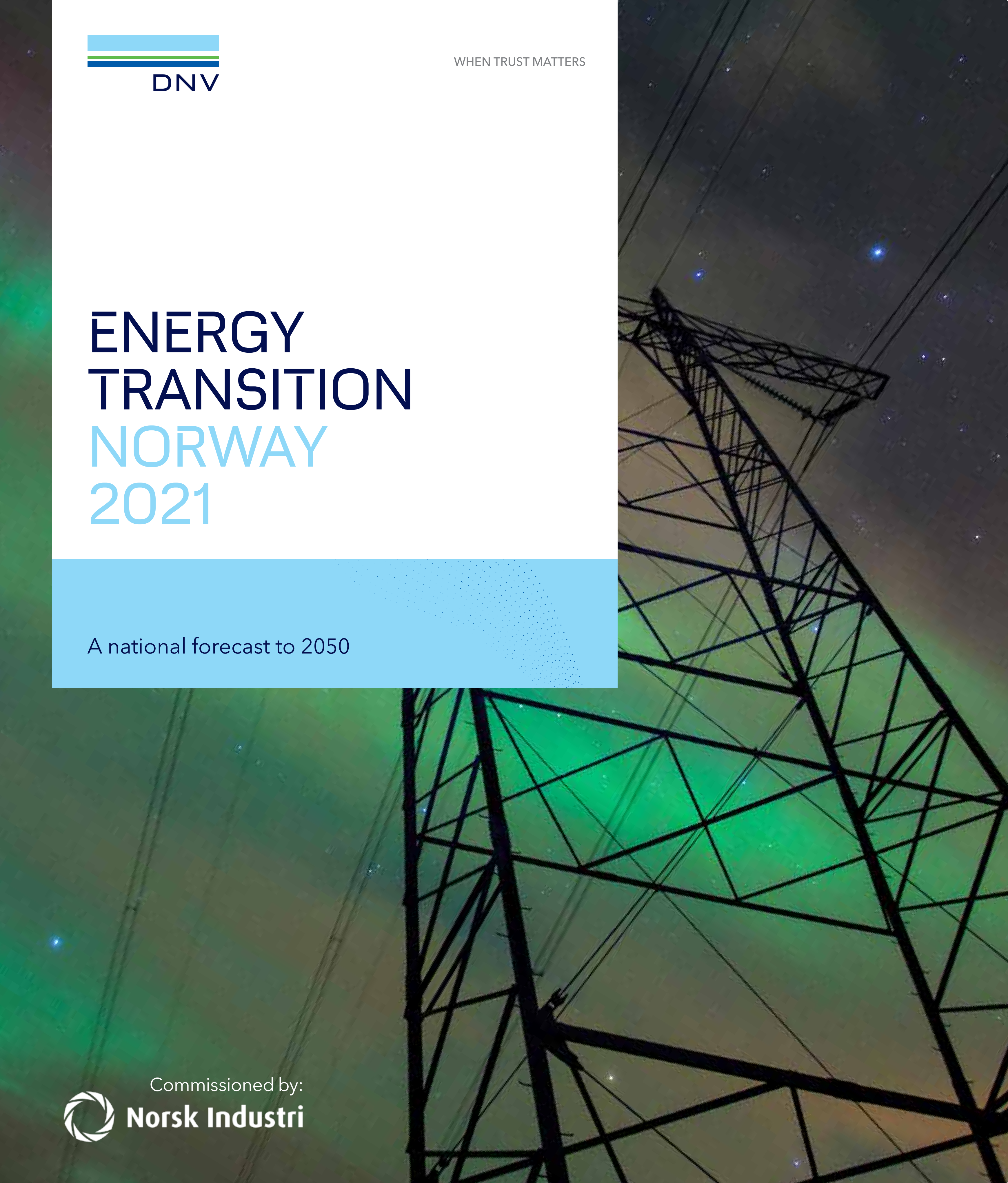


DNV

WHEN TRUST MATTERS

ENERGY TRANSITION NORWAY 2021

A national forecast to 2050

Commissioned by:
Norsk Industri

FOREWORD

This is the second time Norsk Industri (the Federation of Norwegian Industries) and DNV have joined forces to produce this *Energy Transition Norway outlook* report. The 2021 edition is integrated with DNVs global report *Energy Transition Outlook* 2021. This report, focusing on Norway, aims to present a clear and solid picture of our most likely energy transition through to 2050. An important part of the energy transition is to understand how GHG emissions can be reduced to fulfill the commitments Norway has made.

Since the last report was released in November 2020, Norway has further increased its climate ambition to a 55% reduction of GHG emissions in 2030 compared to 1990. That means going down from approximately 52 million tonnes in 1990 to some 23 million tonnes in 2030. However, emissions in 2020 were only slightly lower than in 1990, making the way ahead extremely challenging. In the next nine years, emissions need to fall by approximately 29 million tonnes. That is a very sharp decline relative to the rather flat developments in the period 1990 to 2020.

This report shows that Norway is far from reaching the emission targets set forth for both 2030 and 2050. Our outlook shows that we are only reducing emissions by 24% in 2030, or some 13 million tonnes. That leaves another 16 million tonnes to be removed by 2030 to achieve Norway's committed targets. In 2050 the target is to be a zero-emission country while the outlook shows a reduction of only 79%.

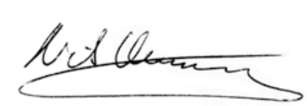
Norway already enjoys a low carbon intensity energy system thanks to its hydropower dominated electricity system. Most of the emissions to be reduced are therefore in the hard-to-abate sectors like oil and gas production, heavy transport, and the industry sector.

Renewable electricity is the key lever for reducing emissions in the main sectors of transport, industry, and oil & gas. Everything that can be electrified should be. Clean electricity is needed for making hydrogen, ammonia, and in carbon capture. New green industries like battery factories will require a large amount of clean electricity. The electricity supply in 2050 is expected to be some 250 TWh or 75% higher than today's production. Floating offshore wind is the key instrument for Norway to scale up electricity supply.

Europe is dependent on energy export from Norway. Due to the export of oil and gas, Norway's trade balance is positive. But oil and gas export values are expected to reduce by some 2/3 by 2050 due to less production. This will have a significant impact on both labour force and trade balance. Green industries and clean energy export need to be developed to regain a positive trade balance.

Time is of the essence. The planet is getting warmer, and we see more frequent natural disasters. It is of paramount importance to increase the clock speed of getting projects approved by a variety of regulatory bodies. Infrastructures for electricity and hydrogen need to be built before demand is committed. Offshore electrical infrastructure is required. Expanding floating offshore wind production must be in place to support the demand for electricity. Governmental support schemes are necessary to kick off projects and to get the cost curve down on new technologies.

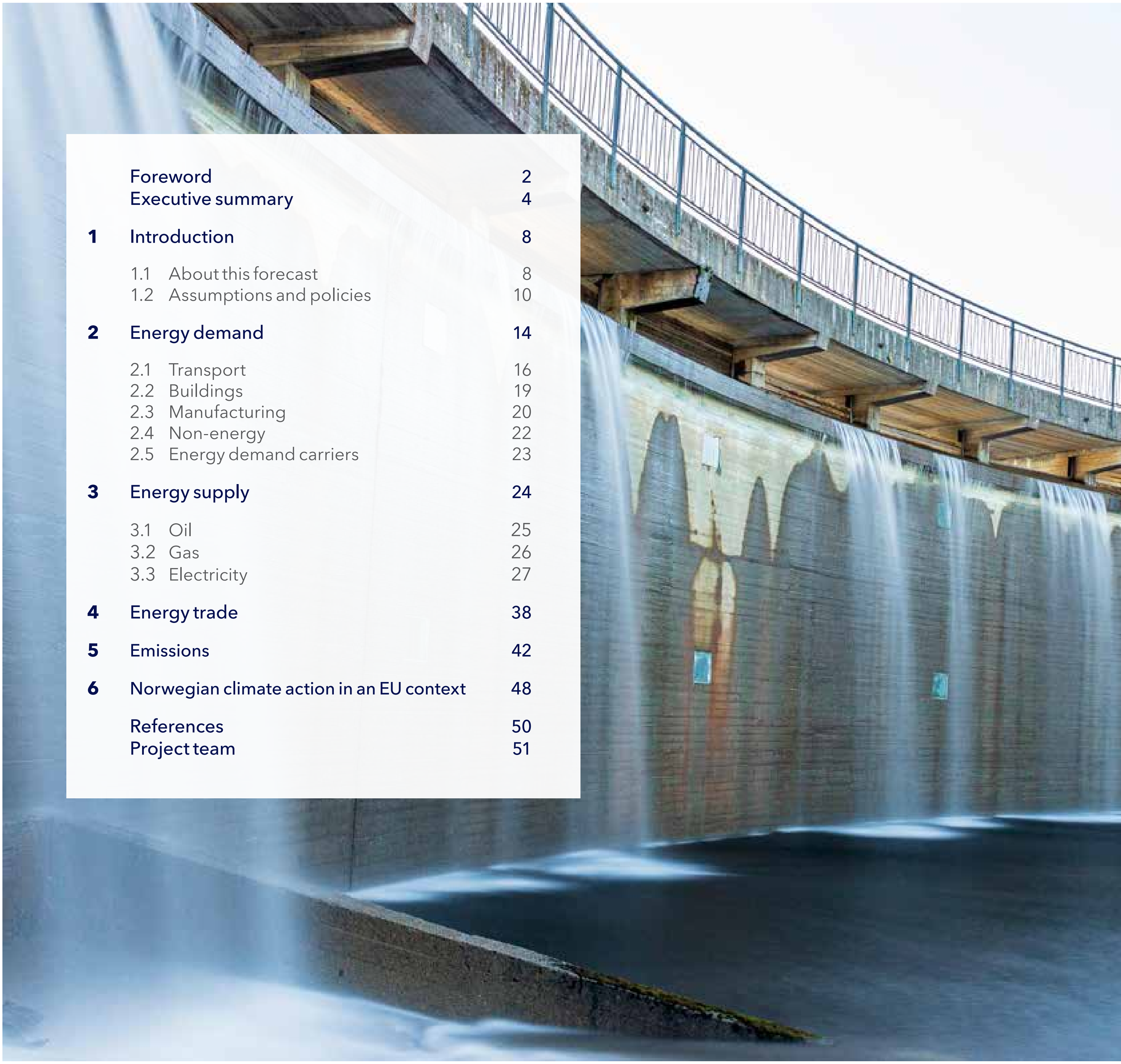
It's time for action – we need to make decisions now. The Norwegian industries are ready to work shoulder to shoulder with our government to solve the climate challenge and build our capacity for future export.



Nils Klippenberg

Chairman Electro and Energy – Norsk Industri

CONTENT



EXECUTIVE SUMMARY

Highlights

1. **Norway is not likely to meet its 2030 climate targets**
2. **Growing renewable electricity is urgent to fertilize green industrial growth and fulfill decarbonization targets**
3. **Oil and gas exports are set for a continuous decline, resulting in dramatic losses of export revenues**
4. **Norway has a solid platform to grow green export-orientated industries – but that needs supporting policies**

All national energy transitions are unfolding within regional transitions shaped in turn by global trends. This analysis of the Norwegian energy transition is noteworthy as it is shows how interconnected countries are to their regional neighbours as well as to energy imports and exports on a global scale.

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

This *Energy Transition Norway* report describes DNV'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 Norsk Industri, Norwegian politicians and other decision makers, and all stakeholders in the energy system.

Norway is not likely to meet its 2030 climate targets

Norway has ambitious climate targets that involve reducing emissions by 55% by 2030 compared with 1990 levels, with a further reduction down to net zero by 2050. Our forecast shows that Norway will most likely only achieve a 24% reduction by 2030 (Figure 1) and an 79% reduction by 2050[1].

Norway's energy use already has low carbon-intensity owing to its hydropower-dominated electricity system. This sets up a challenge because most of the remaining emissions are in hard-to-abate sectors, such as oil and gas production, heavy transport, and agriculture – and it is those sectors that will need to be targeted if Norway is to reach its ambitious climate targets. On the other hand, we see a comparatively successful decarbonization of the road transport sector, especially for passenger vehicles. By 2030, battery electric vehicles (BEVs) will make up half of the Norwegian passenger vehicle fleet, resulting in a CO_2 emission reduction of 25% of the total road sector emissions compared with 1990 levels.

[1] Note that the DNV model quantifies only energy-related CO_2 emissions; projections for other GHG emissions are made outside the model using expert advice and proxies related to energy use such as methane emissions from oil and gas extraction is correlated to oil and gas activities.

Our modelling through to mid-century shows Norway's 2050 greenhouse gas (GHG) emissions reducing 79% compared with 1990, while the Norwegian government's stated ambition is to reduce emissions to net zero by 2050. DNV's recent publication *Pathway to Net Zero* (DNV, 2021c) shows that high income countries, such as those in Europe, must go below net zero in order for the world to reach the ambition of the Paris Agreement, since lower income countries in transition will not be able to reach zero by 2050 due to their different economic development path with weaker technical and infrastructure capacity.

Targeted policies and their effective implementation, including public investments for additional R&D, and funding for real-world projects to trigger technology readiness and scale-up, will be decisive for fulfilling emissions-reduction ambitions. Should Norway ratchet up its ambitions to reach net zero emissions before 2050, such policies become even more urgent and important. Measures are likely to include instruments that may prove unpopular, or which can only be settled by ballot.

Growing renewable electricity is urgent to fertilize green industrial growth and fulfill decarbonization targets

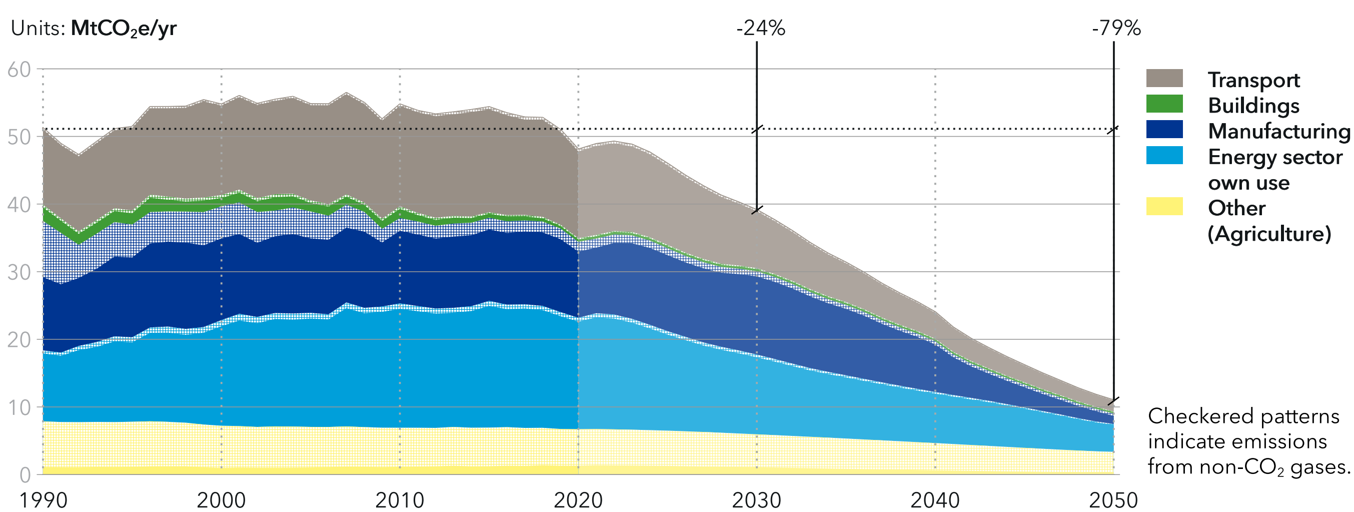
Norway's electricity production is historically almost entirely based on hydropower, but over the last few years onshore wind representing around 10% of generation capacity has been added. In addition to domestic production, electricity is imported and exported continuously through a Nordic grid and interconnector cables to Germany as well as UK. Capacity additions in recent years from hydropower as well as onshore wind have added some variable renewable capacity which has resulted in an almost 10-year streak in annual net-electricity export.

In the coming decade, we foresee a significantly increased electricity demand, but slower production growth. Households, service industries, as well as the electrification of transport, will consume the existing Norwegian electricity surplus. This will lead to a deficit of domestic electricity supply for further decarbonization plans as well as new industrial growth within sectors such as battery factories, green steel, alumina and electrolysis-based hydrogen production.

FIGURE 1

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Emissions from power generation are allocated to end-use sectors. Historical data source: SSB (2021)

To supply the Norwegian Continental Shelf (NCS) with electricity while supporting green industrial growth at the same time, Norway will likely be forced to import electricity for several years between 2025-2035 (Figure 2). Import of electricity can cause volatility as well as potentially higher prices – removing the competitive advantage of low-priced green electricity needed for industrial production.

Our forecast points to severe challenges in juggling ambitions of electricity surplus, reducing emissions as well as supporting industrial growth, without adding considerable new capacity. Around 2030, when offshore wind capacity starts to build out, the situation improves somewhat and, from the mid-2030s, Norway can once again leverage an annual electricity surplus.

Oil and gas exports are set for a continuous decline, resulting in dramatic losses of export revenues

Norway has enjoyed significant energy abundance ever since the start of oil and gas production on the continental shelf in the early 1970s, contributing to continuous budget surpluses and the development of the sovereign wealth fund. Norway is the world's fourth largest gas exporter, the eleventh largest oil exporter, and almost 90% of its petroleum production is exported (Figure 3).

However, Norwegian oil production will start to decline after 2025 when several fields are at the end of their lifetimes and when global demand for oil begins to fall; by 2050, exports will be less than 20% of today's level. We see gas production and export remaining at present levels until around 2030, from when they enter a gradual decline as European gas demand declines in line with aggressive climate policy and renewable energy competition.

Nevertheless, by 2050, the majority of energy exports will still be gas and oil. These exports were valued at 333bn NOK in 2020 (NPD, 2021). Assuming constant prices, a 63% reduction in oil and gas exports will result in a 210bn NOK annual loss in revenue. Even with the assumed build out of offshore wind for energy export, the 11 TWh/yr in net electricity exports by 2050 will only translate to an additional income of 6-7bn NOK/yr. Without an aggressive expansion policy for electricity and other green exports, Norway faces a significant long term export revenue drop.

