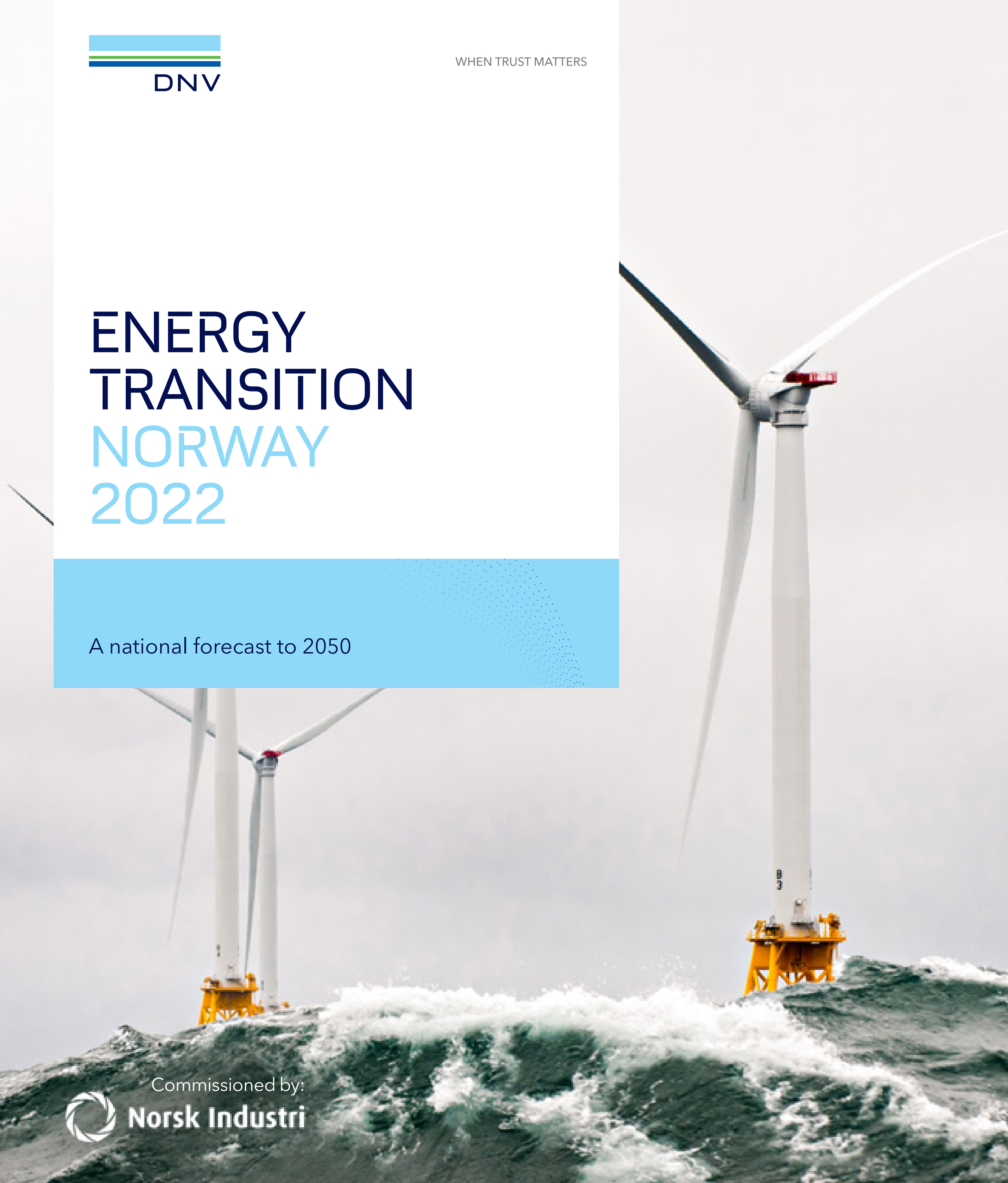
WHEN TRUST MATTERS

ENERGY TRANSITION NORWAY 2022

A national forecast to 2050



Commissioned by: Norsk Industri

FOREWORD

Norway plays an important part in the European energy system. Europe is dependent on secure gas import from Norway and our electricity prices are linked to energy prices in Europe. Geopolitical stability in Europe is dependent on the overall energy situation, and Norway is an important contributor.

The *Energy Transition Norway 2022* report (a joint effort between DNV and Norsk Industri) forecasts the country's GHG emissions, energy demand, and energy supply through to 2050, including the effects of the pandemic and the war in Ukraine.

Norway has reconfirmed the climate targets for 2030, cutting emissions minimum 55% compared to 1990 levels, and to net-zero in 2050. This forecast shows that expected achievement are at the same level as last year – some 25% reduction of GHG emission in 2030 compared with the committed targets of 55%. For 2050 we expect a reduction of 79% compared with the net-zero ambition.

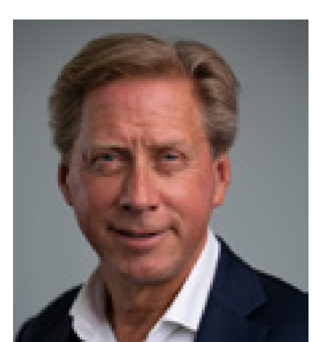
There is no way to reach our climate targets without dramatic additional policy actions.

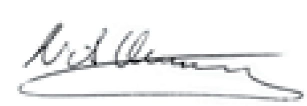
The climate targets can be met with existing technology and capabilities. Innovations and additional technologies will further improve the cost efficiency of the solutions going forward. There are three crucial initiatives to drive down the GHG emissions. First, to dramatically increase the production of green electrons for electrification and new energy carriers like hydrogen and ammonia. Onshore electricity demand is set to double by 2050. Second, to invest and expand in infrastructure to transport and distribute the energy to the industrial users, charging stations, etc. Third, to drive down energy consumption with energy efficiency measures.

Solar power is quick to install but overall has only a small contribution in Norway. Existing hydropower can be modernized for greater output. Combining pumped storage solutions makes hydropower an even better partner for variable wind power. Wind power onshore is more cost efficient than offshore, but it is hampered by local resistance. Therefore, large scale offshore floating wind is the single most important instrument to drive down emissions and ensure new green industry. More electricity production into the southern part of Norway will help to neutralize some of the high pricing we currently experience from the European market.

The Norwegian industry has the means and knowledge to act on all these initiatives. Private funding will be available when the project pipeline is attractive. Predictable and ambitious government policy is required to drive the changes necessary in governmental bodies and regulations.

Time is of the essence: we have only eight years to fulfill our 2030 commitments. Let's work together – industry and policy makers – to create a better tomorrow.

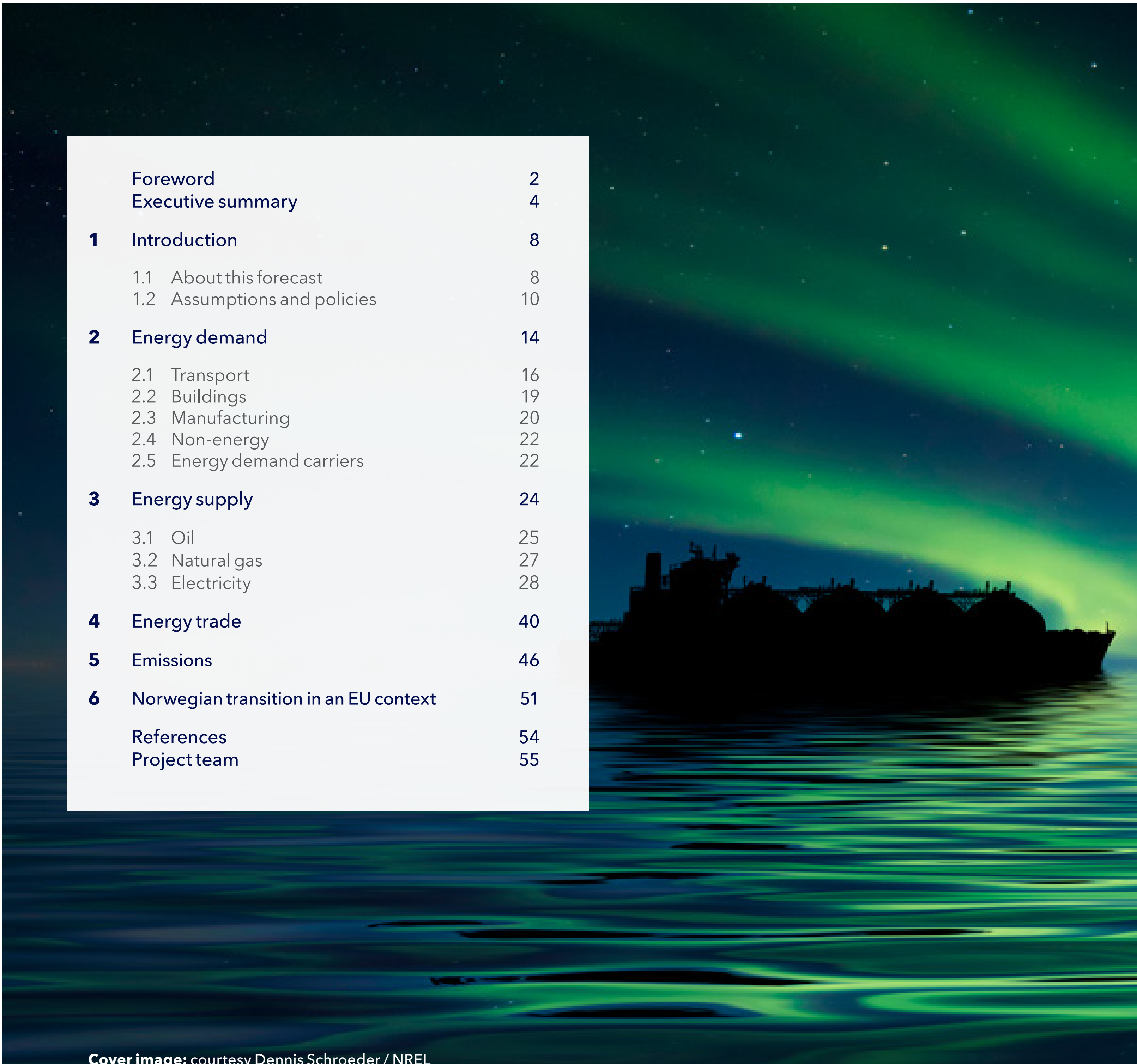




Nils Klippenberg

Chairman Electro and Energy – Norsk Industri

CONTENTS



Cover image: courtesy Dennis Schroeder / NREL

EXECUTIVE SUMMARY

Highlights

1. **Norway is not on track to reach its 2030 and 2050 climate targets. There is no evidence that the actions taken are creating the dramatic shift needed to reach these targets.**
2. **Russia's invasion of Ukraine has raised Norwegian energy exports in the short term, but will lead to a steeper decline in natural gas demand in the long term.**
3. **Record-high electricity prices now and an electricity deficit between 2026-2030 hinders clean-tech industry development.**
4. **Power and hydrogen exports grow towards 2050 but will only amount to a fraction of today's energy export revenues, which will fall dramatically due to declining oil and gas demand.**

All national energy transitions are unfolding within regional transitions, shaped in turn by global events and trends. This has been dramatically demonstrated over the last year by the energy supply shocks in Europe related to the war in Ukraine. Norway's energy system is tightly linked to the European and global energy systems, despite its particularities and peripheral location in Europe. The linkages include grids, pipelines, shipping, technology, economic ties, and policy development.

This *Energy Transition Norway* report sets out 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 country's energy system.

Norway is not on track to reach its 2030 and 2050 climate targets. There is no evidence that the actions taken are creating the dramatic shift needed to reach these targets.

Norway has ambitious climate targets that involve more than halving emissions by 2030 compared with 1990 levels, with a further reduction down to net zero by 2050. The official Norwegian pledge to United Nations is emissions reduction of at least 55 % by 2030. Our forecast shows that Norway will have to *significantly* change its current course to reach the targets in both 2030 and 2050 (Figure 1). Each passing year where concerted action is not taken means the window for achieving these targets narrows, and that applies particularly to the nearer-term ambitions for 2030, where our forecast sees Norway on track to miss its target by 50%.

