anne Louise Koefoed

Communications and editing: Mark Irvine, Ellen Skarsgård

Published by DNV GL AS. **Design** SDG/McCann Oslo/Infogr8. **Print** 07 Media AS. **Paper** Galerie art silk 250/Arctic Matt 115. **Images** Cover image: Getty Images, p. 2: Getty Images, p. 9: Hydro, p. 11: Getty Images, p. 25: Mo Industripark, p. 48: Getty Images.

Historical data

SAFER, SMARTER, GREENER

HEADQUARTERS:

DNV GL AS
NO-1322 Høvik, Norway
Tel: +47 67 57 99 00
www.dnvgl.com

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.

dnvgl.com/eto