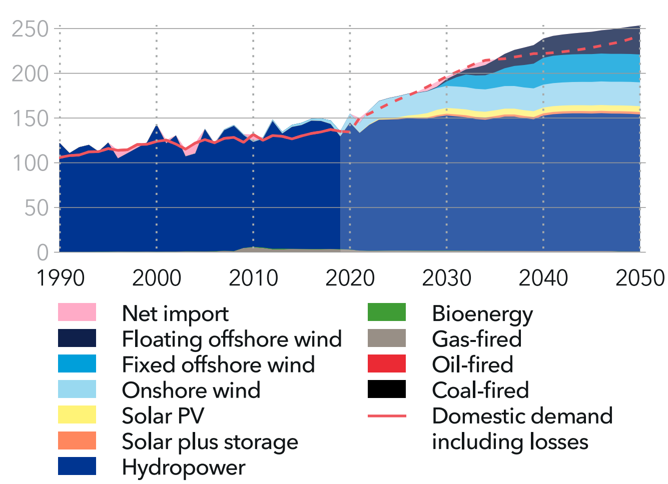
Norway has a solid platform to grow green export-orientated industries – but that needs supporting policies

Observing the global energy transition as described in our ETO (DNV, 2021a) there are some sectors where we

FIGURE 2

Norway electricity supply by power stations and net imports

Units: TWh/yr

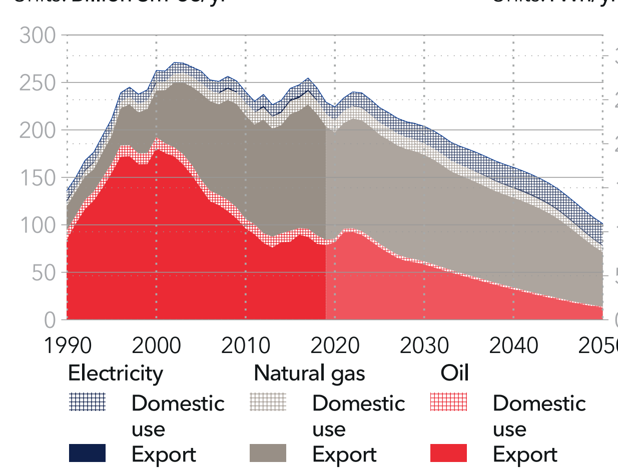


Historical data source: SSB (2021), IEA WEB (2020)

FIGURE 3

Norway's energy production allocated to domestic use an

Units: Billion Sm^{3}oe/yr Units: TWh/yr



Oil includes condensates, natural gas includes NGLs.
Historical data source: NPD (2019), IEA WEB (2020)

expect significant growth: A 20-fold increase in solar PV capacity and 10-fold growth in wind capacity. Offshore wind will grow from today's share of less than 1% to represent almost 15% of global electricity generation. The number of EVs and their associated batteries are set to grow at an average annual compound growth rate of 19%. However, even with the explosive growth of these green industries, the climate challenge will intensify and, in our Outlook – rapid as it is – we expect average global temperature to reach 2.3°C above pre-industrial levels. Thus, we expect that there will be mounting pressure to further decarbonize the so-called hard-to-abate sectors (e.g., industrial heat, aviation, trucking and shipping), with solutions such as CCS, hydrogen and biofuels. Norway is already at the forefront of developments in these decarbonizations technologies.

Norway is especially well positioned for a leading role in floating offshore wind (FOW) power production. Hywind Tampen in the North Sea will be the world's largest FOW development when it is commissioned in 2022. DNV forecasts that by 2050, the world will have installed just over 260 gigawatts (GW) of FOW – corresponding to 3,000 Hywind Tampen fields – of which almost 7 GW will likely be in Norwegian waters and 40 GW in rest of Europe. 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.

CCS will have a significant role to play in decarbonizing the power system globally, as well as heavy industry. Our ETO forecast finds that 26% of natural gas used in Europe in 2050 will likely be decarbonized, either as hydrogen or via post-combustion carbon capture and storage (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's CCS initiative, Longship, is a leading example of public-private project/policy initiative that can lead to opportunities for future growth, expertise and technology transfer. In addition to hydrogen based on natural gas with CO_2 removal, hydrogen based on electrolysis can further supply domestic demand as fuel in hard-to-abate sectors, as well as decarbonized feedstock in the process industry.

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, including hydrogen fuel cells, for domestic short-sea shipping. Extending this leadership into research, piloting and development of low- and zero-carbon fuels, batteries and related infrastructures for deep-sea shipping is a promising opportunity.

Industrial development policies will be instrumental for unleashing industry opportunities enabling green industrial growth. Building a domestic industry will require opening up the policy toolbox to decide how best to support industry and technology initiatives at various stages of maturity, and to stimulate market and supply-chain creation through projects that enjoy the enthusiastic buy-in of local communities, and the nation as a whole.

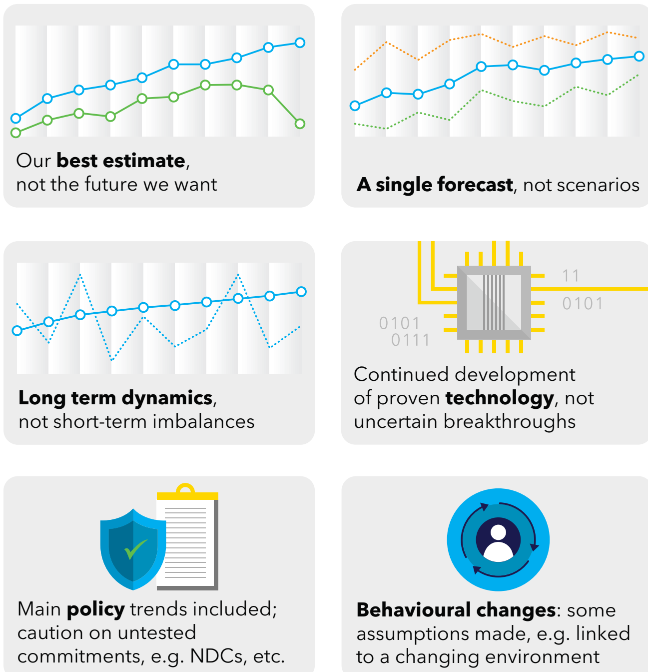
Without aggressive expansion policies for electricity and other green industry exports, Norway faces a substantial drop in energy-related export revenue.

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's global forecast, the *Energy Transition Outlook* 2021 (DNV, 2021a) and Energy Transition Outlook (ETO) model. This is necessary since Norway is part of the global energy system, and the country's demand, as well as its supply of energy, are affected by what happens in the rest of the world. Similarly, what happens in Norway can affect other parts of the world. 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.

Our analysis produces a single 'best-estimate' forecast of the likely energy future for Norway, 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.



Our approach

Our model simulates the interactions over time of the consumers of energy (transport, buildings, manufacturing, and so on) and all sources of supply. It encompasses demand and supply of energy globally, and the use and exchange of energy between and within ten world regions.

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.

The analysis covers the period 1990-2050, with changes unfolding on a multi-year scale that in some cases is fine-tuned to reflect hourly dynamics. We continually update the structure of and input data to our model. In this report we do not repeat all the details on methodology and assumptions from the Energy Transition Outlook 2021 (DNV, 2021a), 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.

When modelling Norway as a standalone region, we have also added a module to the model to accommodate power trade. In our global model, only oil, gas and coal are traded between the regions, as cross-regional trade in power is assumed to be low. However, power 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.

Interviews

Our modelling approach, as well as the calibration of the modelling input values, become increasingly sensitive when we model a country compared with a region or globally. This is especially prevalent when we consider exogenous or outside assumptions such as policies or factors that are country-specific and have a significant effect in forcing the model to select solutions that are not necessarily the cheapest option. Such factors could be energy security, job creation or global climate commitments. Thus, in order to better understand the most likely development in the near- to medium-term where these issues have biggest impact and are also easier to predict, we have conducted a number of interviews with politicians, researchers, advocacy groups and business leaders to gain insights on how they see the medium-term future policy landscape unfolding.

We are deeply grateful to those who took the time to make themselves available for interviews. The interviews were conducted by videoconference and generally ran to about one hour, during which time DNV posed open questions to gain insights from the interviewee's field of expertise and to allow them to express personal opinions that were not necessarily representative of their affiliation. More information on our interviews can be found at the end of this report.

1.2 Assumptions and policies

Key input assumptions in the ETO model are linked to parameters such as 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 combine to drive 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 has developed its own GDP forecast model, basing projected GDP per capita growth on the inverse relationship between GDP per capita level and GDP 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 changes. The 2020 COVID-19 outbreak caused such a change, with negative growth figures. Because our model is not suited for short-run changes, we have chosen to deviate from our model and instead use economic growth figures from the International Monetary Fund (IMF). The GDP change for Norway is therefore -0.5% in 2020, and +4.0% in 2021 and 4.1% in 2022, thereafter returning to the growth rates given by the DNV GDP model.

For Norway, 2020 GDP was USD 379bn, while in 2050 it will be at USD 608bn. This implies a CAGR of 1.6% per year, including the effect of COVID-19. Productivity increases from USD 71,000 to USD 95,000 per person in the same period, measured in USD-denominated 2017 purchasing power parity (PPP) terms.

Technology development
DNV bases its Energy Transition Outlook on the continued development of proven technologies in terms of costs and technical feasibility, not uncertain breakthroughs. However, 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 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. Carbon capture and storage (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 photovoltaic panels, from supporting technologies, i.e. control systems and installation kits. Typically, the latter have a lower CLR. For solar PV, core technologies have a CLR of 28%, while balance of supply (BOS) only has 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 26% for solar PV, falling to 17% later in the forecast 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, 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. For Norway, we incorporate existing and likely future policy factors into the forecast.

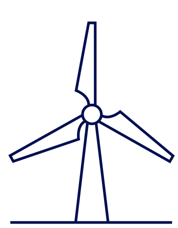
It is not a given that energy or climate ambitions and targets will be met, either on a national, regional, or global level. As such, our forecast does not assume that Norway will accomplish its national target of reducing greenhouse gas emissions by 55% compared with 1990 levels by 2030.

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 translating ambitions into reality influencing the emissions trajectory.

From the main ETO report (DNV, 2021a) we have a comprehensive list of policy factors influencing the forecast. The same policy factors (Figure 1) are incorporated in this analysis with the following adjustments for Norway:

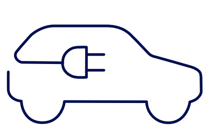
FIGURE 1

Policy factors included in our Outlook



Renewable power support

– Floating offshore wind projects will obtain financial support to supply domestic 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 reduces towards 2050.



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 they reach 90% of new commercial vehicle sales in 2040.

- The support scheme for hydrogen in the commercial vehicle category will help the uptake of fuel cell electric vehicles (FCEVs) based on hydrogen from the early 2030s as production of hydrogen becomes viable, to reach a final new sales share of 10% in the commercial vehicle segment by 2050.

Hydrogen

- Hydrogen production in Norway will mainly be based on electrolysis. We expect to have some projects supported by subsidies to compensate for high prices where CO_2 pricing still makes hydrogen uncompetitive.

Carbon capture and storage support

- The Longship project with CCS from Brevik is included with phase-in by 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 liquefied natural gas (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.

Carbon-pricing

- Carbon prices are reflected as costs for fossil fuels in the power and manufacturing sectors. In these areas Norway is part of EU emissions trading scheme (ETS), and carbon prices equivalent to rest of Europe (reaching USD 100/t CO_2 in 2050) are used.
- A Norwegian CO_2 tax reaching 2000NOK or 230 USD/t CO_2 by 2030s is applied in the energy sector's own use, such as oil and gas extraction.
- 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.

Fuel tax

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

Power capacity limitations

- For political reasons, 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 limitations on capacity expansions, and capacity will be added when profitable, also for export.
- Norway is expected to add generating capacity to support increasing demand for domestic electricity use. Since hydropower and wind production vary 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 expansion of transmission capacity of 1.4GW to Europe to be installed by 2021. Further transmission capacity of 5GW is assumed to be gradually introduced during the 2030s.

2 ENERGY DEMAND

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

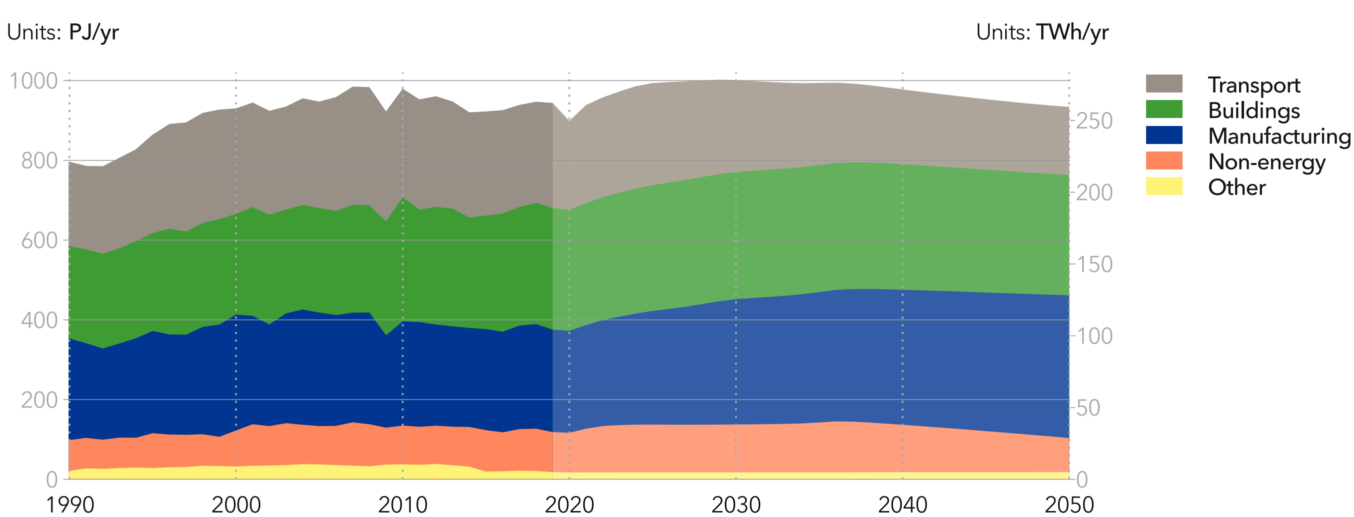
Historically, energy demand has grown in lock-step with population growth and improvements in standards of living. Norway's population growth is slowing down, but still reaches 6.4 million people in 2050. Economic growth will average 1.6% from 2020 to 2050, when the size of the Norwegian economy will be 60% higher than today's USD 379bn.

More people requiring more energy services for transportation, heating, lighting or consumer goods typically means increased energy demand. This held true until around 2008, when demand growth started to level off owing to impressive developments in energy efficiency, achieved by, for example, advances in lighting and heat-pump technologies.

The coming decades are likely to be different. Due to significant efficiency gains – largely enabled by accelerated electrification – energy demand growth will eventually track well below economic growth. A major drop in energy demand in 2020 due to the COVID-19 pandemic will be followed by a pick-up in 2021 with continued growth towards 2030. However, from that point, 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,

FIGURE 2.1

Norway final energy demand by sector



Historical data source: IEA WEB (2020), SSB (2021)

strongest in transport and least in manufacturing energy use.

Energy efficiency is a 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 oil and gas production will improve efficiencies. Efficiencies come not only in the supply of energy, but also in how energy 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.

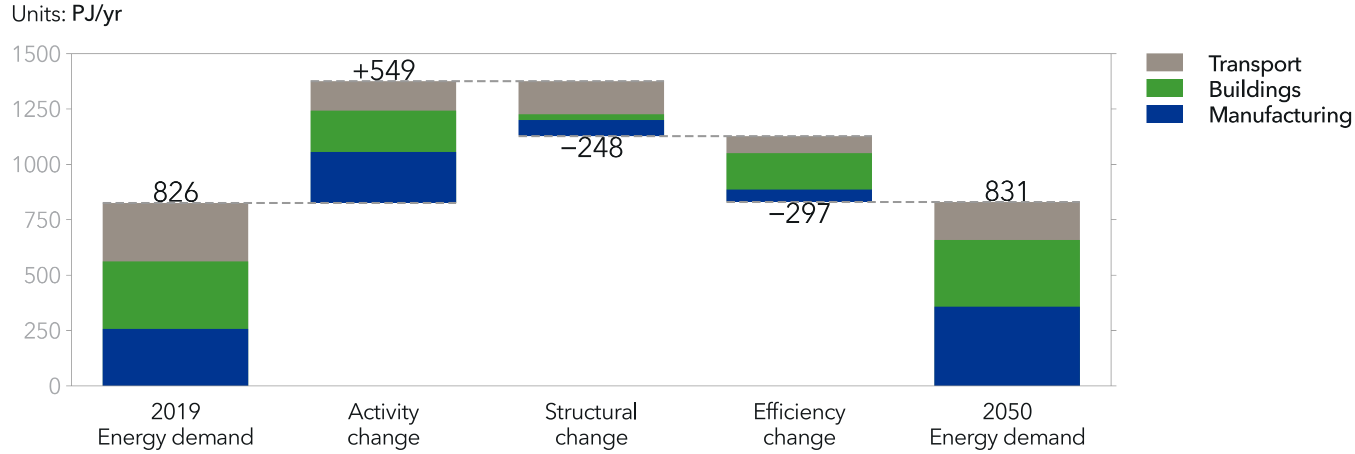
Figure 2.2 shows how Norway's energy demand in 2050 is significantly influenced by efficiency gains and expected structural changes. All sectors will experience activity change (e.g., more people, more buildings to heat and cool) that increases demand, where population and economic activities requires increased energy services delivered. The net effect of structural changes (e.g., technology shifts) – particularly the electrification of the 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 almost the same compared with present energy demand levels.

Energy efficiency is a key driver of the transition over our forecast period. It is also usually the most cost-effective measure to reduce emissions.

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 25% of Norwegian final energy demand in 2020, almost entirely in the form of oil as fuel (86%). We forecast that overall energy demand will decline almost 23% from 223 petajoules (PJ) in 2020 to 171 PJ by 2050 (Figure 2.3).