A large part of Norway's energy use already has low carbon intensity owing to its hydropower-dominated electricity system. It is therefore the emissions from hard-to-abate sectors like heavy industry, heavy transport, oil and gas production, and agriculture that will need to be targeted for decarbonization if Norway is to reach its ambitious climate targets. A good example of the scale of action needed has already been set in the 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 36% of the total road transport emissions compared with 2021 levels.

Our analysis through to mid-century shows Norway's 2030 greenhouse gas (GHG) emissions reducing 25% by 2030 and 79% by 2050 compared with 1990 levels, while the Norwegian government's stated ambition is to reduce emissions to net zero by 2050. DNV's recent publication *Energy Transition Outlook* (2022) shows that high-income countries, such as those in Europe and rest of OECD, must reach net zero well before 2050 to allow the world to reach the ambitions of the Paris Agreement. That makes the distance between Norway's current trajectory and the 1.5°C degree future it aims to support even larger.

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.

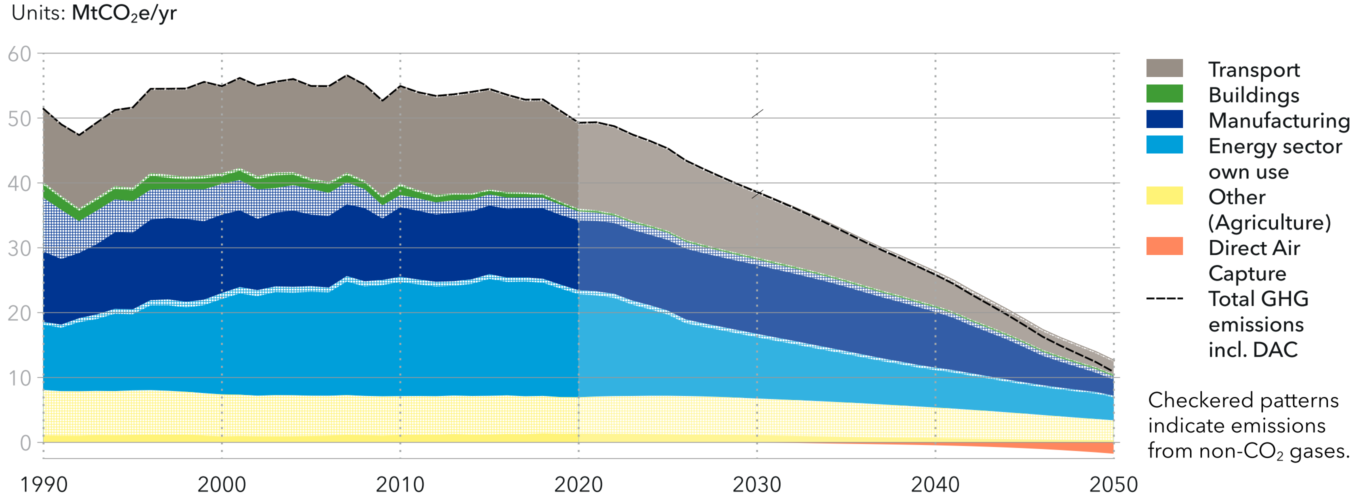
Russia's invasion of Ukraine has increased Norwegian energy exports in the short term, but will lead to a steeper decline in natural gas demand in the long term.

The greatest consequences of the war (ongoing at time of publication) are naturally being felt in Ukraine, but the reduction in grain, vegetable oil, and fertilizer output is deepening worldwide food insecurity – already impacted by climate change and COVID-19 before the invasion. The parallel energy war has also sent shock-waves through world energy markets due to OECD-led sanctions against Russian energy exports that are likely to have considerable long-term consequences even after what now looks to be a protracted war, is over. Some 40% of European gas imports have been covered by Russia in recent years. Terminating this source of supply in line with EU plans before 2027 and possibly even faster with Russian close-down of export, will lead to large changes not only in the European market, but also globally. In the short term, Russian gas is partly replaced by imported LNG and local coal, along with energy efficiency measures. In parallel, the EU plans for an even faster build-out of renewable energy. In the longer term, the combined effect of higher gas prices and energy security considerations (essentially meaning

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 (2022) much more policy support, including tough mandates, for renewable energy) will accelerate the European energy transition.

Notably, European demand for natural gas is falling and will continue to fall much more rapidly than expected before the war. DNV finds European gas demand to reduce from the 540bn m^3 today to 430bn m^3 in 2030 and 170bn m^3 in 2050. This is 20% and 45% lower, respectively, than we forecast one year ago. When EU and UK gas imports decline steeply after 2030, the effect for Norway will be dramatic.

Record-high electricity prices now and an electricity deficit between 2026-2030 hinders clean-tech industry development.

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

In the coming decade, we foresee a significantly increased electricity demand in Norway, but mostly flat production. Households, industry, the electrification of transport, and electrification of several new oil and gas installations, will consume the existing Norwegian electricity surplus – and more.

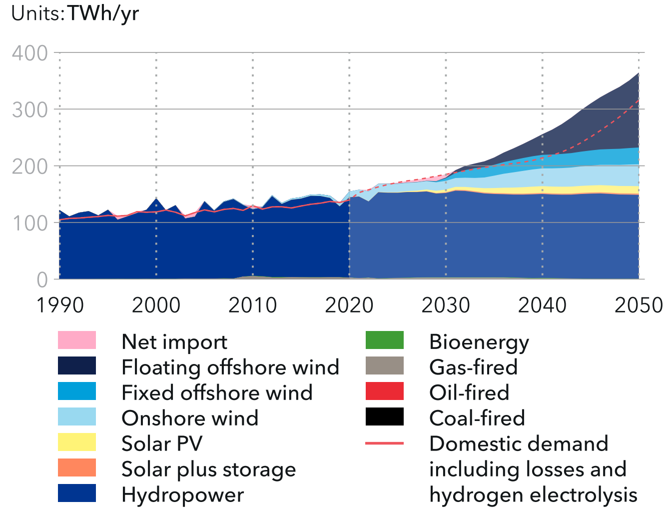
With an annual net electricity deficit in the period 2026-2030, Norway will likely have net import of electricity for several years (Figure 2). Import of electricity can cause volatility as well as potentially higher prices – removing the competitive advantage of low-priced green electricity needed for industrial production.

The electricity deficit threatens the establishment of new industries not only because there are shortfalls in the availability of reasonably-priced renewable power nationally, but also also due to limitations in peak power supply regionally. This is happening already to some extent, judging from reports of new clean tech busi-

FIGURE 2

Norway electricity supply by power stations and net imports

Units: TWh/yr

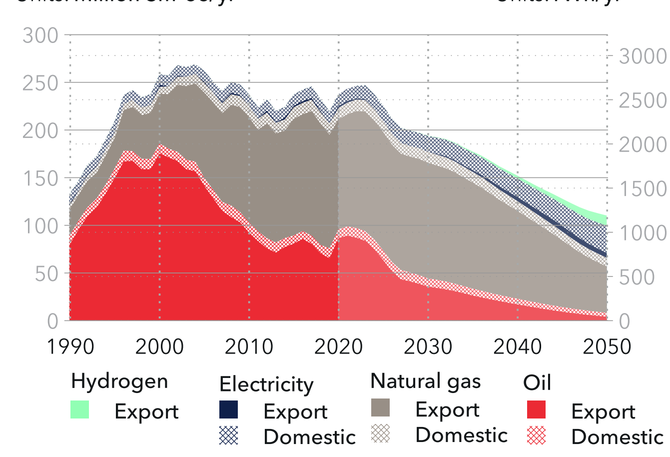


Historical data source: IEA WEB (2022), SSB (2022)

FIGURE 3

Norway's energy production allocated to domestic use and export

Units: Million Sm^3oe/yr Units: TWh/yr



Oil includes condensates, natural gas includes NGLs.
Historical data source: NPD (2022), IEA WEB (2022)

nesses deciding to move to other countries. The situation is expected to worsen in the coming years. It will only improve when there is certainty on when large new offshore wind capacity will come into production, with the simultaneous removal of grid constraints and regional limitations in covering peak power demand.

There is uncertainty about when large-scale offshore wind production will begin. However, DNV thinks it most likely that production will start from 2028 and scale thereafter such that, from 2031 onwards, Norway can once again enjoy an annual electricity surplus.

Power and hydrogen exports grow towards 2050 but will only represent a fraction of today's energy export revenues, which will fall dramatically due to declining oil and gas demand.

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.

However, Norwegian oil and gas production will start to decline after 2025 when several fields are at the end of their lifetimes and global demand for initially oil, and a few years later gas, begins to fall. By 2050, Norway's oil export will be 5% of today's level. Gas production and export will remain strong in the short term while Europe replaces Russian gas. However the long-term effects of European energy security and climate measures will reduce Norwegian gas exports. These will peak by 2025 at almost 130bn m^3, and then quickly decline so that exports are 92bn m^3 in 2040 and at 48bn m^3 in 2050 which is a reduction of 60% (Figure 3).

A growing share of energy exports will be converted to electricity and hydrogen. DNV forecasts that, until late 2030s, most hydrogen in Norway will be produced from natural gas with increasing use of CCS (blue hydrogen). Norwegian domestic demand for hydrogen and hydrogen products will increase from the present 400,000 tonnes H_2 per year to about 1.2M tonnes per year in 2050, with most of the demand coming from industrial heat, followed by e-fuel, ammonia and methanol for shipping and aviation. From 2040 onwards, there will be periods when high energy production from wind across Northern Europe will make it more profitable to produce hydrogen from electricity (green hydrogen) than to export electricity directly. Such production will increasingly be larger than domestic demand, and Norway will reach 1 Mt/yr in hydrogen export per year by 2040 and 3.4 Mt/yr in 2050.

Nevertheless, by 2050, the majority of energy exports will still be gas and oil. Over the last 10 years, oil and gas export revenue has averaged 490bn NOK/year (SSB, 2022). 2021 exports hit an all-time high at 825bn NOK, and 2022 will be even higher due to record high gas prices. Assuming the historical average prices, and a 95% and 60% reduction in oil and gas exports respectively, export revenue will fall by 78% and end up at 108bn NOK/year in 2050. Even with the forecast build-out of offshore wind for energy export, the 55 TWh/year in net electricity exports by 2050 will only translate to an additional income of 36bn NOK/year at historical electricity prices. Adding hydrogen export of 3.4 MtH_2/year and ammonia export of 1.2 Mt/year could yield another 80bn NOK/year using 2.2 USD/kg H_2 as a reference price.

Going forward, Norway faces a significant long term export revenue drop. There is, however, a potentially large upside. Norway has abundant unused energy resources in the form of wind and natural gas, and it is unlikely EU and UK will be able to meet their vast needs for renewable electricity and hydrogen without significant import.

Norwegian natural gas can be converted to blue hydrogen and exported to Northern Europe for a cost somewhat higher than subsidised green hydrogen from Southern Europe. With equal subsidies blue hydrogen from Norway will have similar costs, and the competitive situation will be decided by the degree of reuse of existing gas infrastructure. It is absolutely possible Northern Europe will need both these two sources of hydrogen. Hence, should Norway wish to perpetuate its position as an important energy-export nation, the country has opportunities to export much more power as well as green and blue hydrogen.

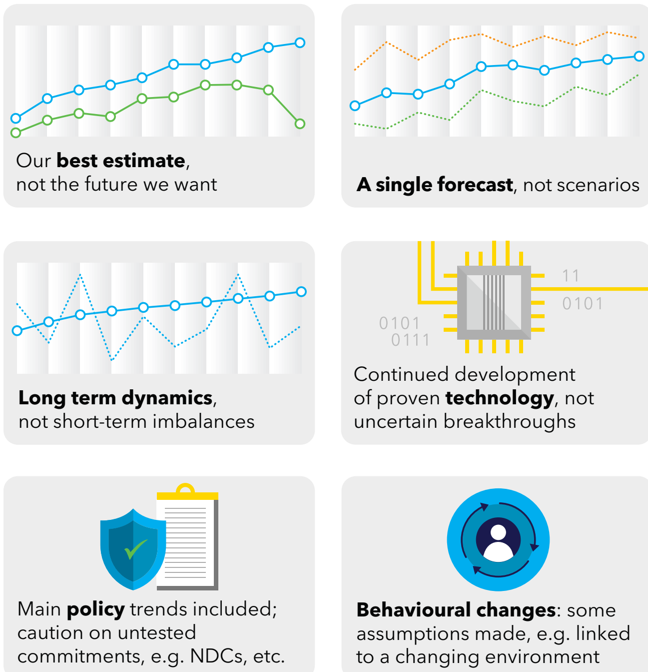
1 INTRODUCTION

1.1 About this Outlook

This 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* (ETO) and model (DNV, 2022a). This approach yields a consistent and energy-balanced result, 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, energy 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 adjustments. 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* 2022 (DNV, 2022a), but refer to that report for further details.

We are also mindful that this analysis has been prepared during the Russian invasion of Ukraine and in the context the unsettled economic environment at the tail-end of the COVID-19 pandemic, which adds uncertainty to several parameters of relevance to the energy transition, first and foremost the unprecedented energy prices, GDP development, EU and Norwegian policy interventions and behavioural changes.

In addition to incorporating the energy trade of oil, gas and coal, we include import and export of electricity as well as hydrogen. We have extended our model to include the energy exchange between Norway and Europe. This is an important dynamic in Norway’s energy system, and will prove increasingly important in the future as fossil-fuel exports decline for Norway and electricity and hydrogen export grows.

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 or ‘most likely’. 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 the biggest impact and are also easier to forecast, we have conducted a number of interviews with politicians, 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 and 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 (2018), 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, which primarily has the biggest impact in developing regions. Norway's population is forecast to grow from 5.4 million people today to reach 6.4 million in 2050.

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 was -0.8% in 2020, and +4.1% in 2021 and an estimated 4% in 2022, thereafter returning to the growth rates given by the DNV GDP model.

For Norway, 2021 GDP was USD 393bn, while in 2050 it will be at USD 599bn. This implies a CAGR of 1.5% per year, including the effect of COVID-19. Productivity increases from USD 72,700 to USD 93,900 per person in the same period, measured in USD-denominated 2017 purchasing power parity (PPP) terms.

Technology development

DNV bases its forecast on the continued development of proven technologies in terms of costs and technical feasibility, not uncertain breakthroughs. However, during the period covered by this Outlook, technologies we currently consider most promising, could shift owing to changes in levels of financial support, or a change in potential for 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 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 are: 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 our forecast.

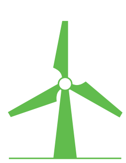
It is not a given that energy or climate ambitions and targets will be met, either on a national, regional, or global level. As such, our forecast does not assume that Norway will accomplish its national target of reducing greenhouse gas emissions by 55% compared with 1990 levels by 2030.

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, 2022a) we have a comprehensive list of policy factors influencing the forecast. The same policy factors are incorporated in this analysis with the following adjustments for Norway:

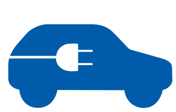
FIGURE 1

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 costs decline 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 changed from existing support to incorporate new scheme from 1 January 2023, slightly increasing costs. However, with existing high cost of gasoline/diesel, the change will be mostly noted in vehicle stock and not so much new sales.
– 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 9% in the commercial vehicle segment by 2050.

Hydrogen

- We expect hydrogen production to have some projects supported by subsidies to compensate for high prices where CO_2 pricing still makes hydrogen uncompetitive. The level of support is expected to be 50% of the investment cost for all low-carbon hydrogen production technologies until 2030. The support is expected to decrease to 25% of the investment cost by 2050.
- We expect grid-connected electrolysers to pay 25% of taxes and grid-charges paid by other industrial consumers. This 25% is a combined result of active government support and the fact that some of grid-connected electrolysers will be renewable electricity producers that will decide between selling electricity to the power grid or hydrogen production based on the price, therefore do not need to buy electricity (rather withhold selling).
- We expect the cost of natural gas for methane reformers to be lower than the industrial gas price, due to the expectation that many of these reformers will be supplied directly by gas producers without going through the transmission network and the market. We assumed the gas price for methane reformers to be 25% of wholesale price to retail price, on the average.

Carbon capture and storage

- 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 Norwegian Continental Shelf 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, albeit taking increasing carbon pricing into account.

Carbon price

- Carbon prices are reflected as costs for fossil fuels manufacturing and buildings; and in power, hydrogen, ammonia, and methanol production, where progressive participation in the same regional and/or sectoral carbon-pricing schemes is assumed. Norway is part of EU emissions trading scheme (ETS), and carbon prices equivalent to rest of Europe (reaching USD 135/t CO_2 in 2050) are used.
- A Norwegian CO_2 price reaching 2,000 NOK 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, carbon price is not used directly, but taxation of fuels, energy, and carbon is incorporated causing additional costs.

Fuel tax

- Fossil-fuel taxation 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 power capacity limitations, and capacity will be added when profitable, also for export.
- Norway is expected to add generating capacity to support increasing demand for domestic 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 further transmission capacity of 5GW. Assumed to be gradually introduced during the 2030s. Total interconnector capacity is 4 GW to UK and 10.5 GW to Europe in 2050.
- We do not expect hydrogen export to be limited by pipeline capacity – but can be exported when needed that could either be new pipelines or repurposed natural gas pipelines.

2 ENERGY DEMAND

Norwegian energy consumption is dependent on a supply/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 lockstep with population growth and improvements in standards of living. Norway's population growth is slowing down but will still reach 6.4 million people in 2050. Economic growth will average 1.5% from 2021 to 2050, when the size of the Norwegian economy will be 53% higher than today's USD 393bn.

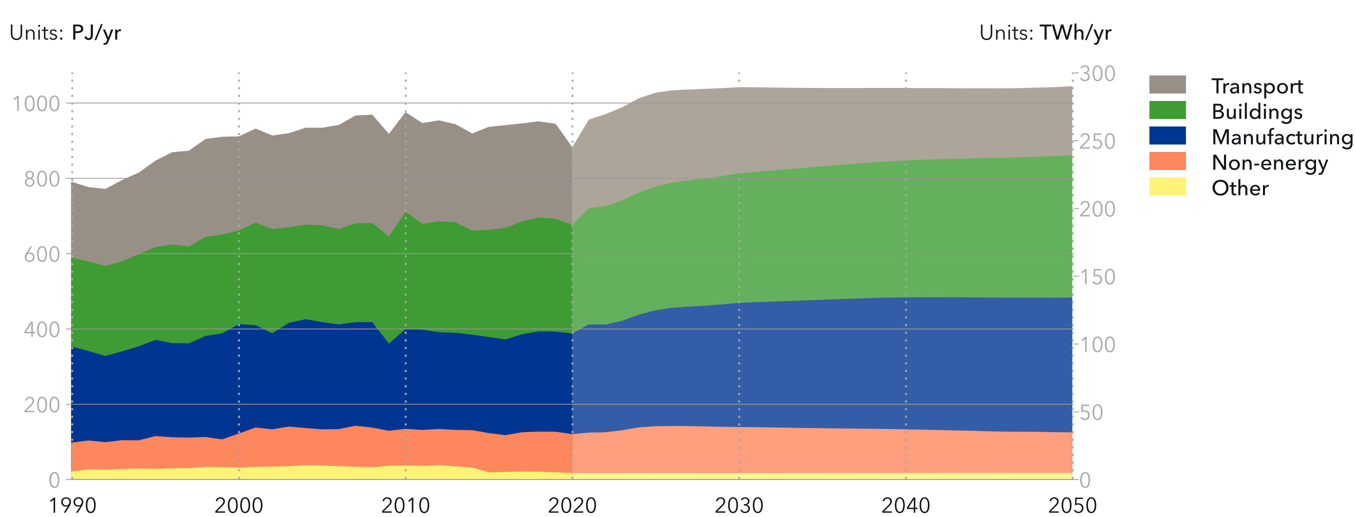
More people requiring more energy services for transportation, heating, lighting or consumer goods typically means increased energy demand. This held true until around 2008, when demand growth started to level off owing to impressive developments in energy efficiency, achieved by, for example, advances 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 was followed by a pick-up in 2021, and the growth will continue 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 is clearly seen, strongest in transport and weakest 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

FIGURE 2.1

Norway final energy demand by sector



Historical data source: IEA WEB (2022), SSB (2022)

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

Due to significant efficiency gains – largely enabled by accelerated electrification – energy demand growth will eventually track well below economic growth.

Electric battery operated passenger ferry in the Oslo fjord

2.1 Transport

Transport – including road, rail, aviation and maritime – accounted for 25% of Norwegian final energy demand in 2021, almost entirely in the form of oil as fuel (86%). We forecast that overall energy demand will decline almost 22% from 235 petajoules (PJ) in 2021 to 183 PJ by 2050 (Figure 2.2).

Passenger and commercial vehicles combined are the largest sources of demand, constituting 64% of total energy demand in 2021. With road transport set to be largely electrified by 2050, its share of demand reduces to 43%. Overall, the transport sector's transformation will include oil's share in the fuel mix dropping from 86% today to 32% 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 (ICEVs) 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 EVs in the passenger segment, driving uptake and further lowering cost. For most uses, EVs will soon become more cost effective than ICE vehicles; EVs typically consume less than a third of the energy that ICEVs do, and cost much less to maintain.

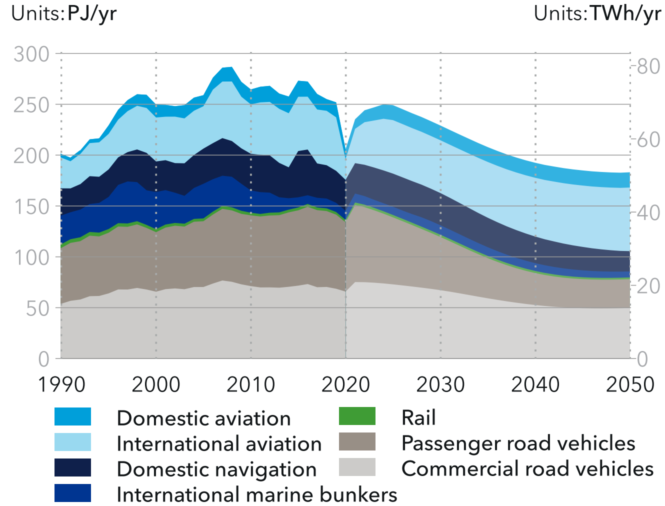
However, battery electric vehicle (BEV) uptake in the near-term hinges on continued policy support, and our forecast factors in a significant level of such support – even if costs will slightly increase owing to a progressive decline of support, starting with a new scheme from 1 Jan 2023 for the most-expensive EV vehicles. New vehicle sales for 2022 will be considerably lower than in 2021, so implying that policies should not only target the proportion of new vehicle sales that are BEVs but also the rate of replacement of existing fossil-fueled vehicles.

EVs will account for 90% of new passenger vehicle sales in Norway in 2025, and 97% by 2030 (Figure 2.3). EV uptake will be somewhat slower for commercial vehicles, which includes everything from smaller trucks and utility vehicles to municipal buses and long-haul heavy road transport. Battery cost and driving range are the key determinants in

FIGURE 2.2

Norway transport sector energy demand by subsector

Units: PJ/yr Units: TWh/yr

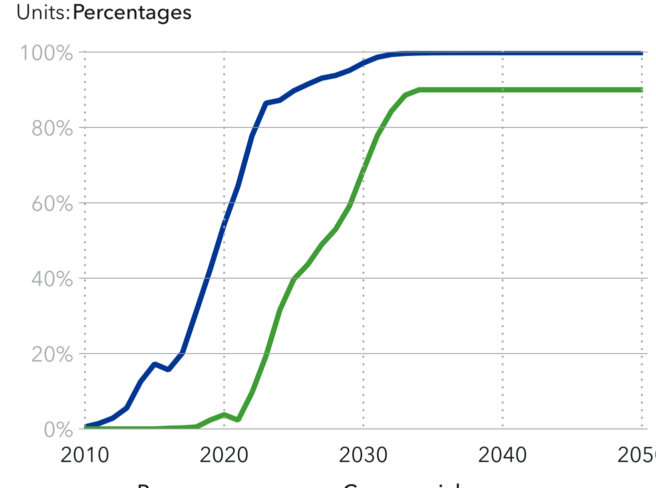


Historical data source: IEA WEB (2022), SSB (2022)

FIGURE 2.3

Norway market share of electric vehicles

Units: Percentages



Electric vehicles include BEVs and FCEVs. Historical data source: SSB (2022) the competition between batteries and ICEs, and hence on the electrification opportunities of various vehicle segments. We expect 17% 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 2040 (Figure 2.4). 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 17% 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 2.5 shows road transport energy demand halving from 151 PJ in 2021 to 78 PJ in 2050, mainly because of the shift from ICE to electric drivetrains. The subsector's energy demand for oil declines 90% while demand for energy from electricity grows more than 10-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.