Passenger and commercial vehicles combined are the largest sources of energy demand, consuming 57% of total energy demand in 2020. With road transport set to be largely electrified by 2050, its share of energy demand reduces to 43%. Overall, the transport sector's transformation will include oil's share in the fuel mix dropping from 86% today to 27% in 2050 as electricity and low-carbon fuels come to dominate. The other three demand sectors modelled do not improve efficiency to the same degree.

Road

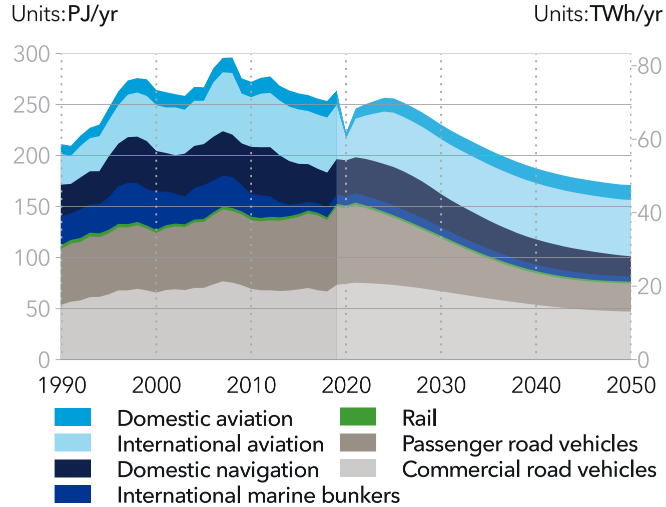
We envisage policy targeting emission reductions from road traffic to continue with significant incentives (purchase and operation) to companies and private individuals encouraging switching from ICE vehicles to EVs. Over time, battery cost-learning rates will render such policies superfluous – at least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

However, BEV uptake in the near-term hinges on continued policy support, and our forecast factors in a significant level of such support – with exclusion from Norwegian value added tax (VAT), and other benefits, continuing at present levels until 2025, then gradually being halved by 2030. EVs will account for 89% of new passenger vehicle sales in Norway in 2025, and 97% by 2030 (Figure 2.4). EV uptake will be somewhat slower in the commercial-vehicle segment, 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 ICEVs, and

FIGURE 2.3

Norway transport sector energy demand by subsector

Units: PJ/yr   Units: TWh/yr

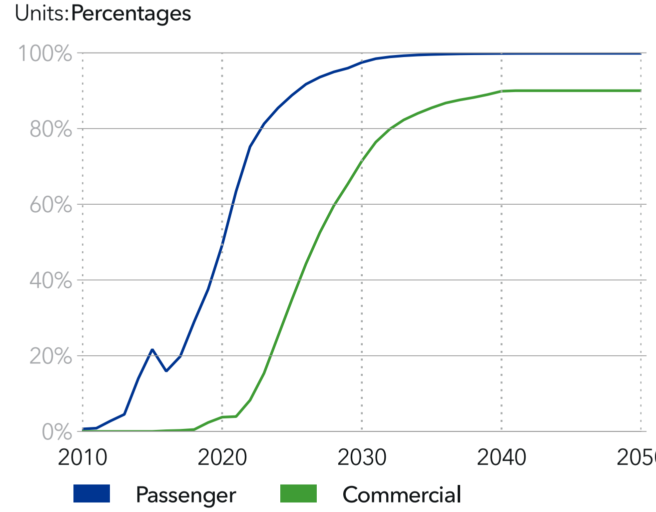


Historical data source: IEA WEB (2020), SSB (2021)

FIGURE 2.4

Norway market share of electric vehicles

Units: Percentages



Electric vehicles include BEVs and FCEVs. Historical data source: SSB (2021) 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 is a world-leading country when it comes to electrifying passenger-vehicle transport, and we predict 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 3.2 million by 2050, 15% 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 18% towards 2050. However, even with this 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 halving from 148 PJ in 2020 to 75 PJ in 2050, mainly because of the shift from ICE to electric drivetrains. The subsector's energy demand for oil declines 89% while demand for energy from electricity grows 20-fold. In 2050, 96% of cars will be electric, but electricity is only two-thirds of total transport energy demand – which reveals both the efficiency of electricity and the corresponding inefficiency of legacy fuels.

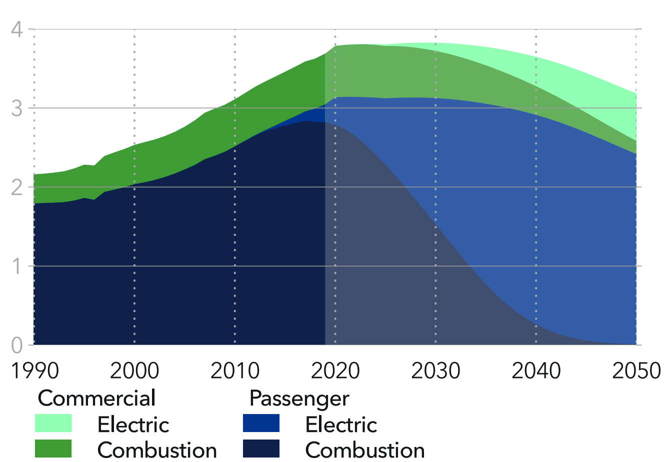
Maritime

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 7% of the world's oil, is consumed by ships today, mainly international cargo shipping. Norwegian energy demand from maritime activities consists of national shipping demand as well as energy demand from international shipping bunkering in Norwegian ports. In 2020, the total demand was 42 PJ of which 80% was domestic use. The COVID-19 pandemic did not affect maritime transport significantly, apart from exposed segments like passenger and cruise traffic. There seems to be a quick recovery and energy demand is growing towards 2030, but the long-term trend will be a decline in energy demand of 42% reaching 25 PJ in 2050.

FIGURE 2.5

Norway number of road vehicles by type and drivetrain

Units: Million vehicles

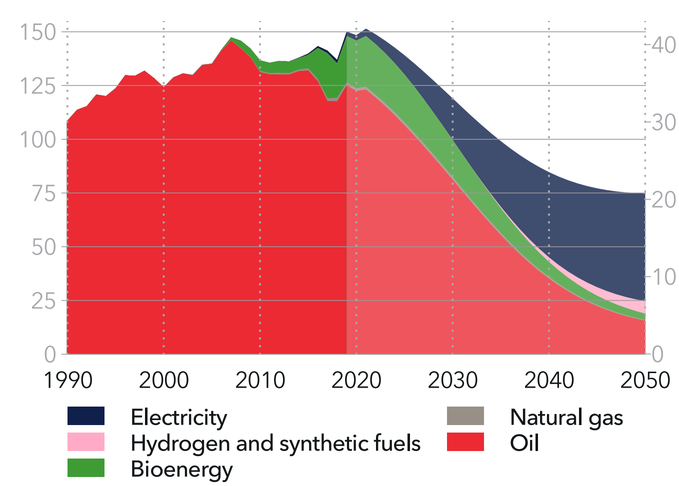


Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs.
Historical data source: SSB (2021)

FIGURE 2.6

Norway road subsector energy demand by carrier

Units: PJ/yr Units: TWh/yr



Natural gas includes LPG. Historical data source: IEA WEB (2020), SSB (2021)

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 ensure this goal is met. Some short-sea shipping and local ferries will use a combination of electric shore power as well as electric propulsion increasing the energy demand for electricity, but it will initially be gas and later other low-carbon fuels that contribute as the main alternative fuel sources for shipping (Figure 2.7).

Aviation

Aviation has grown strongly in recent decades but levelled off since 2010. A dramatic reduction in air travel due to COVID-19 saw the subsector's energy demand fall by more than 60% in 2020. The annual number of air trips is forecast to increase in the future compared with 2020. 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 , parts of which is well suited for electrification, meaning Norway could be a front-runner globally in the electrification of short-haul flights.

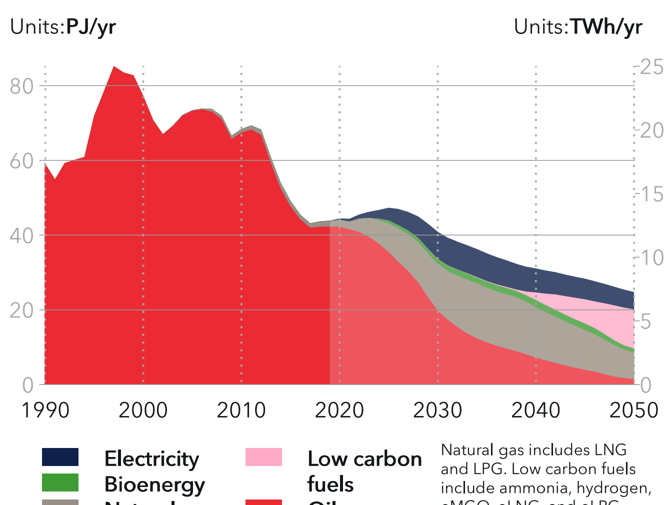
That said, we forecast that sustainable aviation fuels (SAF), particularly biofuel blends, will be the main contributor to aviation emission reductions, especially for international and long-haul flights. Which low-carbon or zero-carbon solution, or mix of fuel solutions, will dominate is not yet known as the alternatives are currently fairly evenly poised in terms of cost and availability. By 2050, 33% (23 PJ in energy terms) of Norwegian aviation's fuel mix will still depend on oil, but the share of biofuels is projected to increase to 24% (17 PJ), hydrogen and synthetic low carbon fuels share is another 26%(18 PJ) and electric aviation to account for 17% (12 PJ) as Figure 2.8 shows.

Rail

The Norwegian rail subsector consists of all tracked transportation including urban rail transport, such as subways and trams. Presently, 1% (2.4 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 fuel mix.

FIGURE 2.7

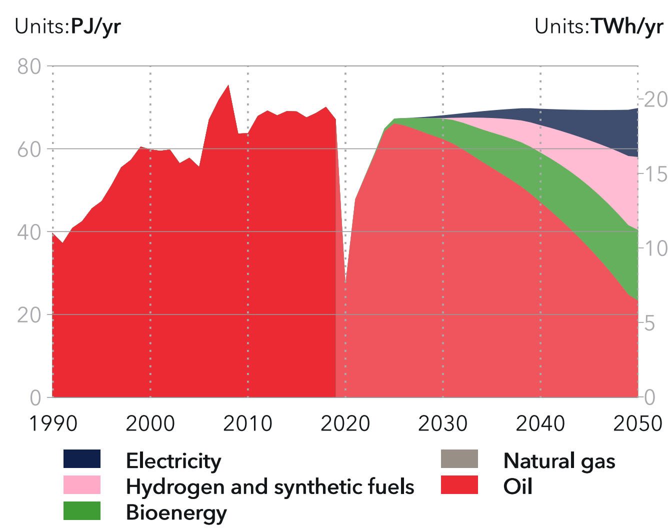
Norway maritime subsector energy demand by carrier



Historical data source: IEA WEB (2020), SSB (2021)

FIGURE 2.8

Norway aviation subsector energy demand by carrier



Historical data source: IEA WEB (2020), SSB (2021)

2.2 Buildings

In 2020, about 34% of Norway's energy was consumed in buildings, making it the largest energy demand sector. Most energy is used for heating (Figure 2.9), and 55% 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. Towards 2050 electricity will grow to represent 91% of the mix with other energy carriers representing the rest equally. We estimate final energy demand for five end-uses: appliances and lighting, cooking, space cooling, space heating, and water heating.

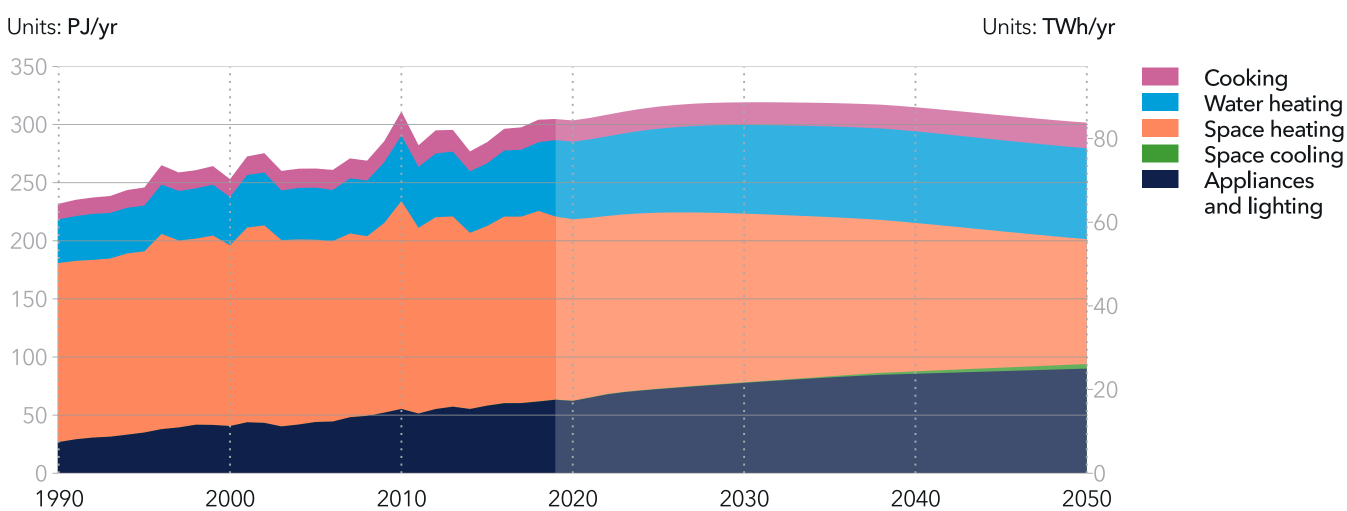
Floor area is one of the most important drivers of energy demand in buildings. While an increasing population with higher GDP per capita will push energy demand in the buildings sector upwards, that will be counteracted by increased efficiencies in appliances and heating.

The residential appliances and lighting segment encompass 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 on the high end of this relationship, and high-income levels manifest themselves in, for example, 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 44% between 2020 and 2050 (Figure 2.9).

Space heating accounts for 51% of all energy demand and is the segment with the biggest expectation of efficiency gains. Buildings heat energy demand will decline from 156 PJ in 2020 by 30% to end at 107 PJ in 2050, even while heating a growing number of buildings. A combination of measures will enable this transformation, including 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



Historical data source: SSB (2021), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2020)

2.3 Manufacturing

The manufacturing sector in our analysis consists of the extraction of raw materials and their conversion into finished goods. However, fuel extraction – coal, oil, natural gas, and biomass – and their conversion, are accounted for under "Energy sector own use" (see below). Manufacturing in our Energy Transition Outlook covers four separate subsectors:

Construction & mining – includes mining and construction (e.g. roads, buildings, and infrastructure).

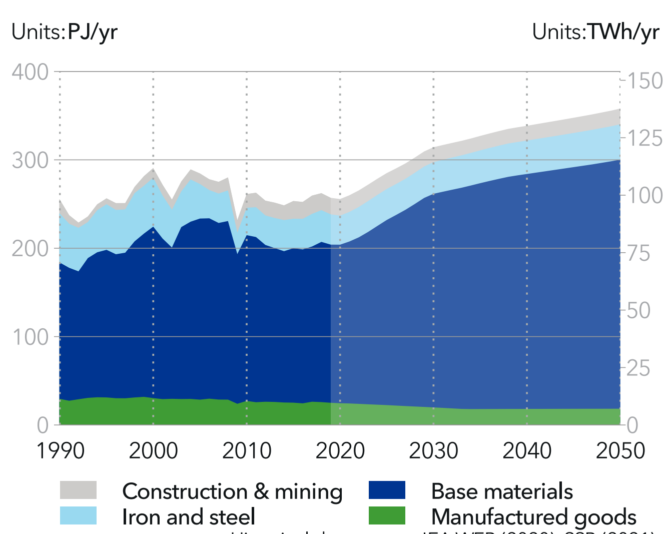
Base materials – includes production of non-metallic minerals (including conversion into cement), chemicals, and petrochemicals; non-ferrous materials, including aluminium; wood and its products, incl. paper, pulp, and print.

Iron & steel – includes the production of iron and steel.

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

FIGURE 2.10

Norway manufacturing energy demand by subsector



Historical data source: IEA WEB (2020), SSB (2021)

There is historical evidence that the industrial sector evolves as the standard of living increases – as measured by GDP per capita. As affluence per person rises, a region transitions from being an agrarian (primary) economy through to being an industrial (secondary) one, and finally, to a service-based (tertiary) economy, whereupon the industrial sector declines. In our analysis, we have mapped the different sectors of the economy from historical records and then extrapolated those trends 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 our Outlook (DNV, 2021a). In Norway, the industrial sector and especially the base material subsector is a large contributor to Norway's manufacturing GDP.

Norway's manufacturing sector consumed 255 PJ in 2020, 28% of the country's final energy demand, and the base materials subsector represents 70% of total manufacturing energy demand (Figure 2.10).

Energy demand from construction and mining was on a continuous growth curve from 1990 until 2015 and at which point energy demand plateaued to the level seen in 2020 at 19 PJ. Going forward, we expect to see energy demand decline slightly towards the mid-2030s and then grow back to end at 18 PJ – slightly lower than today.

Energy demand for the base materials subsector was 179 PJ in 2020. The subsector is energy intensive because it converts raw materials into feedstock for other industries. Energy consumption during base material production is mainly from industrial high-heat processes (70%) and operating machines, motors and appliances (MMA) (27%), as shown in Figure 2.11. COVID-19 appears to have had a limited effect on the subsector's energy demand in 2020. Demand is expected to remain around similar levels for a few more years before growing sharply towards 2030 after which growth eases to 282 PJ in 2050. This overall growth of 60% from today's level is largely driven by an increase in electricity demand from expanding industrial sectors such as battery manufacturing, aluminium and hydrogen production.

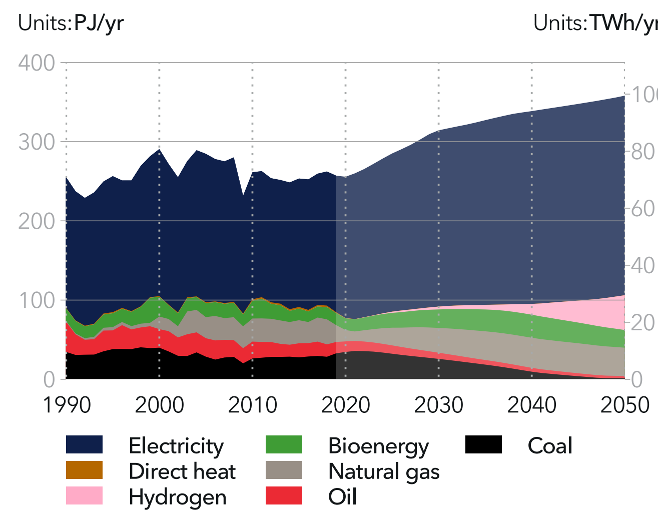
The majority of the Norwegian iron and steel sector's current energy demand is for heat, the rest being for reduction agents during steel production and machinery equipment (Figure 2.11). Energy demand is currently at 33 PJ (33% of total manufacturing) and will see a slight increase as the subsector is set to grow in line with growing GDP. Increasing shares globally of recycled steel in steel production will counter some of the energy demand with reduced need for new virgin iron ore.

Energy demand from manufactured goods has been on a steady decline since 2000 and today represents 10% of manufacturing sector energy demand (25 PJ). The decline is expected to continue towards 2050 and end up at 18 PJ. A large share (60%) of the final energy here is used for heat. Of the remaining most (36%) is to operate machines, motors and appliances (MMA). Driven by automation and digitalization, energy demand for MMA in the manufactured goods subsector will grow towards 2050 (Figure 2.11) when 64% of energy demand will be from MMA while efficiencies in heating will have reduced energy demand to 6 PJ.

Change in the Norwegian manufacturing's energy mix is dependent on technological innovation, resource availability, and on policies and incentives. With 70% of the sector already electrified, further electrification offers only limited efficiency gains, so change between now and 2050 in sourcing energy is most likely for high-heat processes. From the 2030s, we expect 'green' hydrogen produced by electrolysis to increasingly replace coal and natural gas as the energy carriers for manufacturing processes, and rapidly grow from less than 1% of the energy mix in 2030 to 11% in 2050. However, direct electrification will still dominate through to 2050, when it will have a 71% share in the manufacturing energy mix (Figure 2.12).

FIGURE 2.12

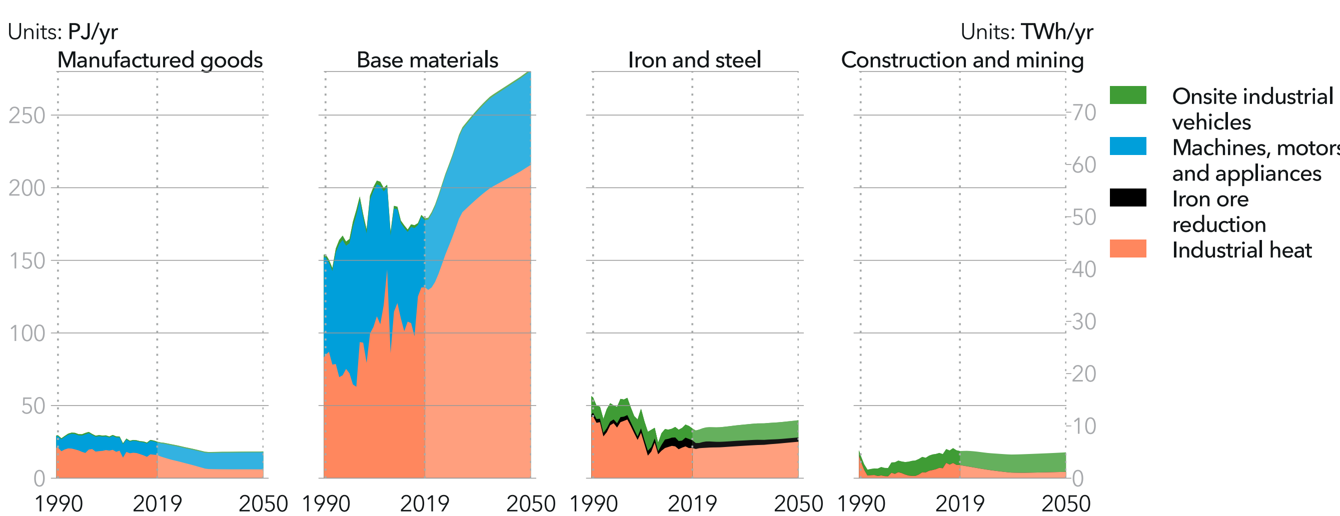
Norway manufacturing sector energy demand by carrier



Historical data source: IEA WEB (2020), SSB (2021)

FIGURE 2.11

Norway manufacturing subsectors energy demand by end use



Historical data source: IEA WEB (2020), SSB (2021)

Quantafuel is co-locating its next generation chemical recycling plant with Replast's existing facilities for mechanical recycling of plastic waste in Kristiansund to maximize plastic waste handling and recycling synergies. *Image courtesy Quantafuel.*

2.4 Non-energy

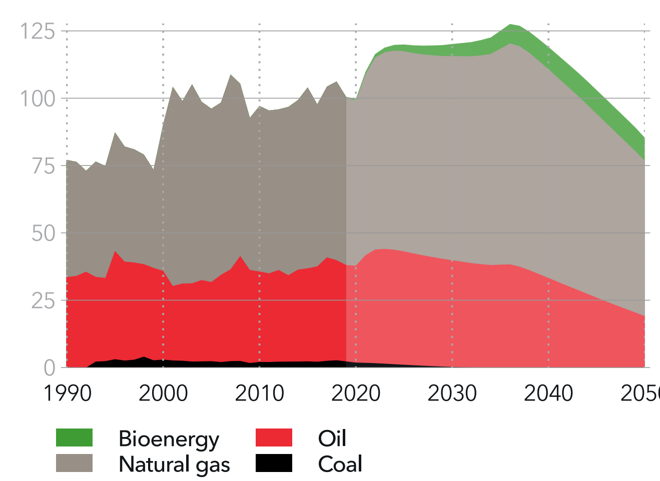
In 2020, 11% or 100 PJ of primary fossil-fuel consumption was used for non-energy purposes. This category represents the use of coal, oil, and natural gas as feedstock. Much of the energy in the form of natural gas goes to petrochemicals as the largest consumer (61%) of feedstock, and the rest is oil 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 2020, with the rest going to making fertilizers, paints, and other chemicals. We expect plastics to account for about 61% of petrochemical feedstock demand globally by 2050. While demand for plastic continues to grow between now and 2050, recycling grows more rapidly. We expect Norway's rate of plastic recycling will improve from an estimate of 26% 2020 to 74% in 2050. It will be boosted by more efficient (and potentially circular) chemical recycling methods supplementing or replacing traditional, mechanical recycling.

FIGURE 2.13

Norway non-energy demand for energy carriers

Units: PJ/yr



Historical data source: IEA WEB (2020)

2.5 Energy demand carriers

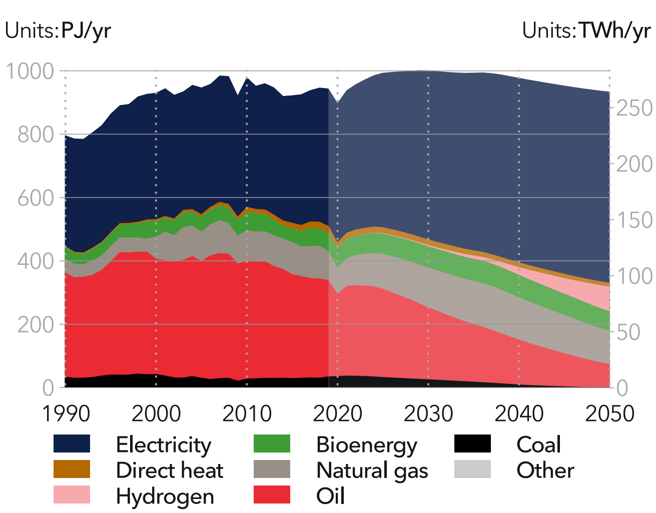
By combining the energy demand of each of the sectors covered, we forecast Norway's final energy demand by energy carrier, as seen in Figure 2.14. 'Final' energy here means the energy delivered to end-use sectors. It excludes energy losses and the energy sector's own use in power stations, oil and gas 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 2020, electricity represented 49% (440 PJ/yr) of Norway's final energy use. In 2050, it will account for 65% (605 PJ/yr). Cheap 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) 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 well as increased renewable-based manufacturing processes. 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



Historical data source: IEA WEB (2020), SSB (2021)

Norway's first large-scale fuel cell production facility could be operational by 2022. (TECO 2030).

3 ENERGY SUPPLY

In DNV's Energy Transition Outlook to 2050 we forecast a future where global energy demand is levelling off, 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 offshore wind.

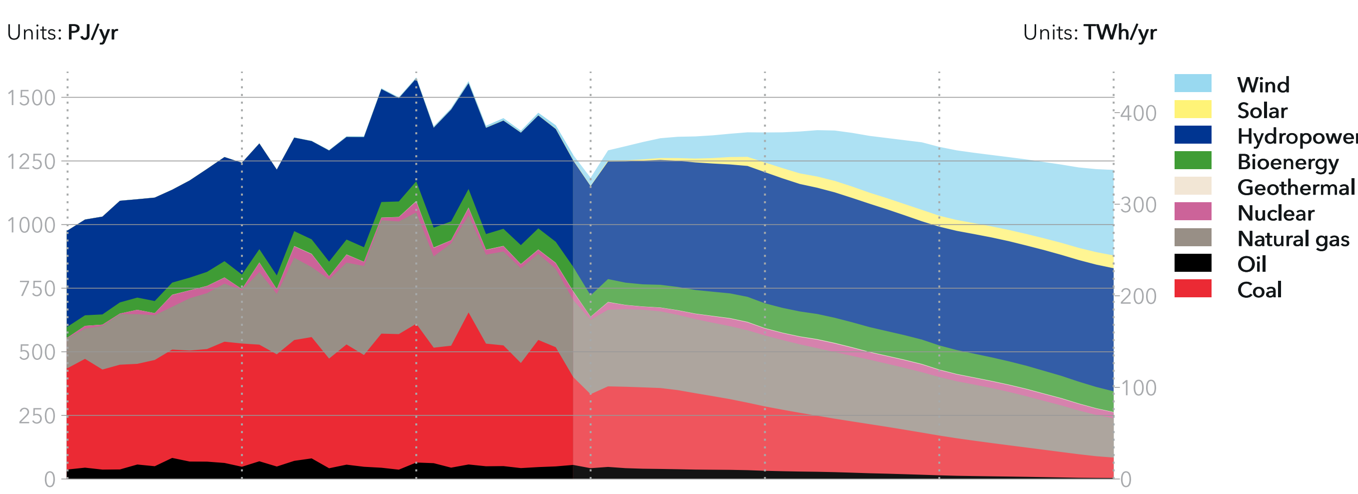
Primary-energy supply is the total amount of energy needed to meet energy demand. There are several ways in which to measure primary energy (DNV, 2021a). In this analysis, we use the Physical Energy Content Method.

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 fall from the high levels seen between 2008 and 2018. However, energy consumption will recover from pandemic-related low levels in 2020 and gradually increase in 2021, rising in the next 10 years before it starts to fall, ending up 3% higher compared to 2020.

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 has traditionally been a net export, which will change in the future with increased demand from the manufacturing sector and electrification of the Norwegian continental shelf supported by interconnection-cables and production capacity increase in Europe. 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 for instance nuclear, as part of the European grid mix.

FIGURE 3.1

Norway primary energy consumption by source (adjusted for gross electricity trade)



Adjusted for gross electricity trade, using average European electricity mix
Historical data source: SSB (2021), IEA WEB (2020)

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 78% of the domestic energy mix, up from the 46% today.

3.1 Oil

For the last 30 years, Norway's domestic oil demand has been on a bumpy ride. Demand declined marginally between 1990 and 2020, from 330 PJ to 274 PJ, with spikes and troughs in between. While historical highs saw numbers up to 410 PJ in 2007, demand was at an unprecedented low-point in 2020 due to the COVID-19 pandemic. As Figure 3.2 shows, we forecast a 73% drop in domestic oil demand with a decrease to about 75 PJ towards mid-century. This decline is similar to developments projected for Europe, where we forecast a reduction of 76% compared with 2020. On a global scale we forecast oil demand to decline gradually to almost half the current consumption level by 2050.

70% 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 63% in 1990 up to 70% in 2020 when it started to decline. In 2020, over 60% of the transport sector's 192 PJ of oil demand came from road vehicles. Going forward, passenger vehicles will experience the most extensive conversion to electricity, boosted by Norway's leading position within 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 2020, 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. The strong growth of alternative fuels for shipping, such as electricity, natural gas and low-and/or zero-carbon fuels in combination with changes in maritime energy demand will drive the reduction. Aviation will be dependent on oil for longer, reducing to a third of pre-pandemic 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 3% of total oil demand in 2020, is expected to decline by 50%. However, because overall oil demand is declining faster, buildings will represent a slightly higher share of total oil demand. The main use of oil in buildings is for space and water heating, which increasingly will be electrified.

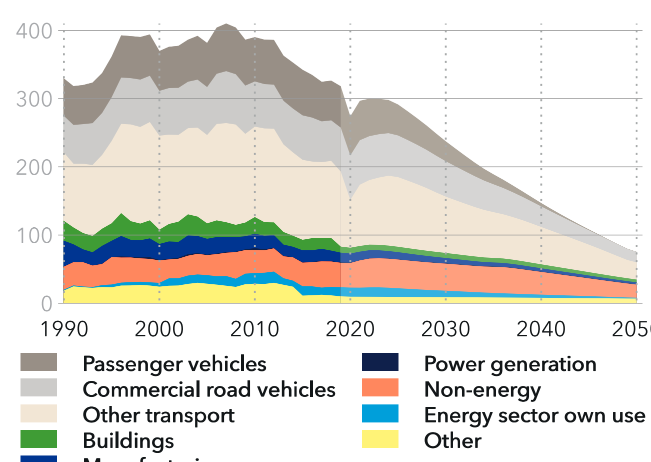
A very similar outcome is expected in manufacturing. Here, the current 5% share will decline by 30% to represent about 4% of oil demand by 2050. The main driver here is less oil use in industrial heat processes where oil is substituted with electricity.

Since 2010, Norway's offshore oil production has plateaued after a decade of strong decline. It will, however, 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 a downwards pressure on oil prices, and relatively few new discoveries are expected to be developed. Reduced oil demand will make it less attractive for the

FIGURE 3.2

Norway oil demand by sector

Units: PJ/yr



Does not include natural gas liquids and bioliquids. Historical data source: SSB (2021), IEA WEB (2020) industry to expand production into challenging environments, such as deep water and/or Arctic locations. Globally, as oil fields are depleting faster than global demand for oil declines, continued investment in new capacity is expected, with investments increasingly targeting low-cost production. Thus, incoming capacity additions in Norway will not replace the capacity being shut down. That said, oil production in Norway in 2050 will be at about 0.24 Mbpd (Figure 3.3), which is still much higher than domestic demand at about 0.06 Mbpd.

Our forecast is that global oil demand will never return to pre-pandemic levels. Although oil demand is rising once again, it will plateau at a level below 2019 before it enters a long decline from 2025. DNV's Energy Transition Outlook (2021a) provides more details on the global dynamics behind these developments.

> Since 2010, Norway's offshore oil production has plateaued after a decade of strong decline. It will, however, increase slightly through to 2025

3.2 Gas

On a global scale, we forecast that world natural gas demand will grow until the 2040s, eventually surpassing oil to become the largest primary energy source in the early 2030s. Natural gas will retain its status as the largest primary energy source throughout our forecast period, even as global demand gently tapers off from 2041 towards 2050. In Europe, which receives almost all of Norway's gas export, consumption will gradually decline to 44% of the current level in 2050.

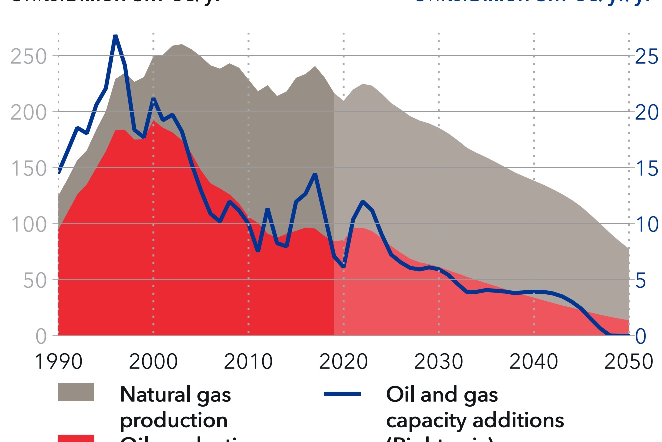
Overall natural gas demand in Norway will halve towards mid-century, mainly due to reduced use offshore. The main natural gas use in Norway is linked to the energy sector's own consumption. Here, consumption has plateaued from 2015 at 220 PJ. Natural gas consumption will continue a few more years before declining steadily through to 2050, reaching 48 PJ. This decline is linked to significant electrification of the Norwegian Continental Shelf (NCS), mainly through shore power, but also through wind turbines like Hywind Tampen, which replace gas turbines onboard offshore installations.