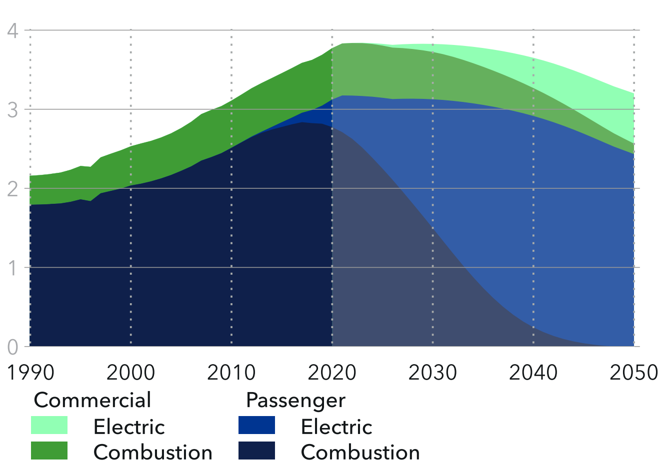
Aviation

Aviation has grown strongly in recent decades but levelled off since 2010. Air travel has substantially decreased in the past two years, but the sector is expected to recover to pre-COVID levels by 2024. The annual number of air trips is forecast to increase in the future compared with 2021. However, fuel use will not grow at the same pace 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, part of which is well suited for electrification, meaning Norway could be a front-runner globally in the electrification of short-haul flights.

FIGURE 2.4

Norway number of road vehicles by type and drivetrain

Units: Million vehicles

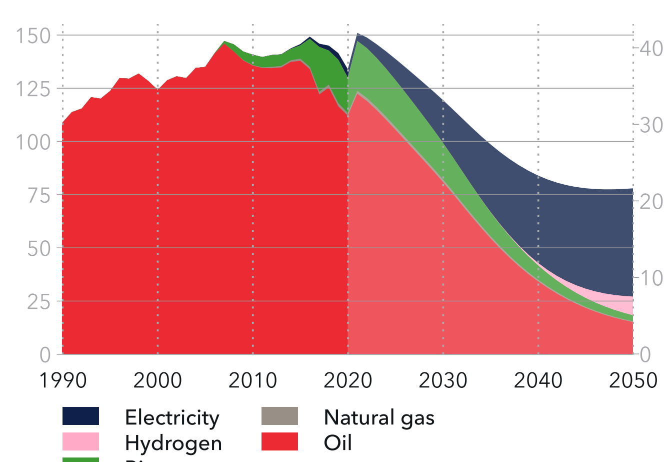


Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs.
Historical data source: SSB (2022)

FIGURE 2.5

Norway road subsector energy demand by carrier

Units: PJ/yr Units: TWh/yr



Natural gas includes LPG. Historical data source: IEA WEB (2022), SSB (2022)

That said, we forecast that sustainable aviation fuels (SAF), particularly biofuel blends, will be the main contributors 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, 53% (41 PJ in energy terms) of Norway's aviation fuel mix will still depend on oil, but the share of biofuels will increase to 21% (16 PJ), hydrogen and synthetic low carbon fuels share is another 23% (18 PJ) and electric aviation will account for 4% (3 PJ) as shown in Figure 2.6.

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 2021, the total demand was 39 PJ, of which 77% was domestic use. There is a fast recovery from the pandemic and energy demand will grow towards 2030, but the long-term trend will be a decline in energy demand of 33% reaching 26 PJ in 2050.

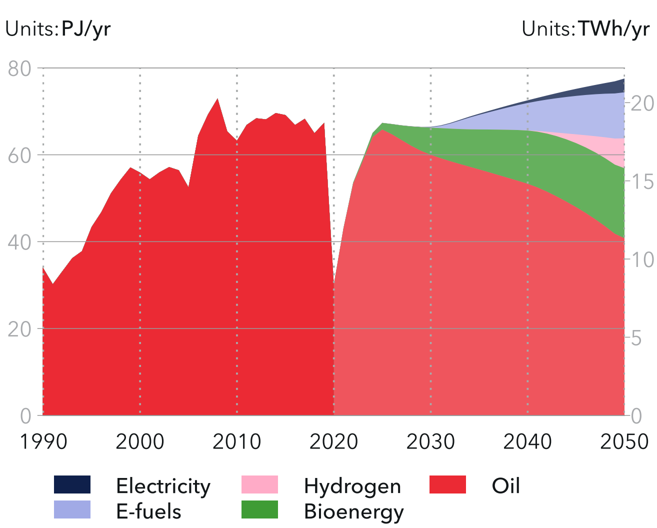
The IMO regulation on global shipping targets a 50% reduction in CO_2 emissions from 2008 to 2050. We forecast that a mixture of improved utilization and energy efficiencies, combined with massive fuel decarbonization, involving conversion from oil to gas and ammonia and other low- and/or zero carbon 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 and/or hydrogen, but it will initially be gas and later other low-carbon fuels (ammonia, e-methanol) that contribute as the main alternative fuel sources for shipping (Figure 2.7).

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 2.6

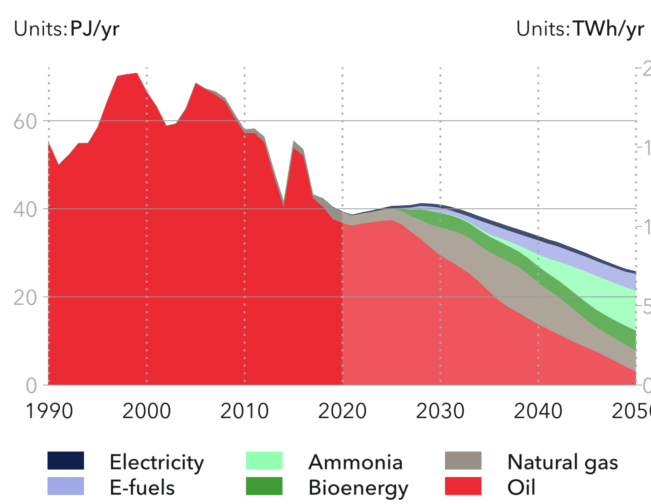
Norway aviation subsector energy demand by carrier



Historical data source: IEA WEB (2022), SSB (2022)

FIGURE 2.7

Norway maritime subsector energy demand by carrier



Natural gas includes LNG and LPG.
Historical data source: IEA WEB (2022), SSB (2022)

2.2 Buildings

In 2021, about a third (32%) of Norway's energy was consumed in buildings, making it the largest energy demand sector. Most of this energy is used for heating (Figure 2.8), and 56% of the total energy consumption is used in residential buildings. 80% of building energy demand is supplied by electricity with the rest covered by biomass, direct heat, and oil to a lesser extent. The relative shares of all these energy carriers will remain stable towards 2050. We estimate final energy demand for five end-uses: appliances and lighting, cooking, space cooling, space heating, and water heating.

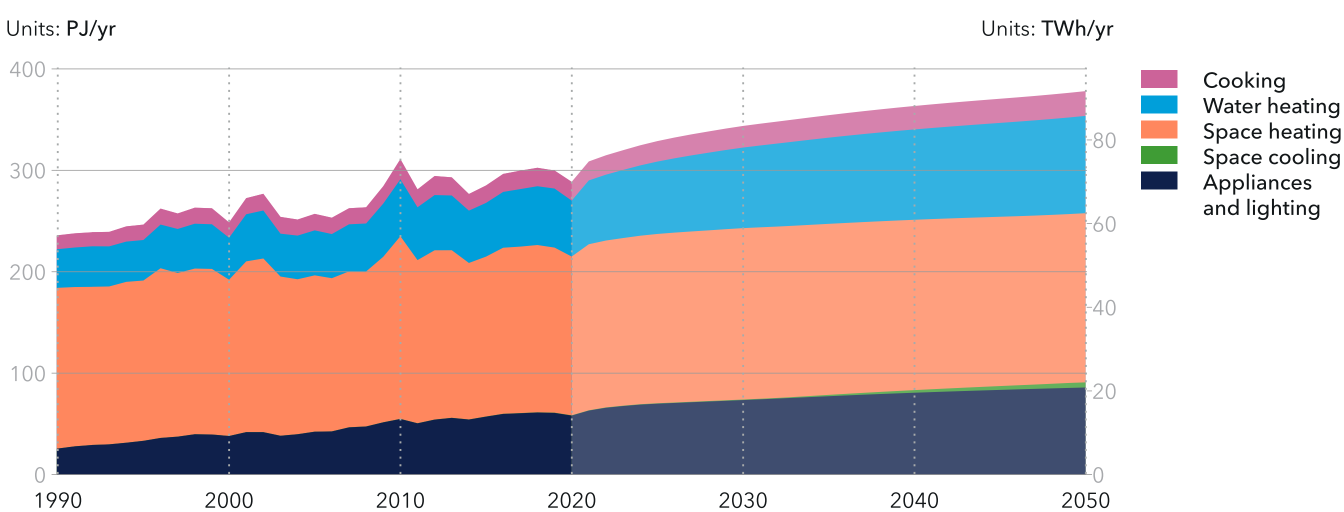
Floor area is one of the most important drivers of energy demand in buildings. While an increasing population with higher GDP per capita will push energy demand in the buildings sector upwards, this will be counteracted by increased efficiencies in appliances and heating.

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. However, recent high electricity prices have added focus on energy savings, also with support from ENOVA to household efficiency improvements. We forecast that energy demand for appliances and lighting for both residential and commercial buildings will grow by a third between 2021 and 2050.

Space heating accounts for 53% of all energy demand and is the segment with the biggest expectation of efficiency gains. Buildings heat energy demand will remain stable over the next decades compared to 2021 (164 PJ), 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 2.8

Norway buildings sector energy demand by end use



Historical data source: SSB (2022), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2022)

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" (covered in Chapter 3). Manufacturing in our Outlook covers four separate subsectors:

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

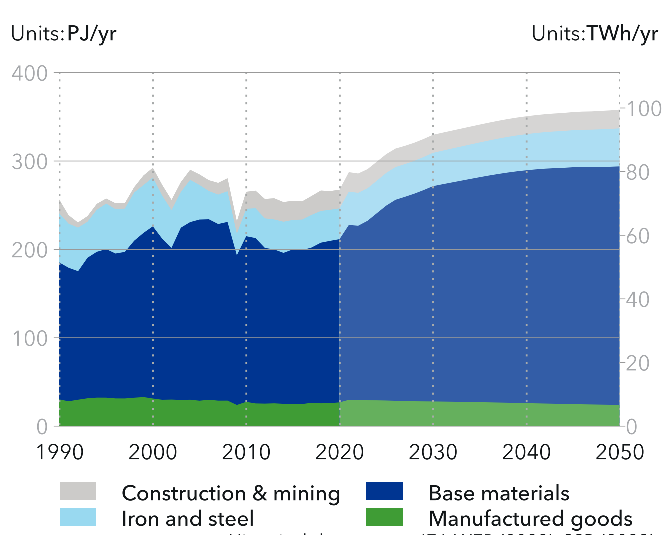
Base materials – includes production of non-metallic minerals (including conversion into cement), chemicals, and petrochemicals; non-ferrous materials, including aluminium; wood and its products, incl. paper, pulp, and print.

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 2.9

Norway manufacturing energy demand by subsector



Historical data source: IEA WEB (2022), SSB (2022)

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 ETO 2022 (DNV, 2022a). In Norway, the industrial sector and especially the base material sector is a large contributor to Norway's manufacturing sector GDP.

Norway's manufacturing sector consumed 287 PJ in 2021, 30% of the country's final energy demand. The base materials subsector represents 69% of total manufacturing energy demand (Figure 2.9), dominated by the production of non-ferrous metals (like aluminium and manganese) and petrochemicals.