The second largest consumption of natural gas is as petrochemical feedstock, representing 20%, a share

FIGURE 3.3

Norway oil and gas production and capacity additions

Units: **Billion Sm³oe/yr** Units: **Billion Sm³oe/yr/yr**

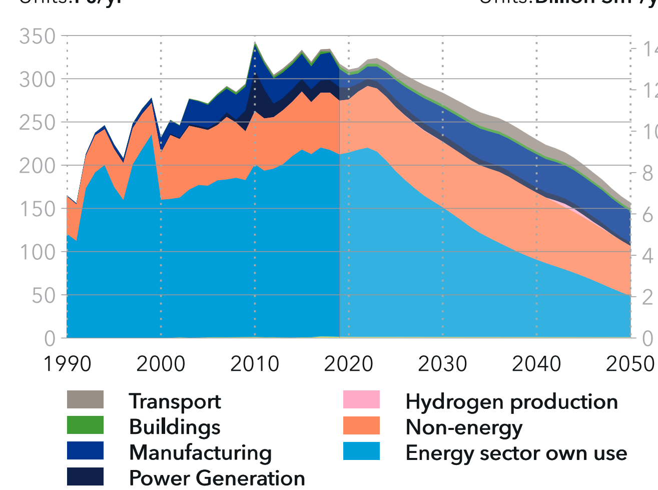


Oil includes crude oil and condensates, natural gas includes NGLs.
Capacity additions are based on asset lifetime of 20 years.
Historical data source: NPD (2019), IEA WEB (2020)

FIGURE 3.4

Norway natural gas demand by sector

Units: **PJ/yr** Units: **Billion Sm³/yr**



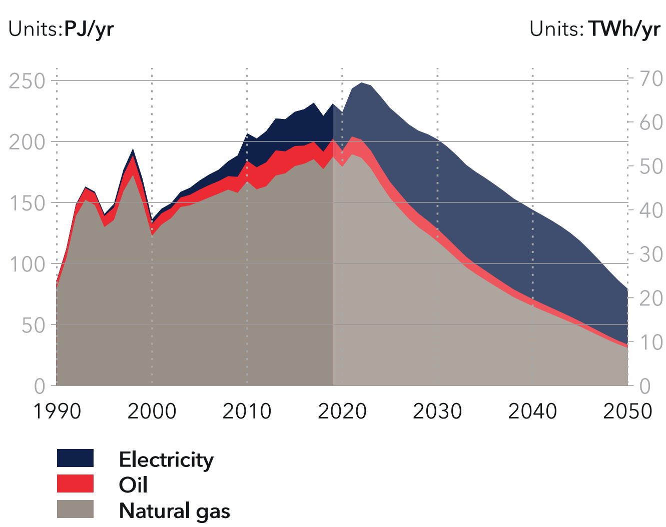
Includes natural gas liquids. Historical data source: SSB (2021), IEA WEB (2020) which is expected to grow to 37% by 2050 (Figure 3.4). Only 3% of all gas use in 2050 will be for power generation; the manufacturing and buildings sectors will account for about 23% and 2% respectively, which is somewhat contrary to the 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 forecast to significantly increase in the coming decades due to the rising use of natural gas in maritime as 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 125 Gm3, is forecast to slightly increase in the coming decade, before starting to decline by 2030. By 2040, we will see an even sharper decline in natural gas production, with production almost halving 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 remain the same during the forecast period. LNG will still only account for 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, albeit at somewhat lower levels.

Electrification of oil and gas production on the Norwegian continental shelf (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 82% as gas-fired onsite power production on offshore installations is replaced by electricity from the mainland or from offshore wind. In 2020, emissions from the oil and gas industry's own use of energy accounted for 29% 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 58% share of electricity in the supply of NCS energy needs (Figure 3.5).

FIGURE 3.5

Norwegian continental shelf energy demand by carrier



Historical data source: SSB (2021), IEA WEB (2020)

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. Ample supply of relatively cheap electricity from hydropower plants have been the main contributor to this development.

As Figure 3.6 shows, total national electricity consumption will grow 57% from 140 TWh/yr in 2020 to 234 TWh/yr in 2050. Four sectors will spur this growth: industry, transport, hydrogen production and oil and gas production. New and existing industries are capitalizing on low carbon electricity and producing lithium batteries, aluminium and green steel, and this will spur electricity demand. We will see electrification of all transport segments, but first and foremost road vehicles, with 14 TWh/yr consumed by 2.4 million passenger and 600,000 commercial EVs 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 17 TWh/yr in 2040 and 38 TWh/yr in 2050. The energy sector's own use related to oil and gas production will continue to grow as both new and some existing fields are electrified. Electricity consumption within the sector is estimated to reach a peak of over 21 TWh in the mid-2030s before declining due to reduced activity on the NCS.

Total electricity use in buildings will be constant for the most part, 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 seasonal variations 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

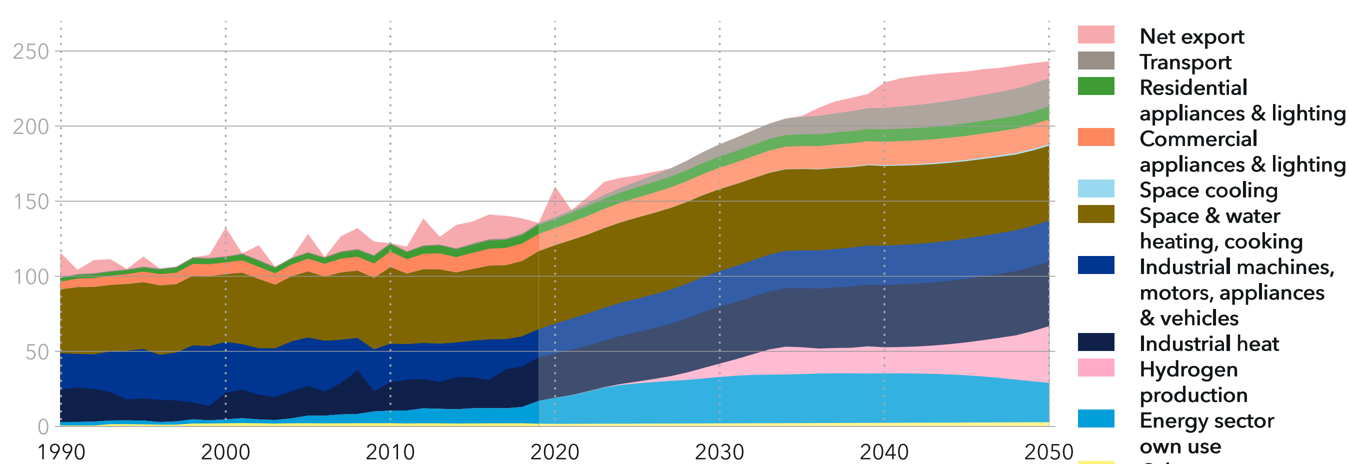
Historically, Norway's electricity supply has been dominated by hydropower (Figure 3.7), and through to 2006, over 99% of domestic electricity was supplied by this source. At that point, other technologies started to make inroads, such that in 2020 non-hydro electricity generation was 8.5%: 6.4% from wind, 1.6% 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 66% to 2050, but annual average hydropower generation will only grow by 8% in the same period. The remainder of the gap will be closed mostly by wind. Onshore wind has seen significant growth however, public opposition combined with almost full stop of issuing new concessions will limit onshore wind growth. From the 2030s, offshore wind, initially bottom fixed and later floating, will grow rapidly, driven by reduced costs, sustained government support and increasing opportunities for electricity trade. 2050 electricity generation will include 4% solar PV, <1% gas, 10% onshore wind and 25%

FIGURE 3.6

Norway electricity demand by sector

Units: TWh/yr



Historical data source: SSB (2021), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2020) offshore wind, with the latter mostly exported. The remaining 60% 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 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 a slight increase in the average capacity factor of hydropower power stations towards 2050.

Wind and solar PV are non-dispatchable because it is only possible to have limited control 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.

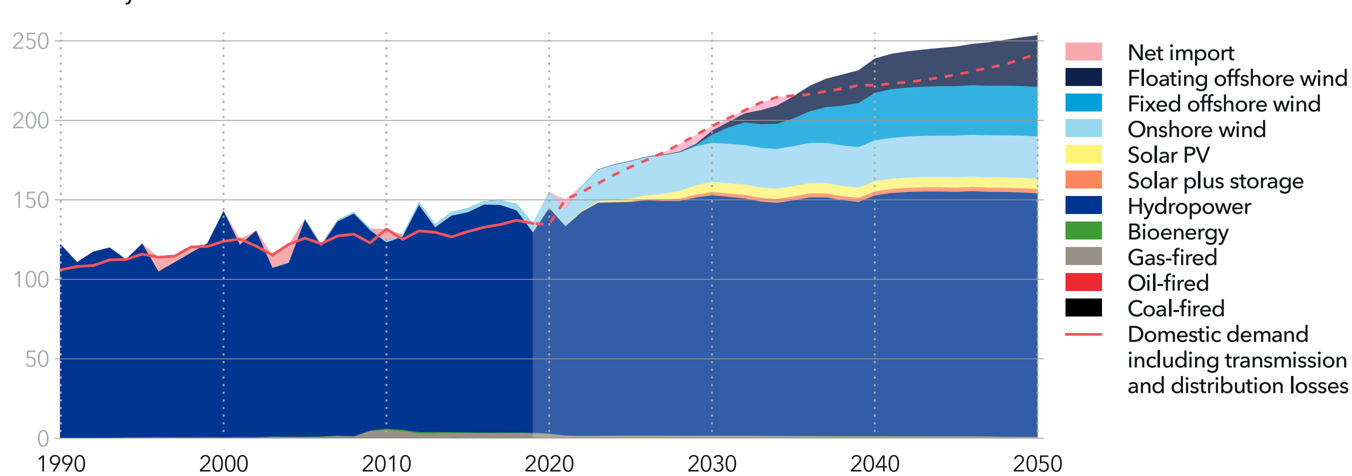
Our forecast also accounts for the impacts of cross-border electricity trade and energy storage, namely pumped hydro storage, battery storage and the storage provided by EVs through vehicle-to-grid systems. We assume that 10% of battery capacity of all EVs will be available to the grid to provide flexibility. 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 region, regardless of location. For Norway, we do not distinguish between the bidding zones and treat the whole country as a single market.

FIGURE 3.7

Electricity generation by power station type and net imports

Units: TWh/yr



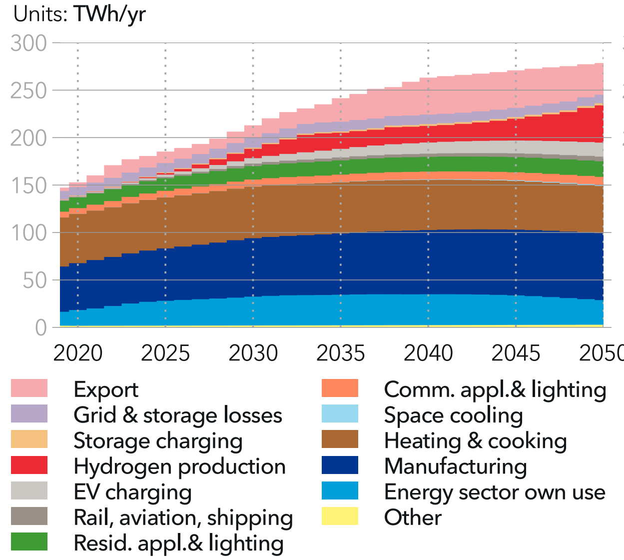
Historical data source: SSB (2021), IEA WEB (2020)

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.

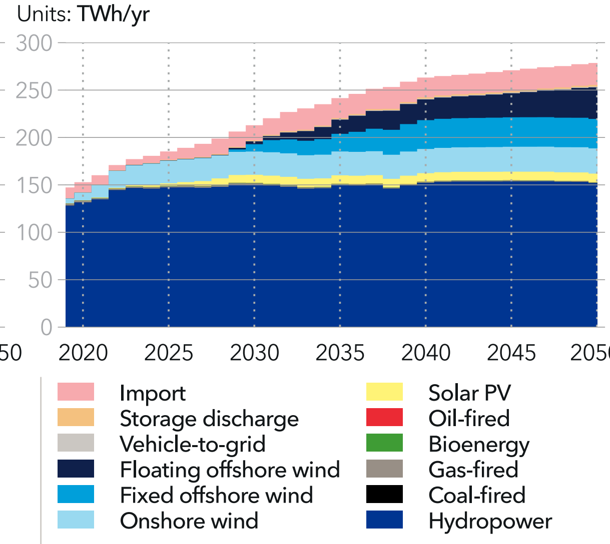
Norway electricity demand by segment; 2019-2050

Units: TWh/yr



Norway electricity supply by source; 2019-2050

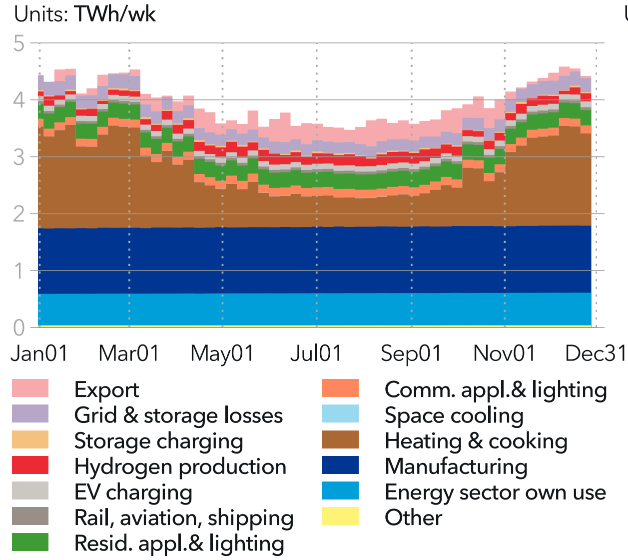
Units: TWh/yr



We expand the year 2029 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.

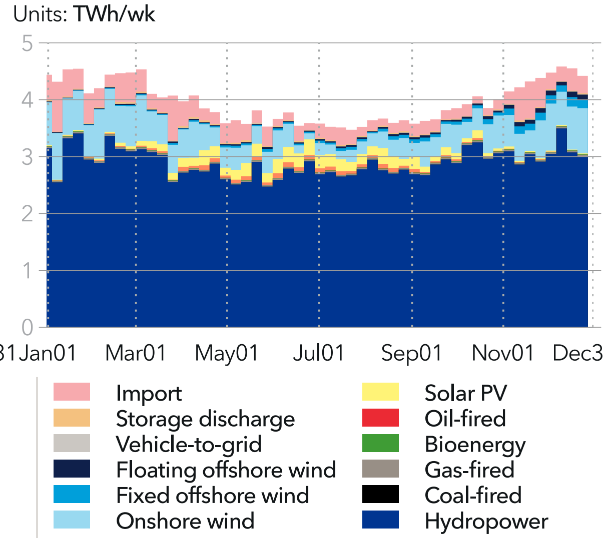
Norway electricity demand by segment; 2029

Units: TWh/wk



Norway electricity supply by source; 2029

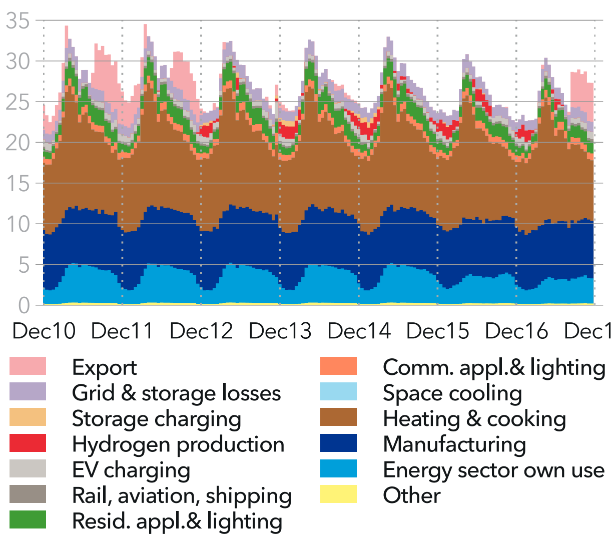
Units: TWh/wk



This next chart zooms in on week 50. 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.

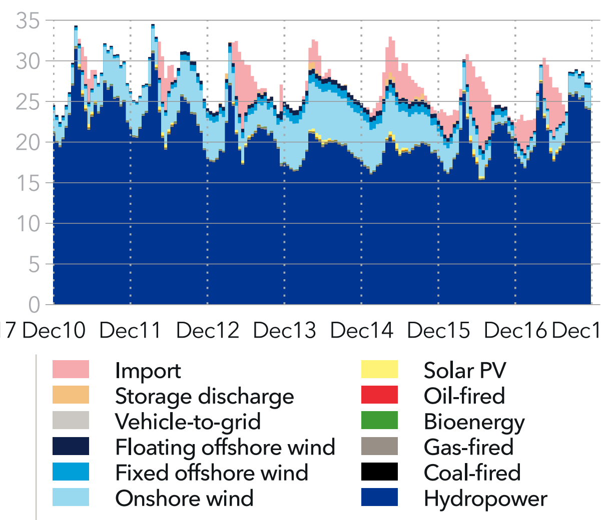
Norway electricity demand by segment; week 50; 2029

Units: GWh/h



Norway electricity supply by source; week 50; 2029

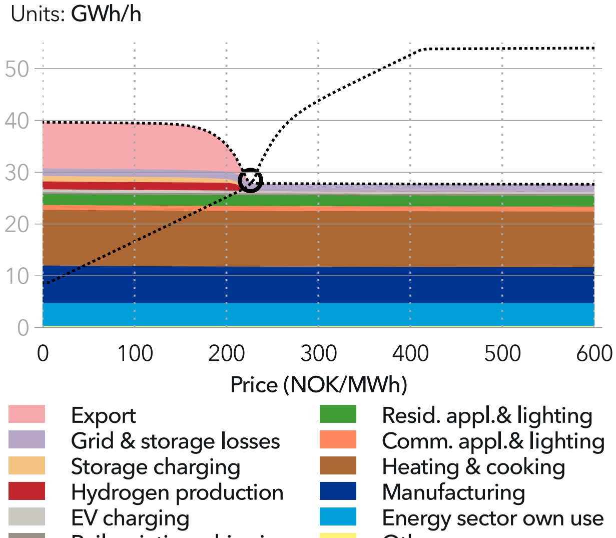
Units: GWh/h



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.

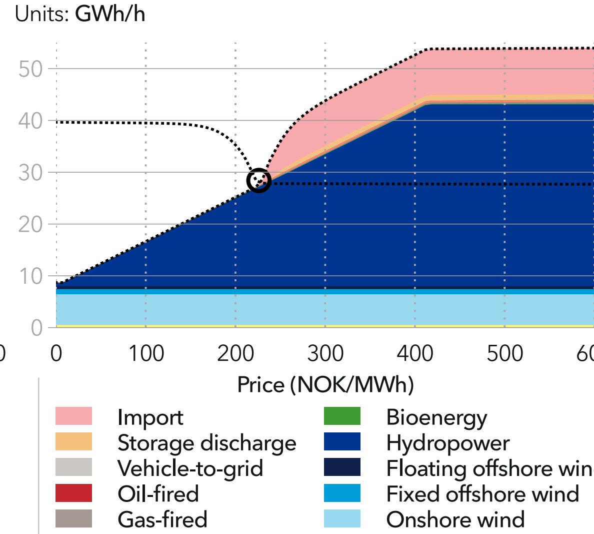
Norway electricity demand curve; 13 December 2029; 12:00-13:00

Units: GWh/h



Norway electricity supply curve; 13 December 2029; 12:00-13:00

Units: GWh/h



Capacity developments

Markets with large amounts of variable renewable energy sources (VRES) such as solar and wind in the power mix, face the major obstacle of securing continued investment in these resources due to reductions in revenue 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. During these hours, electricity prices will drop to zero. As a result, the 'capture price' of variable renewables – 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 future installed renewable energy capacity. 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. Onshore wind becomes cheaper than hydropower, making it unnecessary to continue government support. The same happens with fixed offshore wind, but only by late 2020s when we foresee capacity build out.

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 increased undersea interconnection capacity, 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 below the levels of onshore wind after 2030.

There are certain overlaps in the cost of new developments, as well as many geographical and political factors, resulting in not only the lowest-cost technology being built. Hence, we get a distribution based on price combined with those other factors. Figure 3.9 illustrates historical and future annual power capacity additions by power station type estimated using this logic. Capacity additions in the near future include new capacity under construction. After these power stations come online, investments will slow down in 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

FIGURE 3.8

Norway grid and off-grid installed renewable capacity

Units: GW

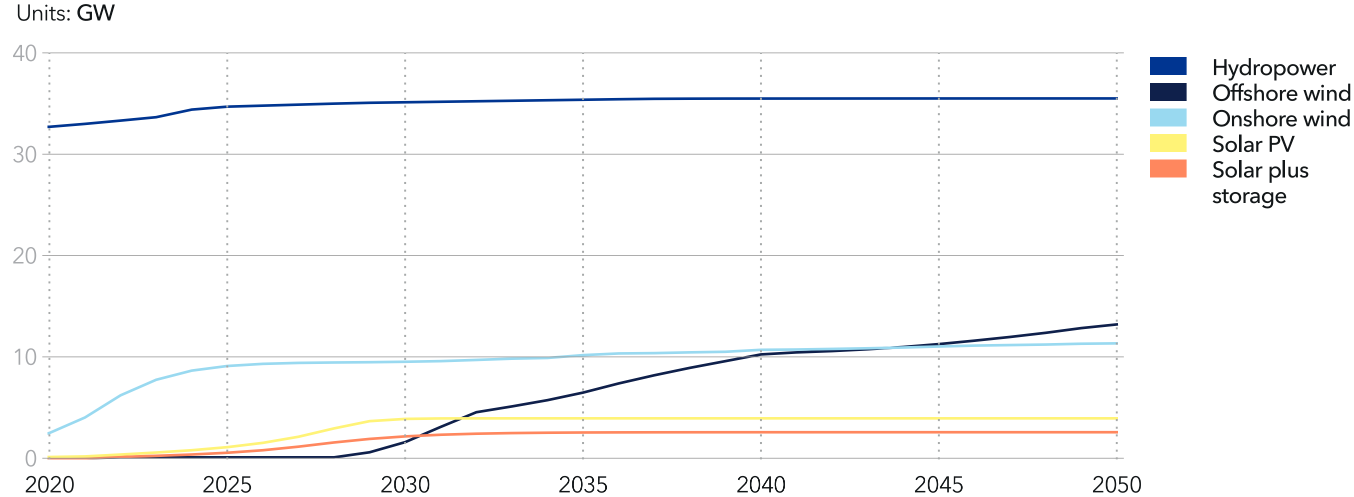


TABLE 3.1
Installed capacity and the annual average capacity factor

	Installed capacity (GW) by the end of year				Capacity factor			
	2020	2030	2040	2050	2020	2030	2040	2050
Hydropower	32.7	35.1	35.5	35.5	47%	48%	48%	49%
Onshore wind	2.5	9.6	9.9	10.2	30%	38%	45%	45%
Floating offshore wind	0.0	0.6	4.2	6.4	45%	62%	62%	62%
Fixed offshore wind	0.0	2.0	5.9	6.0	58%	61%	61%	61%
Solar PV	0.2	3.9	3.9	3.9	17%	20%	20%	21%
Solar plus storage	0.0	2.3	2.6	2.6	17%	10%	11%	12%
Thermal	1.0	0.9	0.9	0.6	36-40%	20-28%	17-23%	17-22%
Wind onshore - off-grid capacity for hydrogen production	0	0	0.8	1.2				
Wind offshore fixed - off-grid capacity for hydrogen production	0	0	0.2	0.8				

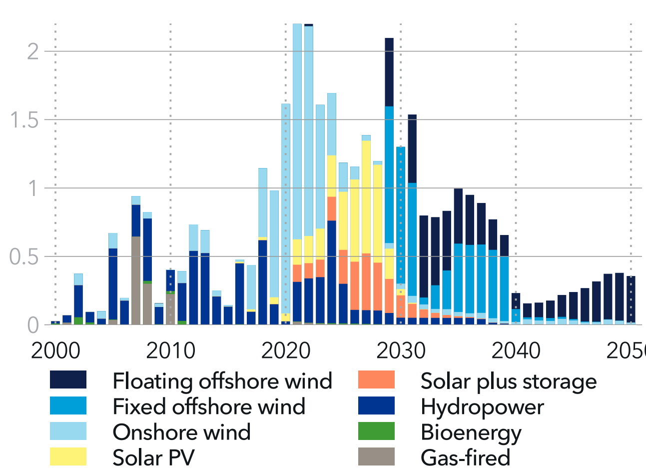
floating offshore wind, where export-driven capacity additions will be sufficient to also cover the anticipated increase in domestic electricity demand.

Table 3.1 shows developments within installed capacity through to mid-century and the average annual capacity factor of the installed capacity. In addition to grid connected capacity we include off-grid capacity dedicated for hydrogen production. To support a grid with variable renewable capacity, we forecast 950 MW of pumped hydro storage and 1.2 GW of utility-scale Li-ion battery storage to support the Norwegian electricity grid in 2050.

FIGURE 3.9

Norway capacity additions becoming operational by powerstation type

Units: GW/yr



Shows the year of becoming operational. Historical data source: IRENA (2020)

Hydropower

With more than 1,600 plants (Energifaktanorge, 2021), hydropower is the backbone of the Norwegian electricity system. Unlike hydropower capacity in relatively flat countries with limited dams, the Norwegian hydropower system is supported by a very strong reservoir storage capacity, with a total of 86.5 TWh across the country (ibid). 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 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 early 2000s, new capacity additions slowed significantly. The start of electricity certificate schemes 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 2050, to reach 36 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 153 TWh in 2050.

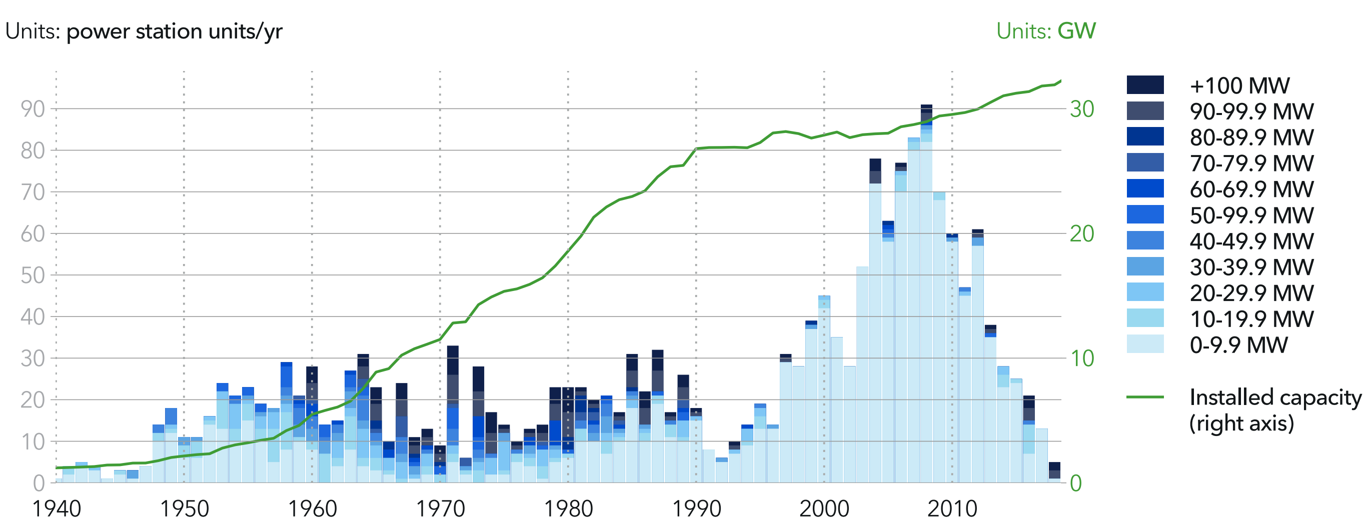
With increased variability on the supply side of the electricity system with a growing share of wind, hydropower will need to respond to fluctuations not only in demand, but also in generation. Adoption of new technologies allowing hydropower plants to ramp up and down more rapidly will be instrumental 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.

Wind

Norway's wind industry has grown steadily since the first installations in 1993. At the end of 2020, the total installed capacity was just below 4 GW, almost all in the form of onshore projects, 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

FIGURE 3.10

Norway number of hydropower units added by size



Shows the year of becoming operational. Historical data source: Platts (2018) 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 it may 'incorrectly' cause domestic electricity prices to increase.

Given the tussle between climate goals and natural habitat preservation, we predict that growth in Norway's wind capacity will be mostly offshore, constituting 71% of 90 TWh wind-based generation in 2050. Cost is the first factor contributing to growth. Figure 3.12 shows how the levelized cost of floating offshore wind declines in Norway until 2050, as a result of global and local developments in various cost components. For onshore wind, about a third of the 47% 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 and maintenance costs, as the 60-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 very quickly off Norway's west coast will limit the share of bottom-fixed offshore turbines, where government subsidies will be needed as they are expected to be built by the late 2020s.

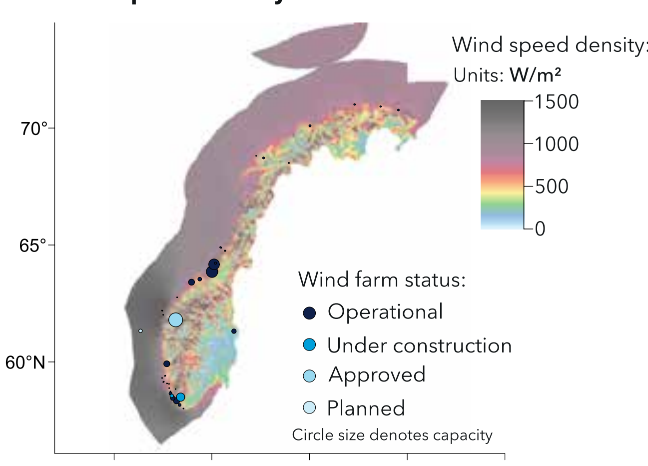
The second driver of the uptake of wind in Norway is the increase in domestic electricity demand, as presented earlier in Figure 3.6. Due to the limited growth possibilities of hydropower, wind is in a prime position to fill the gap between demand and available supply.

Electrification of offshore oil and gas production will be a third driver for offshore wind. With the electricity consumed by offshore platforms increasing to cover up to 58% of energy demand 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 revenues for Norwegian floating offshore wind operators from exports will be twice as high as the revenues from the domestic market. Thanks to these additional revenues from exports, total government subsidies required to support floating offshore wind until 2050 will amount to USD 4 billion, instead of USD 10 billion.

FIGURE 3.11

Mean wind power density and distribution of wind farms

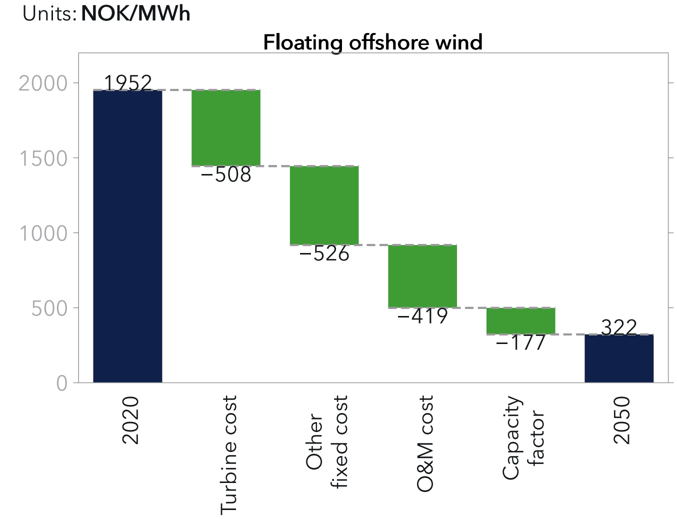


Data source: Global Wind Atlas 3.0, Technical University of Denmark, 2020, Global Power Plant Database 1.2.0, GEO, Google, KTH, Enipedia, WRI. 2019

FIGURE 3.12

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

Units: NOK/MWh



Solar PV

Solar PV will remain a niche technology in Norway. We predict installed capacity to increase from 160 MW in 2020 to 3.9 GW in 2030 and remain flat thereafter. We include two categories for solar: solar PV panels connected to grid via utility scale or rooftops, and a new category called solar plus storage, where storage is integrated as part of the installation producing in effect a powerplant with dispatchable power. Even though solar plus storage is initially more expensive, the ability to capture a higher electricity price when solar PV is not operating will eventually lead to a third of the solar PV capacity integrally including storage capacity by 2050.

However, we reiterate that solar PV will remain marginal for the country. The main disadvantage of solar PV is low solar irradiation in Norway. This leads to capacity factors around 10% on the yearly 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 gas. However, producing hydrogen through electric current requires costly electrolysis equipment and suffers substantial energy losses. The main alternative production method is via steam methane reforming (SMR), where hydrogen is derived from hydrocarbons, and this currently has lower overall costs due to low fossil-fuel prices. We forecast the SMR advantage to decrease with higher carbon prices and ongoing process improvements for electrolysis-based hydrogen production combined with lower electricity prices from variable renewable energy sources (VRES) capacity.

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. Therefore, it will be some time before abundant VRES results in a steep increase in electrolysis-based hydrogen production in Norway. We forecast this will occur in the mid 2030s in the absence of fundamentally new policy choices by government. From 2030 onwards,

FIGURE 3.13

Norway solar PV capacity factor vs. normalized load

Unitless

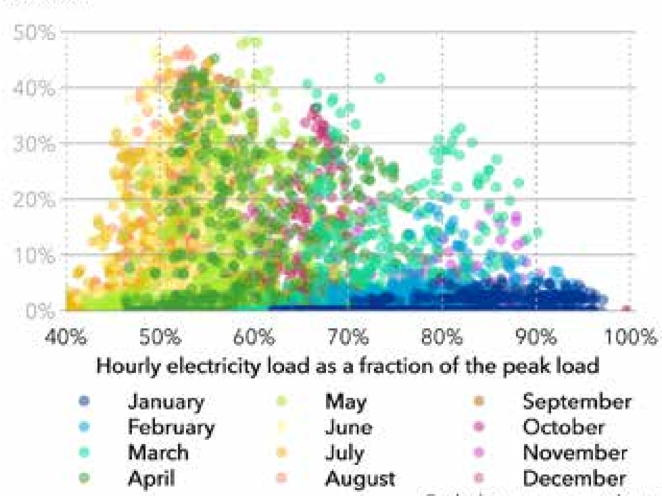
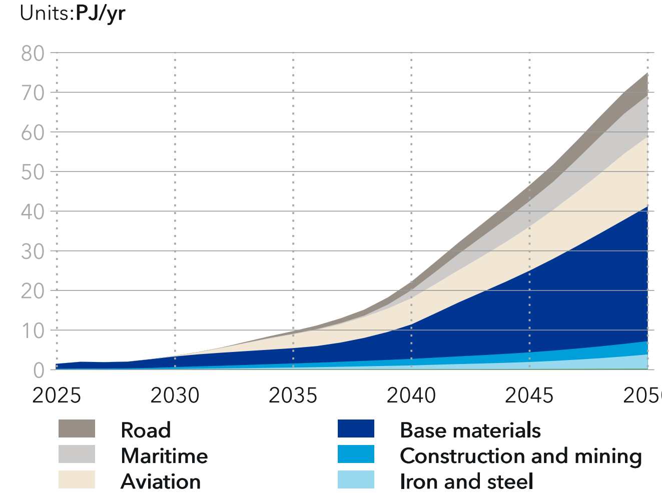


FIGURE 3.14

Norway hydrogen demand by sector

Units:PJ/yr



Only includes hydrogen as energy carrier.

Norway-based hydrogen production as energy carrier will be supplied exclusively by electrolysis, reaching almost 81 PJ per year 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 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 and as a replacement for oil and gas. 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 6 PJ by 2050.

Within maritime transport, covered thoroughly in DNV's Energy Transition Outlook (DNV, 2021a) and in our Maritime companion report (DNV, 2021b), we expect low- and/or zero-carbon fuel alternatives, partly implemented in hybrid configurations with diesel and gas-fuelled propulsion, having significant uptake and providing slightly more than 40% of the maritime fuel mix by 2050, most of which will be synthetic fuels. 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 predict 10 PJ/yr of low-and/or zero-carbon fuels used in Norway's maritime sector.

Aviation is a sector where Norway is well-rounded for battery electric flights on its short haul network connecting coastal cities. However, for long haul and international flights, hydrogen based synthetic fuels will play a role to decarbonize the sector. After 2030 when infrastructure and costs have developed, we see synthetic fuels starting to replace regular jet fuel and by 2050, 25% (18 PJ) of aviation energy demand is covered by hydrogen-based synthetic fuels.

4 ENERGY TRADE

Norway is a significant net exporter of energy and will continue to be so over the next 30 years. 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 63% lower than in 2020 (Figure 4.1). Electricity exports will initially be limited but as power capacity increases, electricity exports will grow. However, 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 333bn NOK in 2020 (NPD, 2021). Assuming constant prices, a 63% reduction in oil and gas exports will result in 210bn NOK in annual revenue losses. However, 11 TWh/yr in net electricity exports by 2050 will only translate to an additional income of 6-7bn NOK/yr.