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 2021 at 22 PJ. Going forward, we expect to see energy demand remaining constant around that value until 2050.

Energy demand for the base materials subsector was 198 PJ in 2021. The sector is energy intensive because it converts raw materials into feedstock for other industries. Energy consumption in the base material sector is mainly from industrial high-heat processes (65%) and operating machines, motors and appliances (34%), as shown in Figure 2.10. Demand is expected to grow sharply towards 2030, after which growth eases to 270 PJ in 2050. This overall growth of 36% 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. Cement, plastics, and other chemicals energy use will remain constant.

The majority of the Norwegian iron and steel subsector's current energy demand is for heat, the rest being for reduction agents during steel production and machinery equipment (Figure 2.10). Energy demand is currently at 37 PJ (13% 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 virgin iron ore.

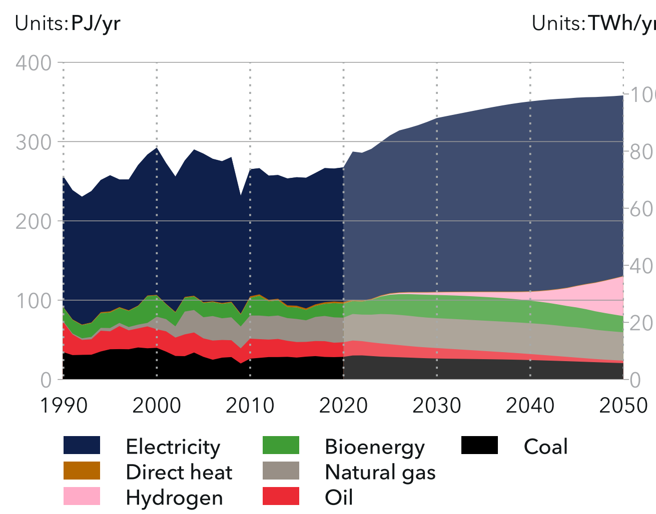
Energy demand from manufactured goods has been on a steady decline since 2000 and represents 10% of the manufacturing sector's energy demand today (30 PJ). The slow decline is expected to continue towards 2050 and ends up at 24 PJ. A large share (64%) of final energy here is used for heat. Of the remainder, most final energy (34%) is used 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 2.10). By then, half of energy demand will derive from MMA while efficiencies in heating will have reduced energy demand to 12 PJ.

Changes in Norwegian manufacturing's energy mix are dependent on technological innovation, resource availability, and on policies and incentives. With 65% of the sector already electrified, further electrification offers only limited efficiency gains, so change between now and 2050 in sourcing energy is most likely in high-heat processes.

From the 2030s, we expect decarbonized hydrogen 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 14% in 2050. However, direct electrification will still dominate through to 2050, when it will have a 63% share in the manufacturing energy mix (Figure 2.11).

FIGURE 2.11

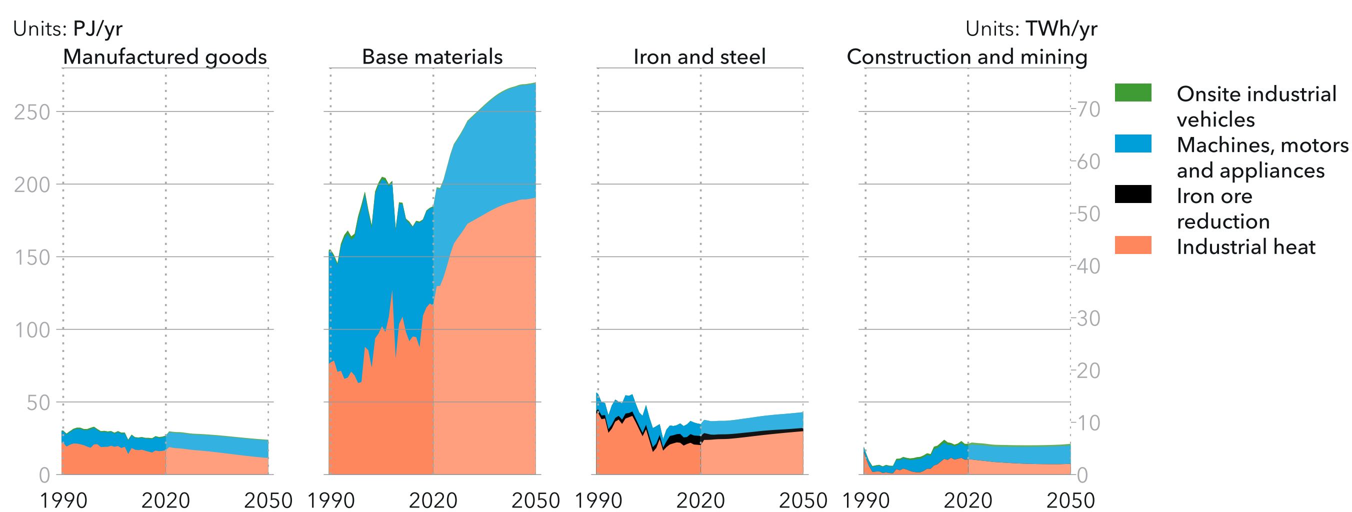
Norway manufacturing sector energy demand by carrier



Historical data source: IEA WEB (2022), SSB (2022)

FIGURE 2.10

Norway manufacturing subsectors energy demand by end use



Historical data source: IEA WEB (2022), SSB (2022)

2.4 Non-energy

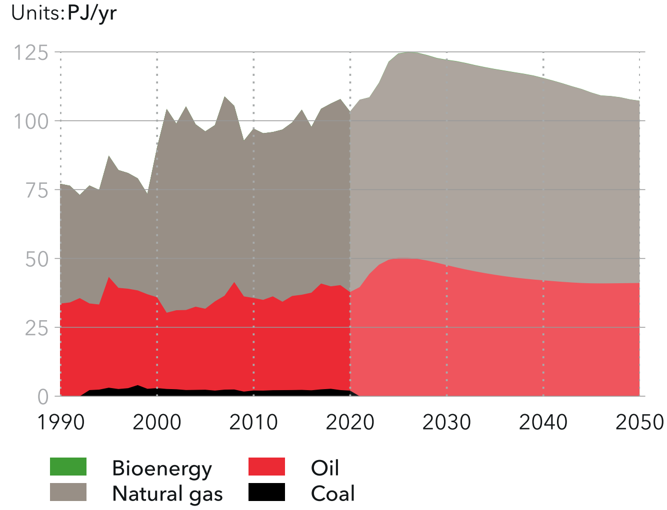
In 2021, 11% or 108 PJ of primary fossil-fuel consumption was used for non-energy purposes. This category represents the use of coal, oil, and natural gas as feedstock. Much of the energy in the form of natural gas goes to petrochemicals as the largest consumer (63%) of feedstock, and the rest is oil used in construction and for producing non-metallic minerals (Figure 2.12).

Half of the sector's natural gas consumption was used to produce plastics in 2021, with the rest going to making fertilizers, paints, and other chemicals. Norway's rate of plastic recycling will improve three-fold to 2050, boosted by more efficient (and potentially circular) chemical recycling methods supplementing or replacing traditional, mechanical recycling. But plastics production will remain stable to serve global markets, as demand for plastic continues to grow between now and 2050 on a global scale.

FIGURE 2.12

Norway non-energy demand for energy carriers

Units: PJ/yr



Historical data source: IEA WEB (2022)

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 Figure 2.13 illustrates. 'Final' energy here means the energy delivered to end-use sectors. It excludes energy losses and the energy sector's own use in power stations, oil and gas fields, refineries, pipelines, and in similar ways.

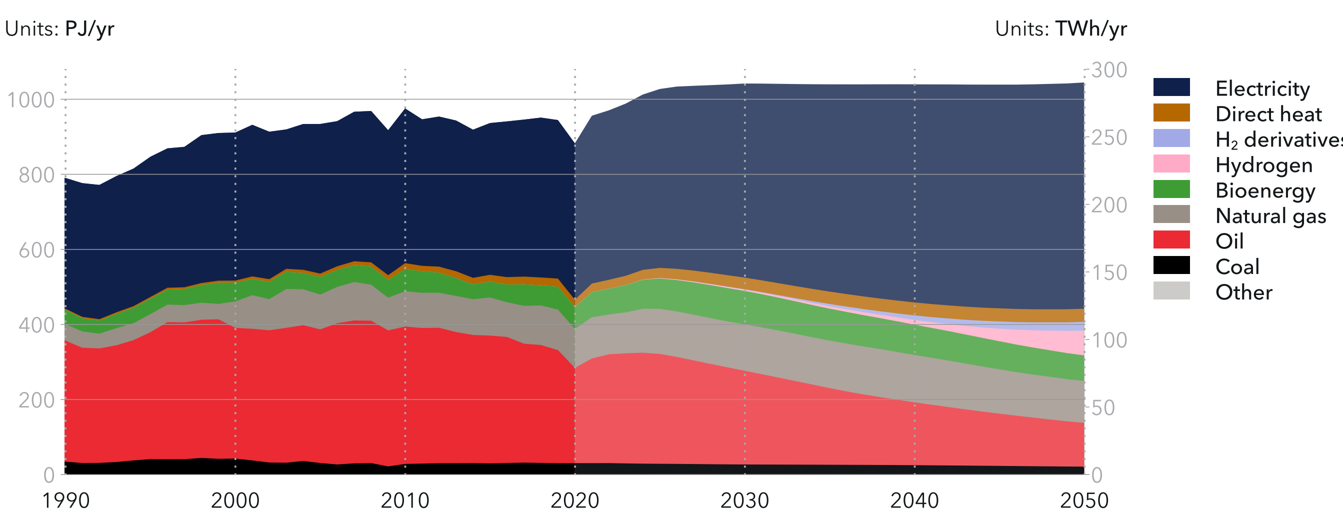
Even for Norway, with one of the world's most renewable energy-based power systems, the ongoing transition will further increase the share of electricity in final energy demand. In 2021, electricity represented 47% (447 PJ/yr) of Norway's final energy use. In 2050, it will account for 57% (600 PJ/yr). 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. In combination, this will raise electricity's share in the final-energy demand mix. The total demand and supply of Norwegian energy resources is discussed in subsequent chapters.

Initial view of FREYR's Giga Arctic Factory in Mo i Rana, Northern Norway. Production is due to start in the first half of 2024.
Image, courtesy FREYR Battery.

FIGURE 2.13

Norway final energy demand by carrier



Historical data source: IEA WEB (2022), SSB (2022)

3 ENERGY SUPPLY

In our *Energy Transition Outlook* to 2050 we forecast a future in which the world's energy demand stops growing even as the global population increases and the economy continues to expand. The global energy mix is also changing rapidly. For Norway, this creates challenges for continued fossil-energy export, but opens opportunities to supply low-carbon electricity and hydrogen 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. Norway's historical and forecast energy consumption, derived from various primary-energy sources, is shown in Figure 3.1. This is adjusted for gross electricity and hydrogen trade. We forecast that the country's primary-energy supply will fall from the high levels seen between 2008 and 2018. There will be a gradual recovery from pandemic-related low levels over the next five years, but primary energy supply will fall almost continuously from 2026, ending up 8% lower by mid-century, compared to 2021.