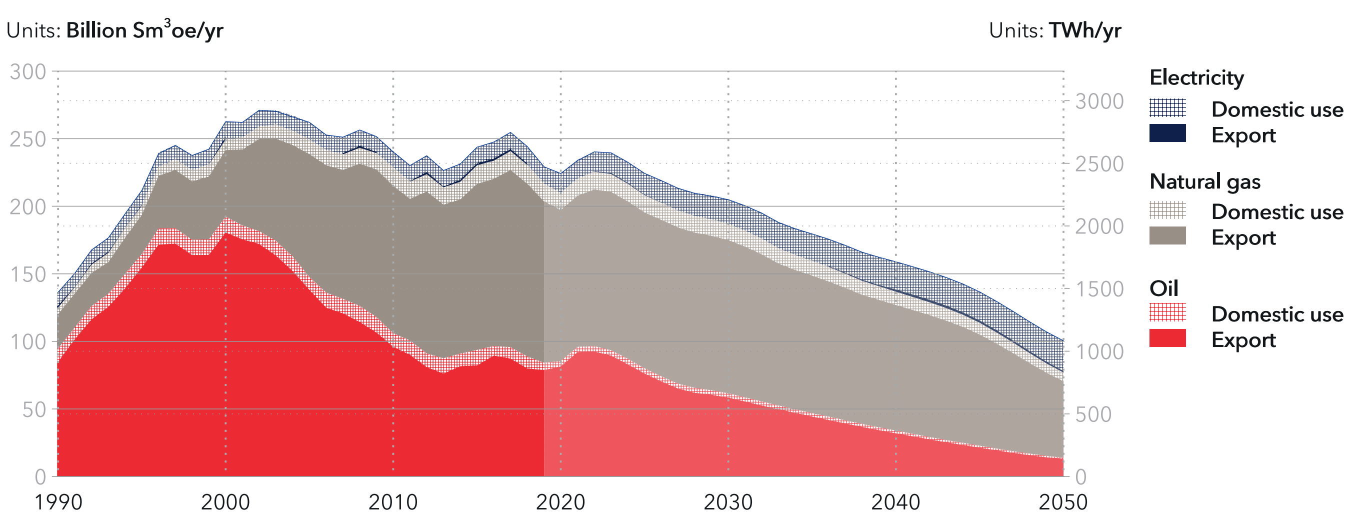
Oil and gas exports

Norway's production meets about 2% of global oil demand. As Norwegian oil's competitiveness against cheaper oil (regions with lower production cost) will weaken in a world with rapidly declining oil demand, its share of the global oil market will gradually reduce to around 1% by 2050. As a result, total oil exports – including oil products – will reduce to 58 billion Sm³/yr in 2030, 32 billion Sm³/yr in 2040 and 13 billion Sm³/yr in 2050.

The outlook for gas is less bleak in the short term, since natural gas will maintain its market position in the European energy system, although it will start to decline from 2030. Norway supplies between 20-25% of Europe's gas

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 (2020) demand (NPD, 2020a). Thanks to relatively stable gas demand in Europe until the early 2030s, Norway's gas exports (including NGLs) will stay at similar levels as today, but will start to decline sharply from 2040 as European gas demand decreases. In 2050, Norwegian gas exports will be 57 billion m³/yr, which is a decline of almost 50% compared to 2020.

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 stay at current levels as gas demand outside Europe will be increasingly uncertain. The main form of export will, however, remain by pipelines to Europe.

Electricity exports

Norway's total net transfer capacity to other countries is 6.1 GW. 3.7 GW of this 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 was put into commercial operation in March 2021 and the North Sea Link to the UK was switched on at the beginning of October. In the mid 2030s we foresee an increase in cross-border capacity to Sweden and Denmark by another 1 GW and 0.4 GW, respectively to facilitate an increase in renewable generation. One more 1.4 GW interconnector between Norway and UK as well as Germany is expected and finally, we assume a 750 MW cable from Northern Norway to Finland to be built by 2040.

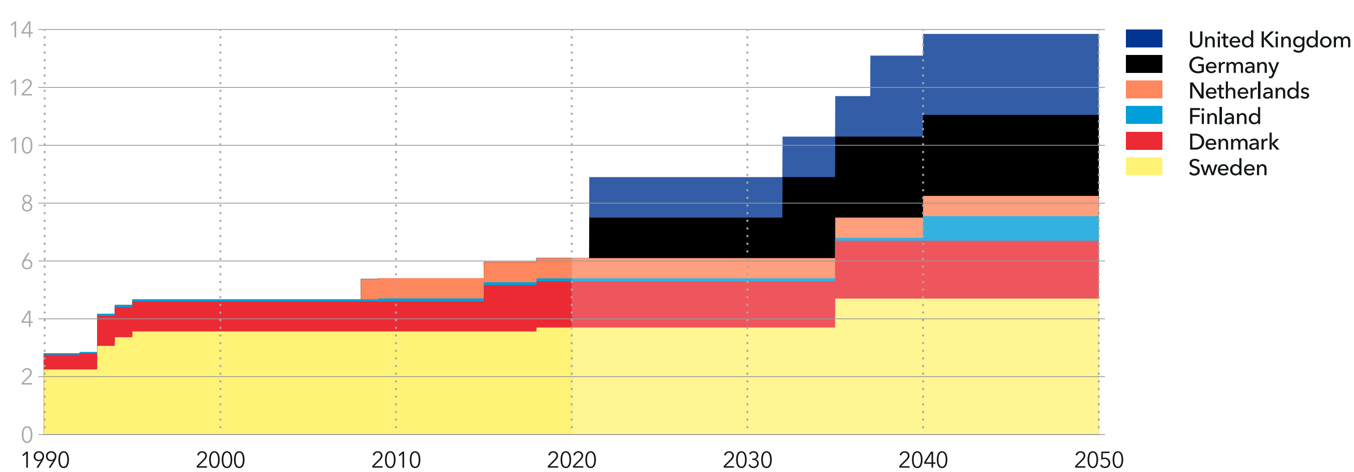
Norway's electricity grid is divided into five bidding zones. The actual cross-border electricity trade is very dependent on the supply and demand conditions in these bidding zones and the markets they trade with. Our model simplifies this structure by representing Norway and the rest of Europe as two 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 can replicate historical trade volumes reasonably well.

Total oil and gas exports in 2050 will be 63% lower than in 2020.

FIGURE 4.2

Norway net electricity transfer capacity

Units: GW



Historical data source: ENTSO-E (2020)

Figure 4.3 presents monthly electricity exports and imports of Norway until 2050, broken down by power station type of the exporting region at that month. The chart gives many clues about the future of Norwegian electricity exports. In the last 20 years, Norway's annual net electricity exports have averaged 10 TWh. Annual total net exports will decline between 2025 and 2035. A significant increase in electricity demand combined with limited capacity additions increase the demand for *imported* electricity by up to 6 TWh/yr. From 2030, new capacity additions from offshore wind improve the balance but it is not until 2035 that Norway again becomes a net exporter, increasing the annual export to 19 TWh/yr by 2040 and dropping to 11 TWh/yr by 2050. This increase is only partially linked to an increase in net transfer capacity, because Norway's electricity export during summer months – the time of year with the most exports and the period that would benefit from an 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, allowing Norway to become a net electricity exporter, throughout the year, however only after 2035.

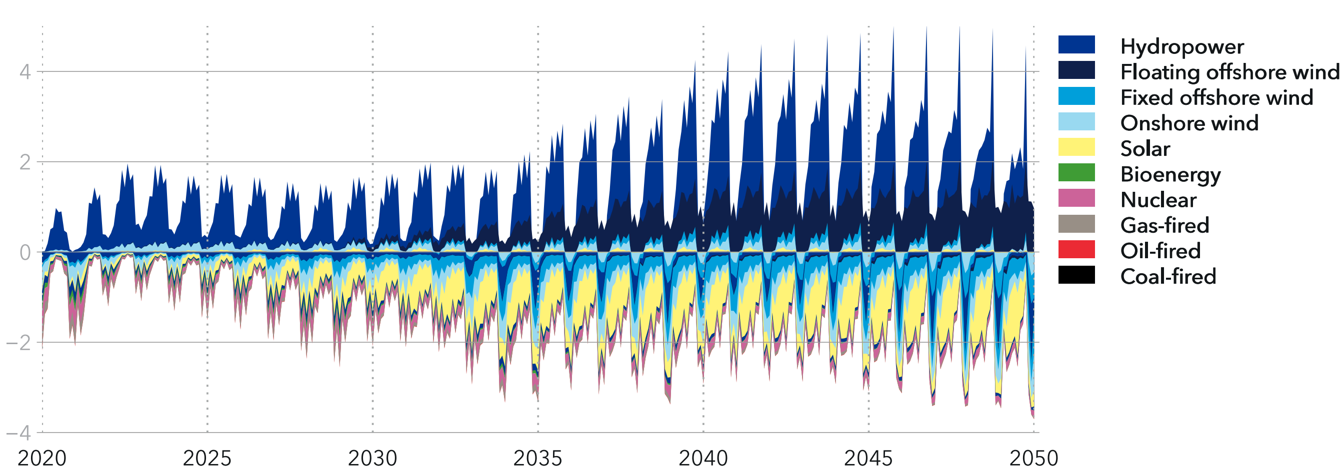
We have assumed that new floating offshore wind capacity will not only be driven by domestic demand and revenue from Norway's own electricity market, but also by increasing European electricity demand and opportunities for high export revenue. We see this happening in a self-reinforcing process, where a year-round export opportunity triggers new floating offshore wind investments, and the availability of sufficient capacity allows for up to 90% of floating offshore wind's annual generation to be exported.

One important dimension of initially increasing electricity imports between 2020 and 2035 is bigger fluctuations in future electricity prices. Our analysis shows (Figure 4.4) that electricity prices initially will increase and face bigger fluctuations. As both capacity and export/import capacity increase, then average electricity prices will decline, however price fluctuation withing the year will remain. 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

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.

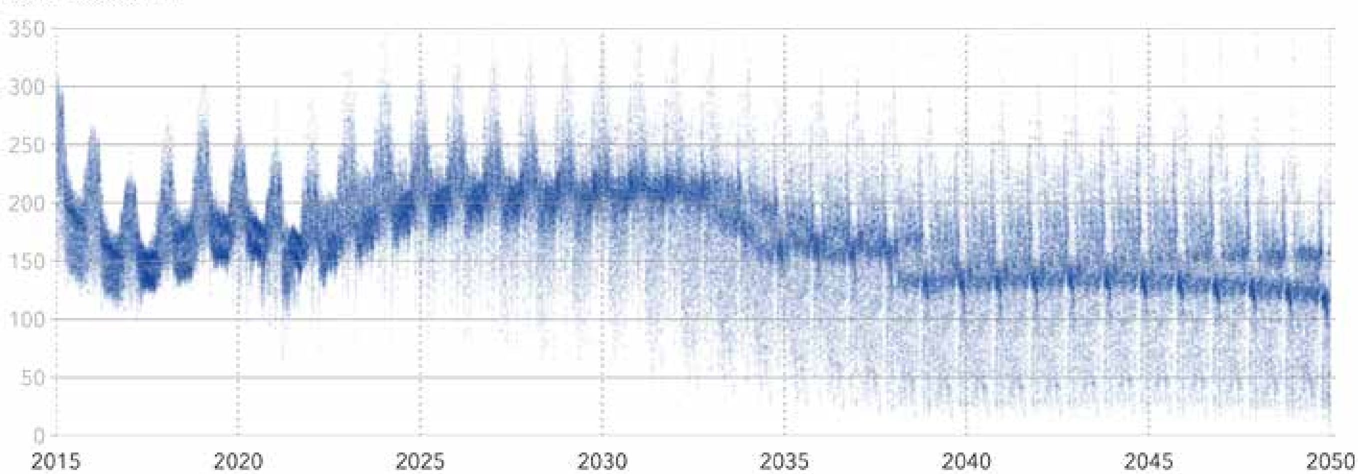
better demand response afforded by widespread adoption of smart grids. An observation is that with interconnectors and a larger share of variable renewables, price fluctuation seems to increase, however one limitation not accounted for in Figure 4.4 is our model's design to not reflect grid constraints. As each specific bidding zone will be constrained by its local supply and demand, as well as its interconnection capacity, the actual variation in price may be different than our model predicts.

We have assumed that new floating offshore wind capacity will not only be driven by domestic demand and revenue from Norway's own electricity market, but also by increasing European electricity demand and opportunities for high export revenue.

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 (GHG) 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 to develop a full account of the country's emissions. We begin with the estimated energy-related CO_2 emissions derived from our model, and then list the remaining GHGs and their origin. Since our modelling focuses mainly on the energy system, we make some assumptions on the decarbonization possibilities for the other, non-energy-related anthropogenic GHG emissions. We conclude with a discussion on developments relating to the capturing and storing of some of these emissions.

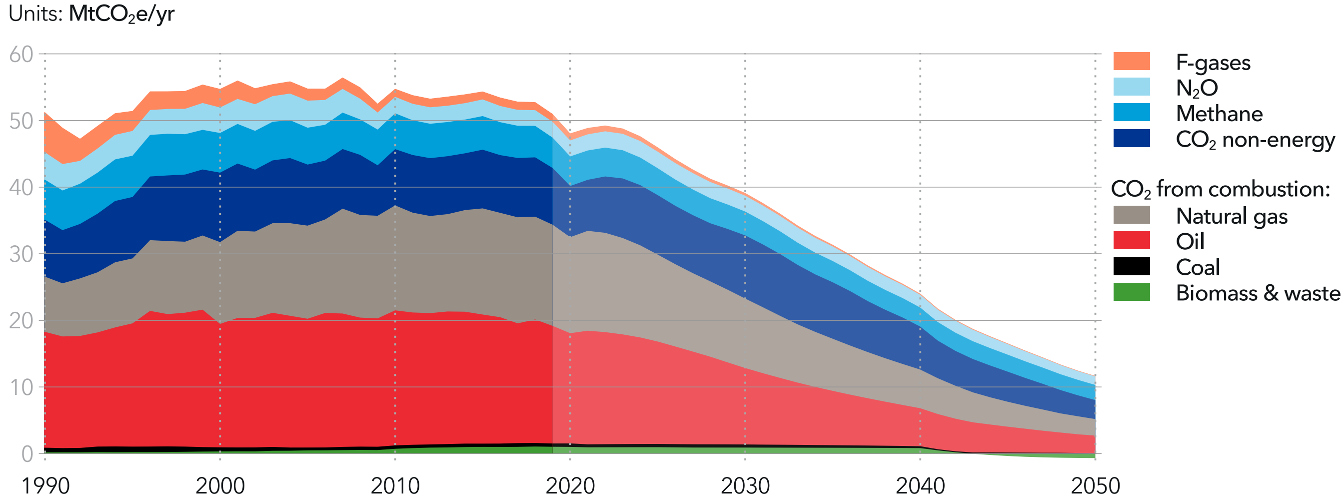
Emissions by source

Energy-related CO_2 emissions increased steadily in Norway for three decades, and a decline has only been observed in the last 5 years. In addition to CO_2 emissions from combustion of fossil fuels, a large share of Norwegian CO_2 emissions stems from non-energy related emissions. A high quantity of these emissions derive from the use of fossil fuels as feedstock in the steel and petrochemical industries. Non-energy emissions also come from the calcination process of cement production, as well as other process-based emissions from anodes. Other GHGs included in the Norwegian footprint are methane, nitrous oxide and industrial f-gases (HFC, PFC and SF6). All these gases have a much more aggressive global warming potential than CO_2. Tonne-wise, these emissions are small compared with CO_2, but converted to CO_2 equivalents, they make up 15% of the total GHG emissions in 2020 and will grow to represent 33% in 2050.

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 (2021)

Our forecast indicates that GHG emissions will continue to decline over the over entire forecast period. Emissions in 2020 were slightly lower than in 1990 and by 2030 will have declined 24% compared with 1990 levels. By 2050, we expect an emissions decline of 79% compared with 1990, to 11 million tCO_2e (Figure 5.1), hence falling short of both the 2030 (55% cut) and the 2050 net zero ambition.

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 the removal of natural-gas driven turbines for gas and oil production through electrification, 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 either used current levels of emissions to forecast trends for each sub-source or 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.

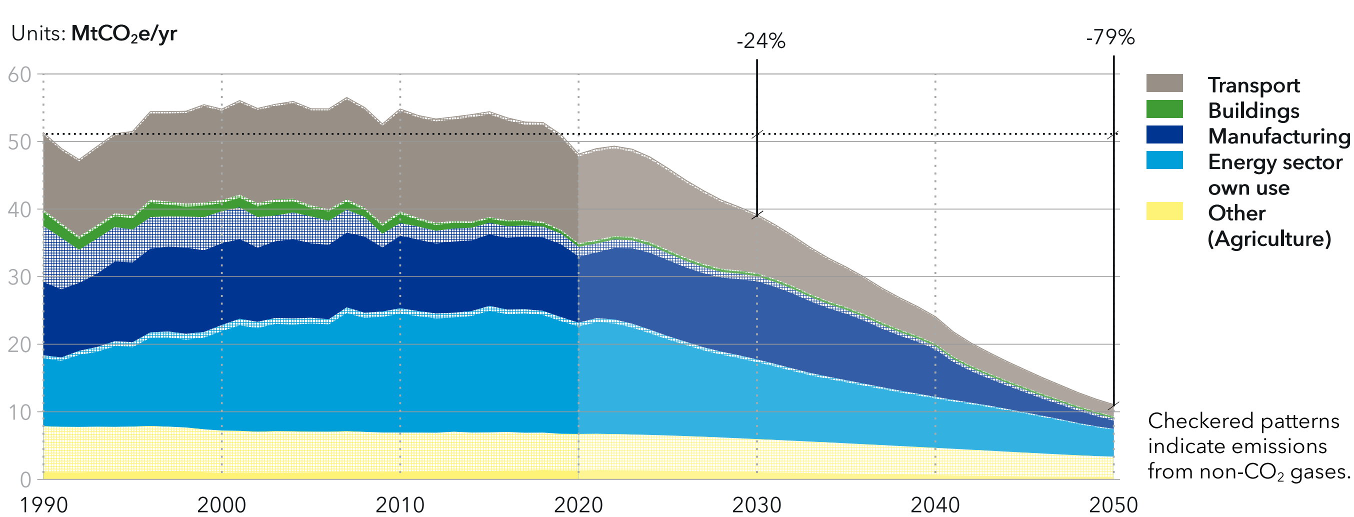
Emissions by sector

From a sectoral perspective, all emissions have been associated with the main sectors described in our energy systems model. In all sectors, except the 'Other' category which in this context equates mainly to agriculture, emissions from CO_2 dominate. In the agricultural sector, emissions are largely methane from animal management through enteric fermentation and manure. The other major source in the 'Other' category is methane from landfills. We do not expect Norwegian agriculture and animal management to decline significantly, but follow a trend of decarbonization ambition in the sector, which extrapolated to 2050 declines by 44% non-CO_2 emissions. Some activities, such as mechanical machinery in the agricultural sector, will have CO_2 emission reductions comparable to those seen in the commercial vehicle segment.