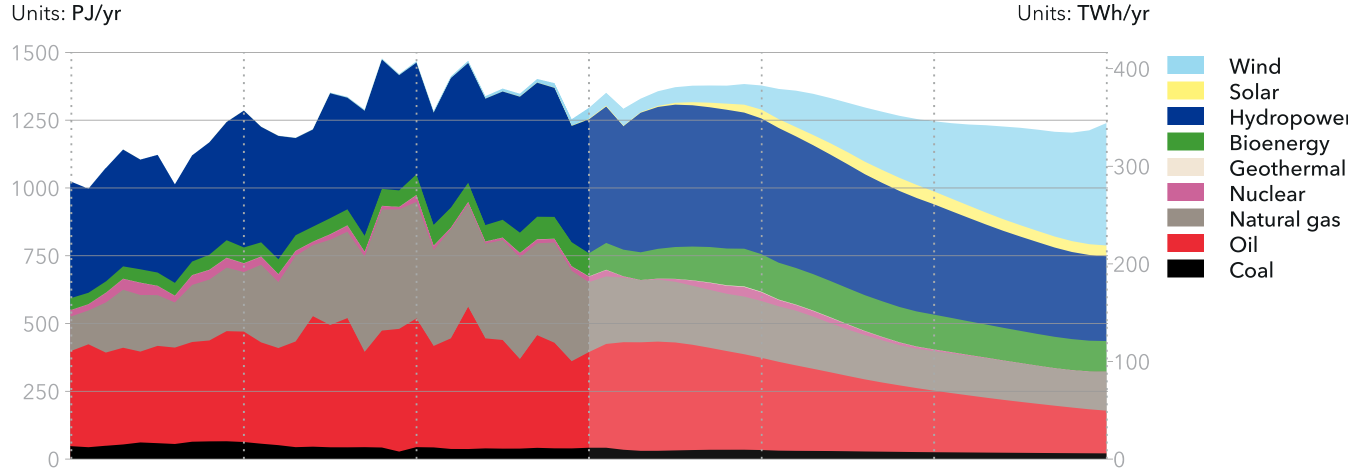
In addition to its domestic consumption, Norway exports large amounts of energy, mainly oil and gas, as described in Chapter 4 of this report. Norway also exports and imports some electricity on a daily and seasonal basis. Apart from exceptionally dry years, the annual balance has traditionally been a net export, which will change in the future with increased demand from the manufacturing sector and electrification of the Norwegian Continental Shelf (NCS) supported by interconnection-cables and production capacity increase in Europe. The flow to and from Norway, will thus impact the Norwegian grid mix,

FIGURE 3.1

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

Units: PJ/yr

Units: TWh/yr



Adjusted for gross electricity trade, using average European electricity mix
Historical data source: IEA WEB (2022), SSB (2022)

which is shown in Figure 3.1 as including electricity production from, for instance, nuclear as part of the European grid mix.

The domestic energy mix today is mostly electricity- and oil-based, whereas natural gas is mainly used offshore. In our forecast, we see fossil fuels being replaced by renewables, mainly wind and hydropower. By 2050, renewable primary-energy supply will represent 74% of the domestic energy mix, up from the 48% in 2021.

Thanks to the aggressive adoption of EVs both in Norway, and to a certain extent in the rest of Europe, primary oil will reduce 3% year on year in Norway. To counteract this reduction in oil in transport and other sectors such as oil and gas production, wind in primary energy will grow 8% year on year from 2021 to 2050.

Norway's primary energy mix will see oil decline by 3% year on year, while wind energy grows 8% year on year from 2021-2050.

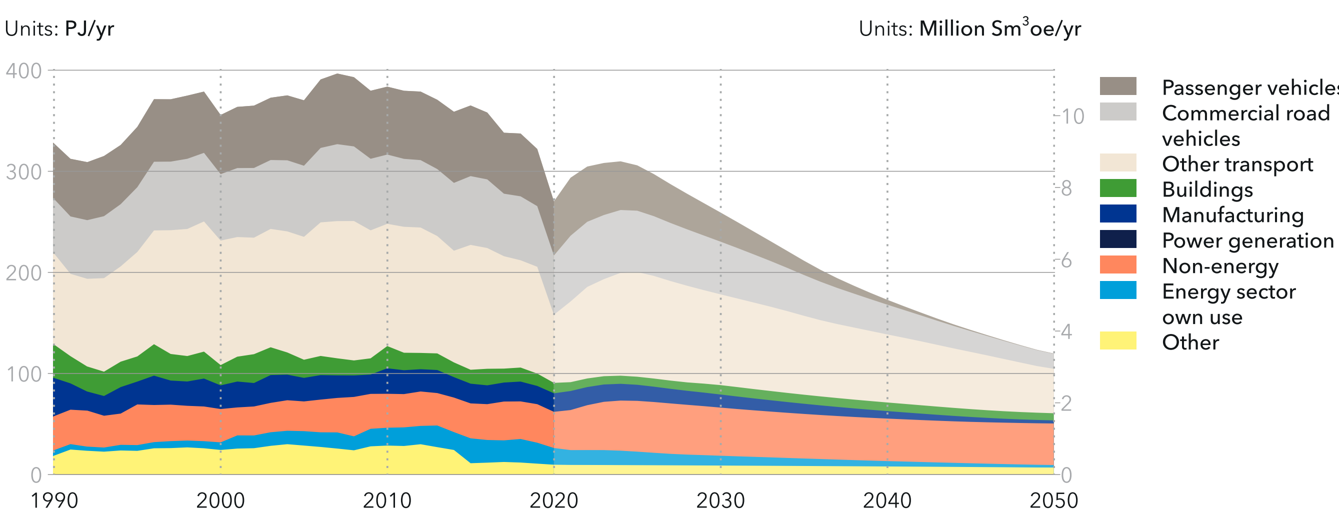
3.1 Oil

For the last 30 years, Norway's domestic oil demand has been on a bumpy ride. Demand declined marginally between 1990 and 2021, from 330 PJ to 294 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 59% drop in domestic oil demand with a decrease to about 120 PJ towards mid-century. This decline is similar to developments projected for Europe, where we forecast a reduction of 59% compared with 2020. On a global scale we forecast oil demand to decline 35% to the current consumption level by 2050.

69% 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 69% in 2021 when it started to decline. In 2021, over 60% of the transport sector's 202 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

FIGURE 3.2

Norway oil demand by sector



Does not include natural gas liquids and bioliquids. Historical data source: IEA WEB (2022), SSB (2022) demand from commercial vehicles will be slower. By 2050, the road subsector's oil demand will have reduced by almost 90% compared with 2021, a development similar to that in Europe.

Maritime will see an even faster reduction, declining to less than 3% 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's dependence on oil will be more protratced, 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.

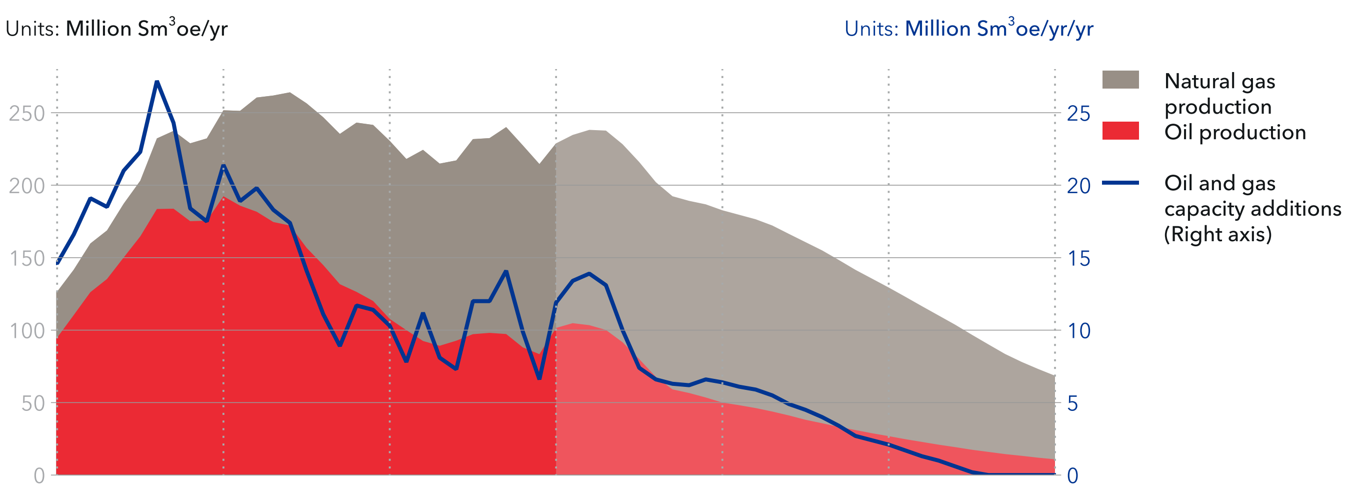
Oil demand from buildings, at 3% of total oil demand in 2021, is expected to decline by 20%. However, because overall oil demand is declining faster, buildings will represent a slightly higher share of total oil demand. The main use of oil in buildings is for space and water heating, which will increasingly be electrified.

A very similar outcome is expected in manufacturing. Here, the current 6% share will decline six-fold to represent about 3% of oil demand by 2050. The main driver here is less oil use in industrial heat processes where oil is substituted with electricity.

Norway's offshore oil production has plateaued since 2010 after a decade of strong decline. Production increases are expected over the next three years, due in part to the capacity increases from the Johan Sverdrup field and because of the supply shocks associated with Russia's invasion of Ukraine. The longer-term picture, is, however, one of decline (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 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. But that is not the case for Norway, where no new oil fields will be developed after 2025 in our forecast. Thus, incoming capacity additions in

FIGURE 3.3

Norway oil and gas production and capacity additions



Oil includes crude oil and condensates, natural gas includes NGLs. Capacity additions are based on asset lifetime of 20 years.
Historical data source: NPD (2022), IEA WEB (2022)

Norway will not replace the capacity being shut down. That said, oil production in Norway in 2050 will be at about 0.2 Mbpd (Figure 3.3), which is still much higher than domestic demand at about 0.1 Mbpd.

3.2 Natural gas

On a global scale, we forecast that world natural gas demand will plateau to 2030, and then decline from 163 EJ to 140 EJ by 2050, a 14% reduction. By mid-century, globally natural gas will overtake oil in primary energy. In Europe, which receives almost all of Norway's gas export, gas demand consumption will gradually decline 60% compared to 2050, due to European efforts of to reduce gas dependency.

Overall natural gas demand in Norway will only reduce 13% towards mid-century from today's levels, despite the reduced use in offshore oil and gas fields. At present, the main natural gas use in Norway is linked to the energy sector's own consumption. Here, consumption has plateaued from 2015 at about 215 PJ. Natural gas consumption will continue a few more years before declining steadily through to 2050, reaching 54 PJ. This decline is linked to significant electrification of the NCS, mainly through shore power, but also through wind turbines like Hywind Tampen, which replace gas turbines onboard offshore installations.

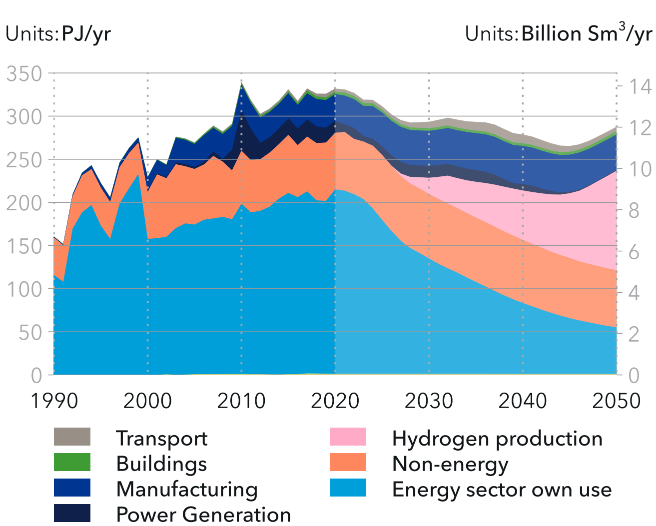
But, despite this four-fold reduction in own-use, the demand of natural gas for hydrogen production will somewhat counteract the demand reduction in Norway. By 2050, 115 PJ/year of natural gas will be consumed to produce hydrogen in Norway, representing a 40% share of the total demand.

The second largest consumption of natural gas is as petrochemical feedstock, representing 20% in 2021, a share which is expected to grow to 23% by 2050 (Figure 3.4). Almost no natural gas will be used for power generation in 2050; the manufacturing and buildings sectors will account for about 14% and 1% 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.

On a global scale, one can summarize that gas production will remain stable and move to new locations around the world. In terms of absolute output, the three dominant

FIGURE 3.4

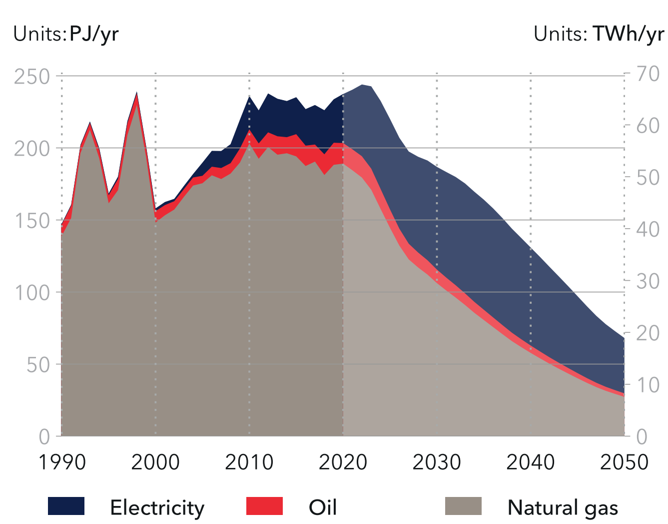
Norway natural gas demand by sector



Includes natural gas liquids. Historical data source: IEA WEB (2022), SSB (2022)

FIGURE 3.5

Norwegian continental shelf energy demand by carrier



Historical data source: IEA WEB (2022), SSB (2022)

players in 2020 were North East Eurasia, North America, and the Middle East and North Africa. But the Ukraine war has led to severe curtailment of North East Eurasian natural gas supply, at least in the period up to 2030.

Norway's natural gas production, currently at about 135 Gm³, is forecast to increase to about 138 Gm³ by 2023, before starting to decline. By 2050, natural gas production will be a little less than half of the level in 2021 (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. Should Europe choose to limit Norwegian gas purchases even further, the LNG share could increase dramatically.

Electrification of oil and gas production on the NCS started as early as 1996 with Troll East (A) connecting to the mainland electricity grid. With ongoing electrification of the NCS, natural gas use, as part of oil and gas extraction processes, will decrease 85% as gas-fired onsite power production on offshore installations is replaced by electricity from the mainland or from offshore wind (Figure 3.5).

In 2021, emissions from the oil and gas industry's own use of energy accounted for 33% 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 56% share of electricity in the supply of NCS energy needs (Figure 3.5).

By 2050, natural gas production will be a little less than half of the level in 2021.

3.3 Electricity

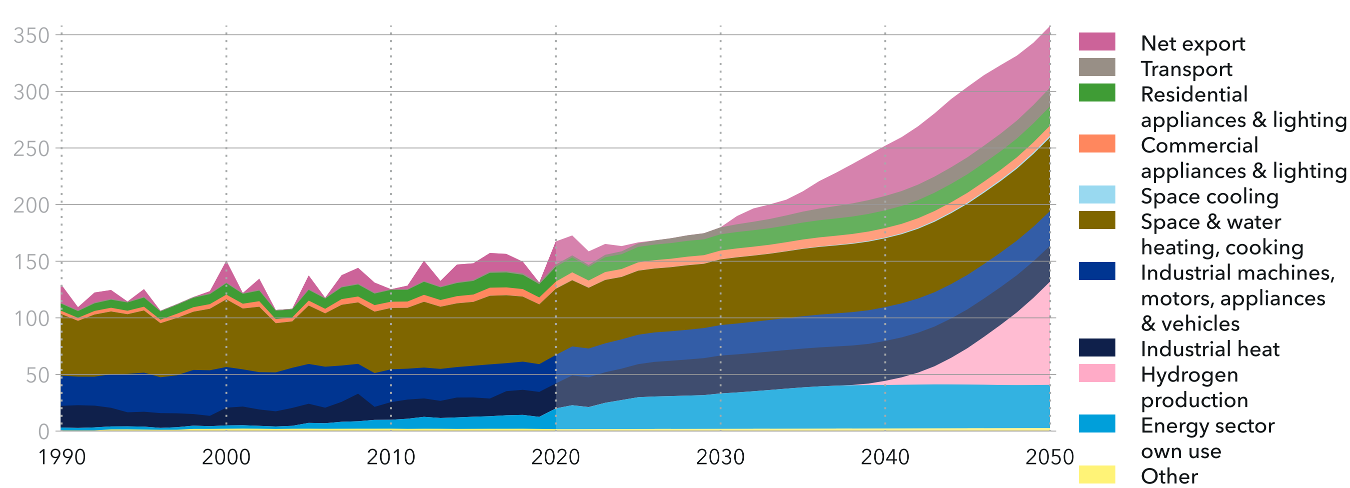
Electricity demand

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

FIGURE 3.6

Norway electricity demand by sector

Units: TWh/yr



Historical data source: SSB (2022), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2022) 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.

Total electricity demand in Norway, including net electricity imports (gross imports minus gross exports in every year) is expected to double, from 144 TWh in 2021 to 310 TWh in 2050. Four sectors will spur this growth: hydrogen production, transport, oil and gas production and lastly in smaller absolute numbers, space cooling.

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 0.9 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 4 TWh/yr in 2040 and 90 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 plateau of 20 TWh in the mid-2030s and thereafter decline in line with reduced activity towards 2050 but representing 56% of the sector's total energy demand.

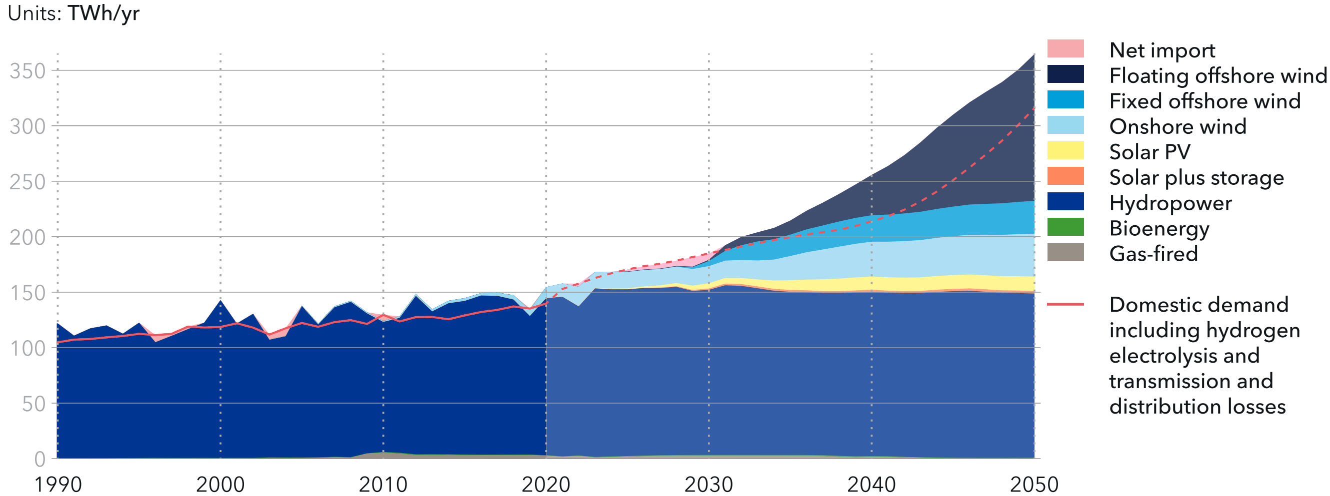
Total electricity use in buildings will be constant for the most part, but there will be shifts within the sector. More-efficient heat pumps, better insulation and a warming climate will result in stable electricity use for heating purposes. Meanwhile, the appliances and lighting segment will grow in 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.

Unsurprisingly, increasing global warming will result in higher summer temperatures, which results in higher electricity demand for space cooling in Norway. From less than 75 GWh consumed in 2021, space cooling electricity demand will grow to about 1.5 TWh in 2050.

FIGURE 3.7

Grid-connected electricity generation by power station type

Units: TWh/yr



Historical data source: IEA WEB (2022), SSB (2022)

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 2021 non-hydro electricity generation was 9%, split as 7.5% from wind, 1% from gas, 0.3% from biomass and 0.1% each from coal and solar PV.

In the future, we foresee an even more diverse production mix. Domestic electricity demand will double from 2021 to 2050, but annual average hydropower generation will only grow by 3% 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 what amounts to almost a halt in the issuance of new concessions will limit onshore wind growth in the short term.

From the 2030s, offshore wind, with policies favouring floating more than fixed, will grow rapidly, driven by reduced costs, sustained government support, and increasing opportunities for the trade of electricity. 2050 electricity generation will include 4% solar PV, <0.5% gas, 11% onshore wind and 44% offshore wind, with the latter mostly exported. The remaining 41% 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 control over how much electricity these technologies provide is limited. 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 the battery capacity of EVs available for grid flexibility will gradually increase and reach 10% of battery capacity of all EVs in 2035 and remain at that level thereafter. The electricity trade with the rest of Europe is based on the wholesale price differences between Norway and rest of 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.

Domestic electricity demand will double from 2021 to 2050 but hydropower will only grow 3%.

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.

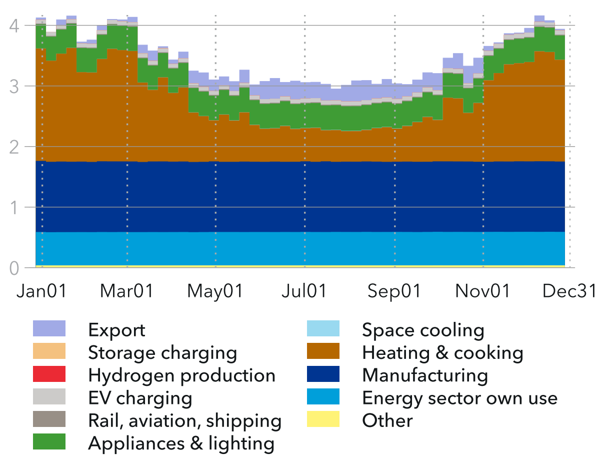
The graphic overleaf summarizes the operation of our model's power-market module, and the dynamics of power supply and demand over three different weeks in Norway. Our hourly model ignores any grid constraints, meaning that, within the model, any demand can be met by any generator in the country or region, regardless of location. For Norway, we do not distinguish between the bidding zones and treat the whole country as a single market.

Norway's hourly supply and demand at various points in the future

Here, we illustrate how Norway transitions in the coming three decades. Initially in the 2020s, from being a net importer of electricity, to the 2030s and 2040s to become a net exporter of electricity, even in a typical winter week.

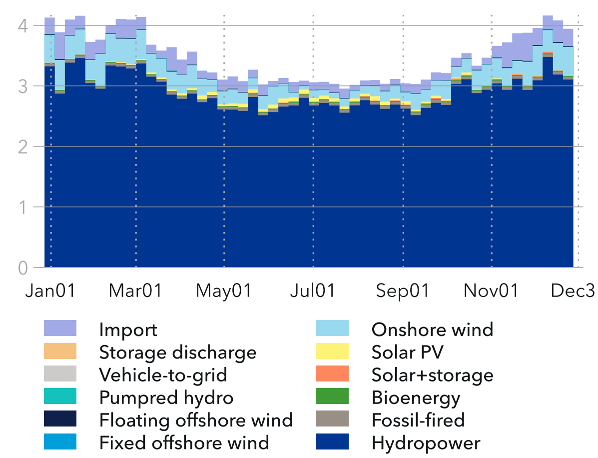
Norway electricity demand by segment; 2026

Units: TWh/week



Norway electricity supply by source; 2026

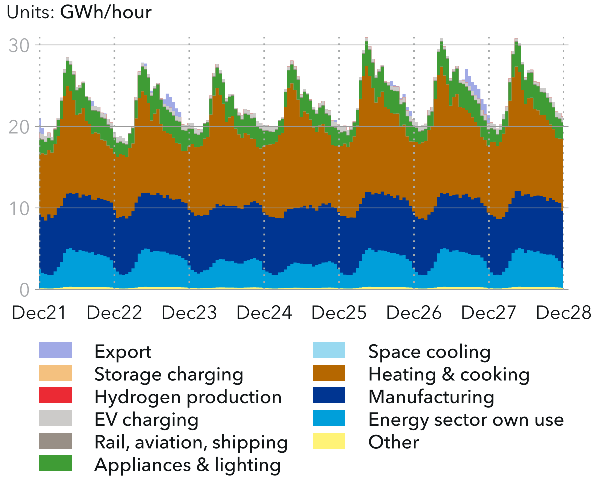
Units:TWh/week



In 2026, over the year, there are very few hours where Norway has surplus electricity to export to Europe. On the contrary, with high demands from manufacturing and energy sectors own use, Norway has to import electricity around 50% of the time (approximately 4300 hours).