The sector with the highest emissions today (33%) is the energy sector's own use, which mainly includes energy extraction and production. Most of these emissions are CO_2 from gas-turbines generating electricity on the Norwegian continental shelf (NCS). As the NCS continues to electrify more of its production, emissions will decline

FIGURE 5.2

Norway greenhouse gas emissions by sector



Emissions from power generation are allocated to end-use sectors. Historical data source: SSB (2021) gradually towards 2030 by 32% compared with 2020 levels. By 2050, the energy sector's own use reduction is 75% at 4.1 $MtCO_2$ due to declining activities on the NCS and an electrification rate of over 50%.

The manufacturing sector currently emits 11 $MtCO_2e$. Most of these emissions (50%) are associated with non-energy related CO_2 emissions in heavy industry, together with combustion emissions from fossil fuels. By 2030, these emissions will not have changed due to an expected growth in industrial output and will remain at the same level. By 2050, emissions will be down to 1.5 $MtCO_2e$, a decline of 85% mainly due to fuel switching to cleaner sources in industrial heat (electricity and hydrogen) and more CCS to capture process emissions.

In 2020, the transport sector was responsible for 27% (13.1$MtCO_2e$) 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 55% compared with 1990 levels. Today, the road transport sector emits 8.6 $MtCO_2e$. By 2030 this will decline to 5.6 $MtCO_2e$, a reduction of 25% compared with 1990 and 35% compared to 2020 levels. The main contributor to this reduction is the electrification of the road sector, especially passenger vehicles, which manages to pass a 57% reduction mark from 1990 levels to 2030. By 2050, road transport emissions will decline by 88% compared with today's levels, to represent 9% of Norwegian emissions, leaving 1 $MtCO_2e$.

Aviation, rail and maritime combustion emissions have been declining since 2000 and are currently 35% of Norwegian total transport emissions. However, these emissions will not decline as fast as those from road transport. The overall GHG emissions from these non-road sectors are expected to decline by 22% from 1990 to 2030 and end up at 3 million tCO_2e. Longer term, synthetic fuels biofuels and hybrid electric solutions will contribute to a reduction of 86% by 2050 compared with today, leaving 0.6 $MtCO_2e$, most of which will come from the aviation sector.

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 remaining emissions are in the form of methane from burning biomass for heating. Today, the buildings sector represents only 1% of Norwegian emissions at about 500ktCO_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, these emissions will have further declined by 43% leaving a bit less than 300ktCO_2e.

Carbon capture and storage

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 predict that in the future, large-point sources, mainly in the manufacturing sector, will increase the capture of carbon from their waste streams. However, collectively, the developments we are aware of today and have modelled are not happening at sufficient scale to make a significant contribution to the emissions reductions required to reach Norway's climate ambitions.

Today there are two CCS processes in Norway, both related to oil and gas activities. At the Sleipner field some 850ktCO_2/yr is removed from gas and injected into an offshore sandstone reservoir (CCSI, 2020). At the Melkøya LNG facility, an additional 700ktCO_2/yr is captured and transported back to the Snøhvit field and stored in offshore reservoirs to prevent dry ice formation in the liquefaction process. 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 Sleiper to be replaced by other activities. However there is a likelihood of the CCS activity at Melkøya being replaced by other activities where the capture of CO_2 is necessary for gas shipped on keel.

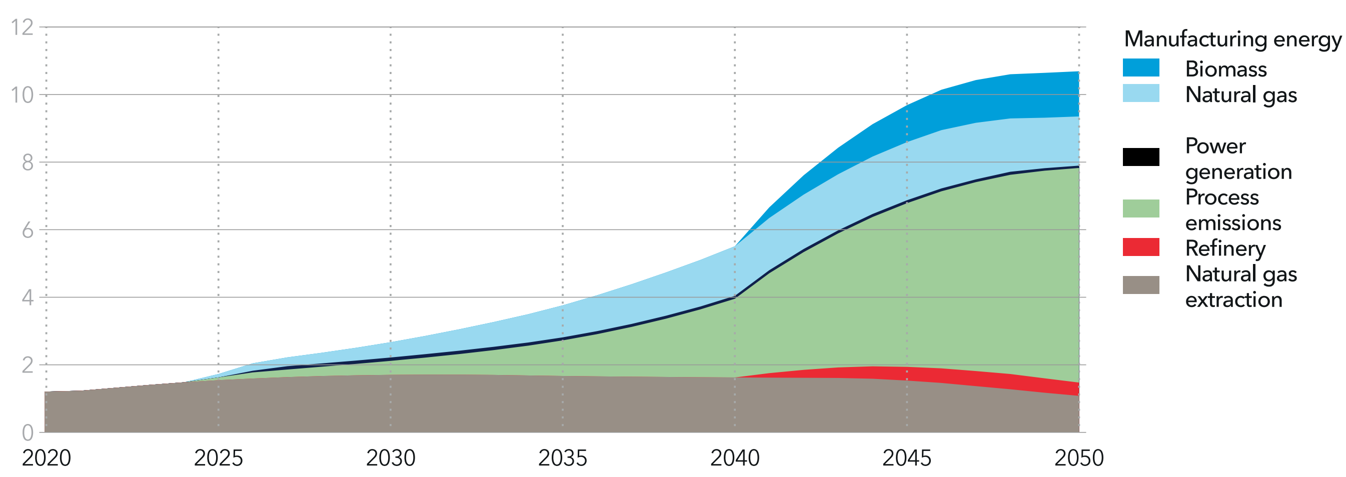
Other anticipated capture processes included in our modelling is the 400ktCO_2/yr at Brevik cement plant. We have also added another 400ktCO_2/yr from the Klemetsrud waste-to-energy plant. Both these capturing streams are anticipated to come online gradually from 2024 to 2027.

The Norwegian government approved state funding of NOK 16.8 billion as part of the Longship carbon and capture initiative in 2020 (government.no, 2020). Such a significant investment incentivizes an increased activity level for CCS which we have included in our analysis, along with an increasing CO_2 price. This shows CSS starting to grow by 2025 and slowly growing towards 2040, where carbon prices start to approach the cost of CCS, accelerating uptake. By 2050, we expect emissions captured by CCS to be 10.7 MtCO_2/yr, amounting to 60% of all Norwegian CO_2, leaving 7.4 MtCO_2 uncaptured in 2050. Even with CCS receiving significant government funding, there are long lead-times before actual projects with significant capture potential are operational.

FIGURE 5.3

Norwegian CO_2 emissions captured

Units: MtCO_2/yr



In some sectors, the level of capture will reach rates where capture is no longer possible, leading to capture leveling off (Figure 5.3). Remaining emissions stem from sectors such as transport, where mobile dispersed sources (low density of emissions) make capture difficult, as well as from the energy sector where the capture of small point sources offshore remains expensive and complicated. Remaining CO_2 emissions (7.4 Mt) and other GHGs (3.6MtCO_2e) will be increasingly difficult to avoid or remove without behavioural changes as well as significant further efforts in fuel switches and technical investments.

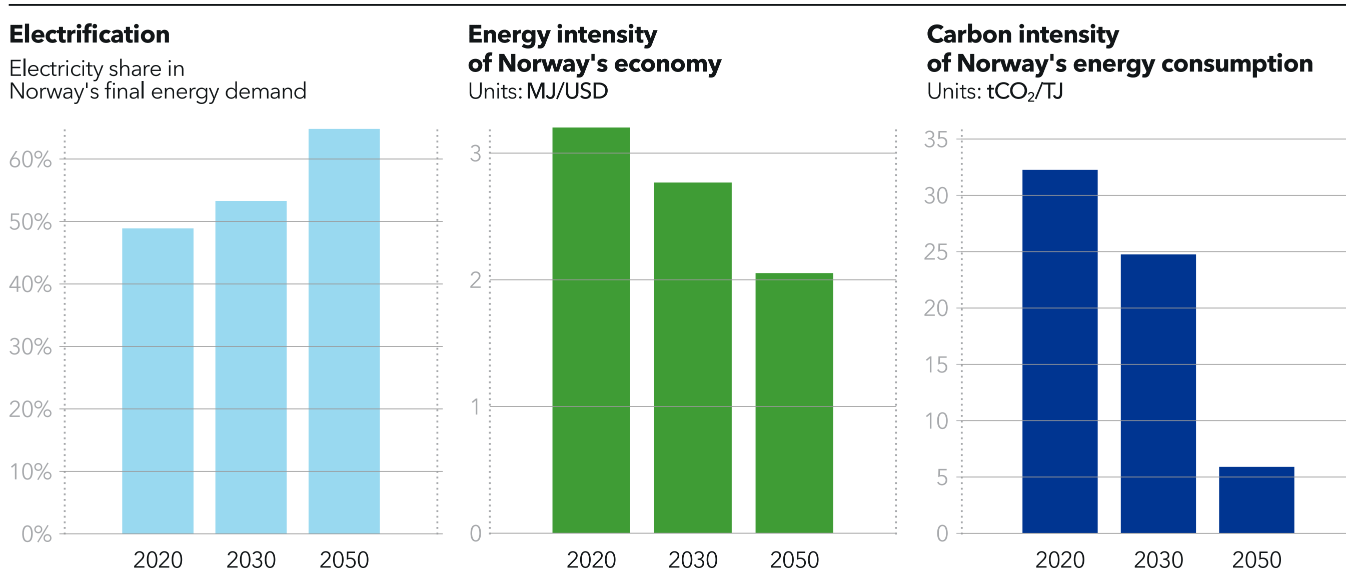
Energy transition indicators

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 forecast. Energy intensity is reduced to 2 MJ/USD, a level slightly above the rest of Europe which is expected to reach 1.8 MJ/USD in 2050. Carbon intensity significantly declines between 2030 and 2050, reaching a final value of 6 tCO_2/TJ. This level is much lower than in Europe, where we see a 60 % decline to 18 tCO_2/TJ.

The main reason for these differences is that emissions in Europe mainly stem from transport and buildings. These are sectors that Norway has electrified significantly, which places Norway at an advantage when considering carbon intensity.

We predict that in the future, large-point sources, mainly in the manufacturing sector, will increase the capture of carbon from their waste streams.

FIGURE 5.4



6 NORWEGIAN CLIMATE ACTION IN AN EU CONTEXT

There is an abundance of climate science stressing the urgency of implementing ambitious global, regional, and national climate policies. The unequivocal message in the first part of the Sixth Assessment Report (AR6) – The Physical Science Basis - from the United Nations Intergovernmental Panel on Climate Change (IPCC, 2021) is that with current trends, the world will exceed the Paris Agreement's 1.5-degrees threshold over the coming decade, unless emissions are cut by at least 49% from 2017 levels by 2030. National and corporate climate strategies not aligned with a 1.5°C warming outcome are facing rising scrutiny.

Alignment with the EU ambition level

The EU Green Deal is among the most ambitious and holistic cross-sector strategies attempting to limit the global temperature increase to 1.5 degrees globally, and to ensure that it is well below 2 degrees. The adopted EU Climate Law is a key component of this and entails the overall reduction of GHG emissions by at least 55% by 2030 compared with 1990 levels and achieving carbon neutrality by 2050. As a result, EU and EEA members such as Norway face the combination of i) sweeping EU regulatory changes that seek to stimulate GHG reductions and (ii) rising pressures to implement supplementary national measures to deliver on EU targets.

Against this backdrop, expectations for Norway to align with best practice emission reduction trajectories are rising. The spotlight will be on how Norway manages to reconcile deep decarbonization with economic pressures associated with transitioning the composition of the Norwegian economy. The Hurdal Platform, announced by the new Labour and Centre Party coalition government in October 2021, upgrades the Norwegian GHG emission reduction target from at least 50% by 2030 to 55% (compared with 1990 levels) and from 90-95% by 2050 to net zero. The new government platform pinpoints that the 55% reduction concerns the entire economy, including sectors in the present EU ETS-system. The Norwegian climate targets are aligned with those of the EU and require Norwegian policymakers to develop and implement measures to accelerate emission reductions accordingly.

Meeting 2030 targets: domestic action and emissions trading

Developing robust measures to meet increasingly stringent GHG reduction targets for the next decade and beyond will be a key part of the continued evolution of the Norwegian climate strategy. This point is particularly relevant given that Norway failed to meet its 2020 target for GHG emissions, after emitting about 50MtCO_2e – roughly the same as 1990 – against the target of 48.6MtCO_2e[1]. This failure can only be partly attributed to Statistics Norway adjusting annual emission levels upwards due to underreported figures for the use of marine gas oil (MGO) and diesel. It is clear that efforts to accelerate emission reductions must intensify, particularly considering upgraded targets from the Hurdal Platform and the reality that the 55% cut needs realization over a 9-year period.

The EU is strengthening the role of emissions trading for more sectors and deeper emission cuts. Overall, sectors under the revised EU Emissions Trading System (ETS) by 2030 will need to reduce their emissions by 61% compared to 2005 levels (representing an increase from the current -43% contribution to EU's climate target). The supply of emission allowances is tightening to reflect the EU 55% GHG emission reduction targets, and therefore also affect the new Norwegian target. Notably, under the 'Fit for 55' package of regulatory revision, the annual linear reduction factor (LRF) of the ETS available permits under the Phase IV (2021-2030) could nearly double from 2.2% to 4.2%. Furthermore, the revision would imply that aviation faces tightened regulation with the removal of free allowances, and the phase in of large ships with >5000 gross tonnage under the maritime sector over the period 2023 to full ETS inclusion from 2026. This would accelerate the rate at which existing and new ETS sectors would need to reduce emissions and bolster the ETS

[1] Norge bommer på nok et klimamål: – Utrolig flaut – Tu.no.

permit price – driving ETS sector emissions reductions in Norway. Finally, the revised EU ETS proposal would also establish a new, separate ETS scheme for emissions from fuels used in road transport and buildings, targeting fuel suppliers and to become operational from 2026.

As such, EU climate policy and the role of emissions trading in reducing emissions are expanding in the latter half of the decade, also suggesting that an increasing share of Norwegian emissions will be covered by EU ETS schemes. Other proposals under the 'Fit for 55' revisions, will also require monitoring and decisions in the Norwegian Parliament, such as the Renewable Energy Directive and the revision of the Energy Efficiency Directive and the Carbon Border Adjustment Mechanism (CBAM).

For traditional non-ETS sectors, such as waste and agriculture, emission cuts will rely on domestic initiatives, such as the gradual increase in the carbon tax as well as implementation among the 60 measures identified in Klimakur 2030 (Miljødirektoratet, 2020), under the previous government.

The challenging route to meeting climate targets

With the upgraded GHG reduction targets, there are increasing concerns that there will be a widening gap between actual emissions and targets leading up to 2030. The forecast emissions reduction achieved by 2030 compared to 1990 levels has only increased by 1 % since last year's ET Norway report, from 23% to 24 %. This is less than half of the new Norwegian target of 55%, clearly indicating that Norway must substantially gear up its efforts to reduce GHG emissions and quickly implement policies that have a real and lasting effect on emissions.

There is no doubt that Norway finds itself on the horns of a dilemma in trying to balance economic and climate goals. Pressure to act on climate ambitions will only increase, and the costs of not doing so will mount. However, there is scope for Norway to accelerate GHG emissions substantially beyond the projections made in this report, and, with decisive action, become a global frontrunner in low-carbon technology.

European Parliament in Strasbourg. Photo: Jaap Bunschoten

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LIST OF INTERVIEWEES

A number of interviews were conducted to form a basis for how to implement some of the near- to medium-term activities in the Norwegian energy landscape. The activities are related to decisions on policy as well as ambitions for new green growth. In the context of Norway, such decisions are difficult to forecast as step-changes are not well suited to our modelling approach. Thus, we asked a number of experts to help us with their personal point of view on likely developments in the coming decade. All interpretations and conclusions on what to implement in our modelling and analysis were made by DNV. We are deeply grateful to those who took the time to make themselves available for interviews. They are listed in alphabetical order with their assigned affiliation:

Hildegunn T. Blindheim NOROG**, Trym Edvardsson** NOROG, **Lars H. Gulbrandsen** FNI, **Ellen Hambro** KLD, **Stein Lier Hansen** Norsk industri,**Ingrid Endresen Haukeli** NVE, **Harald von Heyden** Artic Sectirities, **Marius Holm** f.d. ZERO, **Tor Håkon Jackson Inderberg** FNI, **Arne Klette** ABB, **Nils Klippenberg** Siemens, **Eystein Leren** Yara, **Jon André Løkke** NEL, **Toini Løvseth** Energi Norge, **Nils Kristian Nakstad** Enova, **Hans Gunnar Nåvik** Artic Sectirities, **Marianne J. Olsnes** Shell, **Finn Bjørn Ruyter** Hafslund, **Johan Sandberg** Aker Wind, **Hans Erik Vatne** Hydro, **Lene Westgaard-Halle** Stortinget, **Eirik Wærness** Equinor, **Ann Myhrer Østenby** NVE

THE PROJECT TEAM

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

Core contributors from DNV:

Project responsible: Sverre Alvik

Project manager: Mats Rinaldo

Modelling responsible: Onur Özgün

Core modelling- and research team and contributing authors: Kjersti Aarrestad, Gudmund Bartnes, Daniel Brenden, Anne Louise Koefoed, Adrien Zambon

Communications and editing: Mark Irvine, Anne Vandbakk, Therese Sanni

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Historical data

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