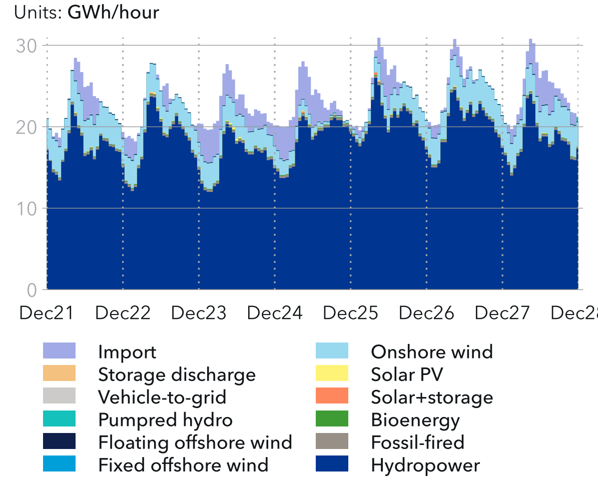
Norway electricity demand by segment; week 52; 2026

Units: GWh/hour



Norway electricity supply by source; week 52; 2026

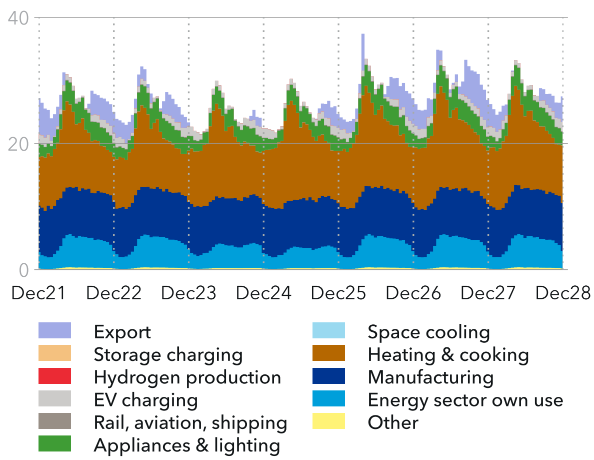
Units: GWh/hour



Heating and cooking sub-sector provides the highest demand, which peaks during mid-day. While hydropower generation can be ramped up to match or follow the demand profile, when there is insufficient wind to cover the demand in conjunction with hydro, Norway has to resort to electricity imports. Hence, there is considerable imports of electricity (75% of the hours), especially during a typical winter week, as presented here.

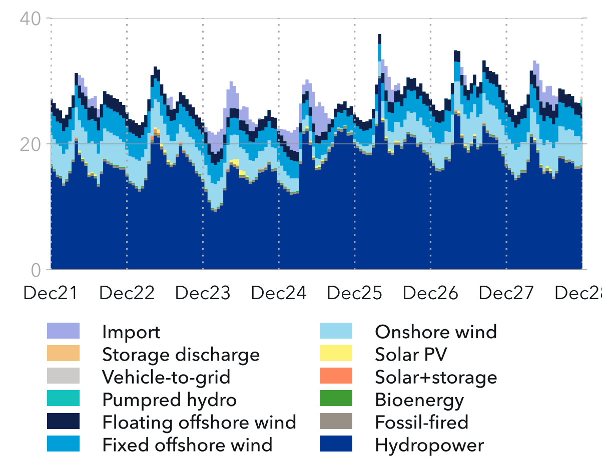
Norway electricity demand by segment; week 52; 2033

Units: GWh/hour



Norway electricity supply by source; week 52; 2033

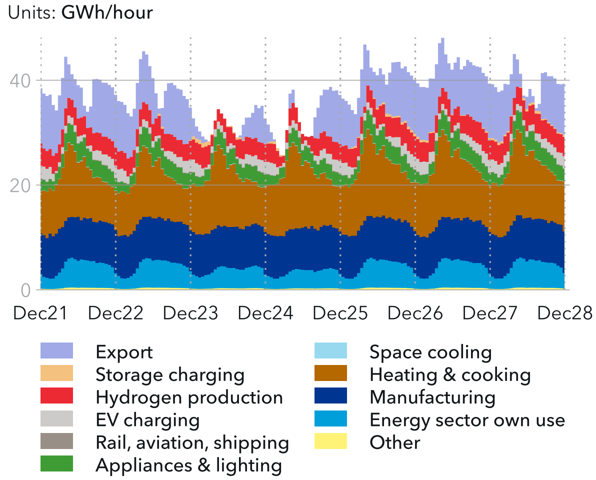
Units: GWh/hour



The Norwegian hourly power supply and demand profiles in the same winter week in 2033 already starts to show contrasting characteristics to that of 2026. Unlike in 2026, Norway has significant hours with surplus electricity which is exported to Europe, in large part thanks to the capacity built of both floating and fixed offshore wind. Unlike 2026, week 52 in 2033 has more hours with export than import (62 hours of export as opposed to 61 hours of import).

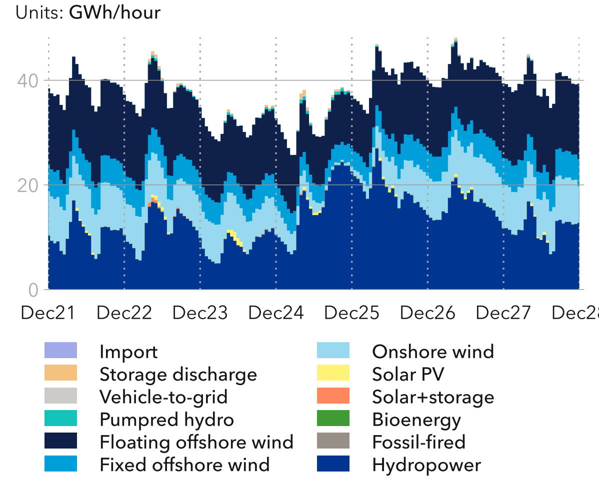
Norway electricity demand by segment; week 52; 2043

Units: GWh/hour



Norway electricity supply by source; week 52; 2043

Units: GWh/hour



By 2043, the Norwegian power supply and demand profiles are completely transformed. In the same week as presented in 2026 and 2033, Norway has enough surplus electricity to export 88% of the time and does not need to import at any time. This is in complete contrast to the period leading up to 2033. Similarly, there is surplus electricity to also run the grid-connected electrolysers, to produce hydrogen, a part of which is exported as well. The grid also transitions to one with vehicle-to-grid providing supply during mid-day peaks, along with other storage discharge.

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. With greater saturation of VRES, 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. But, for Norway we do not foresee this being a problem. The reason for this is that hydropower, and pumped hydro which has higher and stable variable costs, will counteract the variability of wind and solar and will set the price, in combination with the European electricity market. In 2050, hydropower will still have a significant share of both hourly and yearly generation in Norway. Additionally, the ability to export wind power to other regions and gain revenue also offsets the declining 'capture price' problem.

Figure 3.8 shows our estimates for the installed renewable energy capacity in the future. 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. In 2047, we foresee offshore wind capacity, both grid-connected and off-grid, overtaking hydropower capacity in Norway. We forecast higher uptake of floating offshore wind compared with fixed offshore wind, despite the lower levelized cost of the latter. The main reason being additional governmental support as well as no major limitations to ocean space, where fixed offshore wind will have to co-exist with other economic activities, such as fishing.

Our hourly comparative analysis of Norwegian and European power systems indicates that up to 56% of annual output from Norwegian FOW can be exported to Europe. Most of the rest is used to produce electrolysis-based green hydrogen, also for export purposes.

There are certain overlaps in the cost of new developments, as well as many geographical and political factors, resulting in the technology built not always being the lowest cost option. Hence, we get a distribution based on price and 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.

FIGURE 3.8

Norway grid and off-grid installed renewable capacity

Units: GW

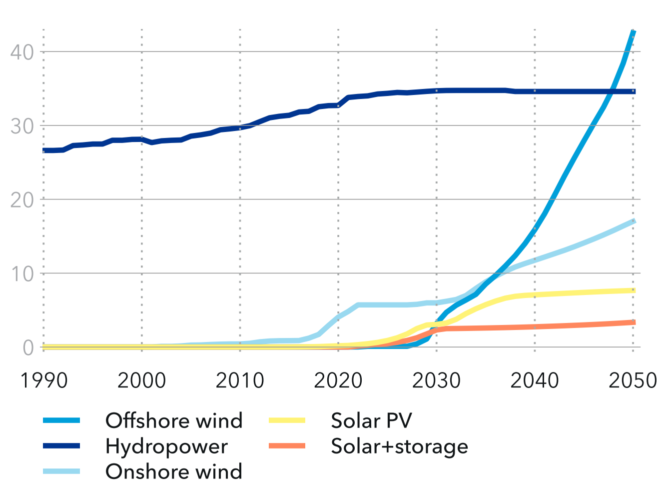


FIGURE 3.9

Norway capacity additions becoming operational by power station type

Units: GW/yr

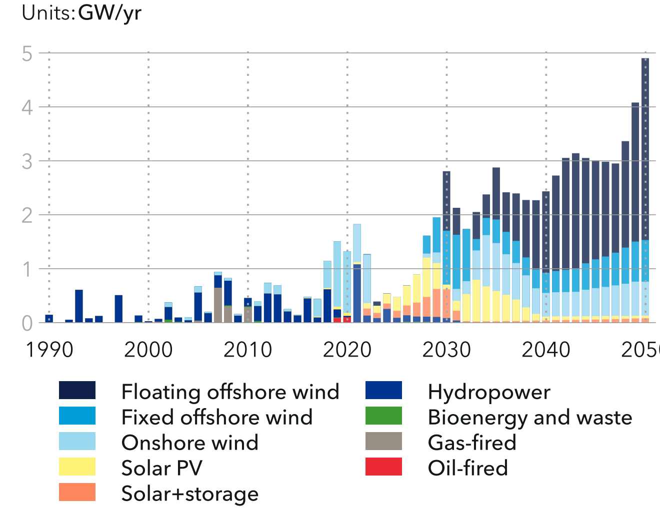


TABLE 3.1
Installed capacity and the annual average capacity factor

	Installed capacity (GW) by the end of year				Capacity factor			
	2021	2030	2040	2050	2021	2030	2040	2050
Hydropower	33.8	34.7	34.6	34.6	49%	49%	49%	49%
Onshore wind	4.8	5.9	10.5	12.3	30%	38%	45%	45%
Floating offshore wind	0.0	1.2	9.1	29.9	45%	54%	57%	59%
Fixed offshore wind	0.0	2.0	5.3	6.5	48%	53%	56%	58%
Solar PV	0.2	3.0	7.0	7.6	18%	20%	20%	21%
Solar plus storage	0.0	2.3	2.7	3.3	17%	6%	8%	8%
Thermal	1.0	1.0	1.0	0.7	36-40%	19-26%	16-23%	16-21%
Wind onshore - off-grid capacity for hydrogen production	0.0	0.0	1.2	4.7				
Wind offshore fixed - off-grid capacity for hydrogen production	0.0	0.0	1.5	6.1				

After these power stations come online, investments will slow down in mid 2020s. The 2020s will be the last decade with significant hydropower additions. From mid-2020s, solar PV additions take place, motivated by electricity deficits and the desire for local energy security. After 2040, we foresee almost all new capacity to be in wind power, dominated by a large share of FOW, to the point where Norway will boast 10% of all installed FOW capacity in the world.

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 960 MW of pumped hydro storage and 10 GW of stand-alone Li-ion battery storage to support the Norwegian electricity grid in 2050.

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. However, the existing 33 GW installed capacity will expand only slightly until 2050, to reach 35 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 halt 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 150 TWh in the 2040s.

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 2021, the total installed capacity was just below 5 GW, almost all in the form of onshore projects, with 59 MW of offshore floating wind projects. But as Figure 3.11 shows, most onshore wind turbines are on the southwest, west and north shores. Favourable wind conditions exceeding 1000 W/m² wind speed density in some locations, proximity to the grid, and large areas with relatively sparse population makes the Norwegian west coast advantageous for wind developments.

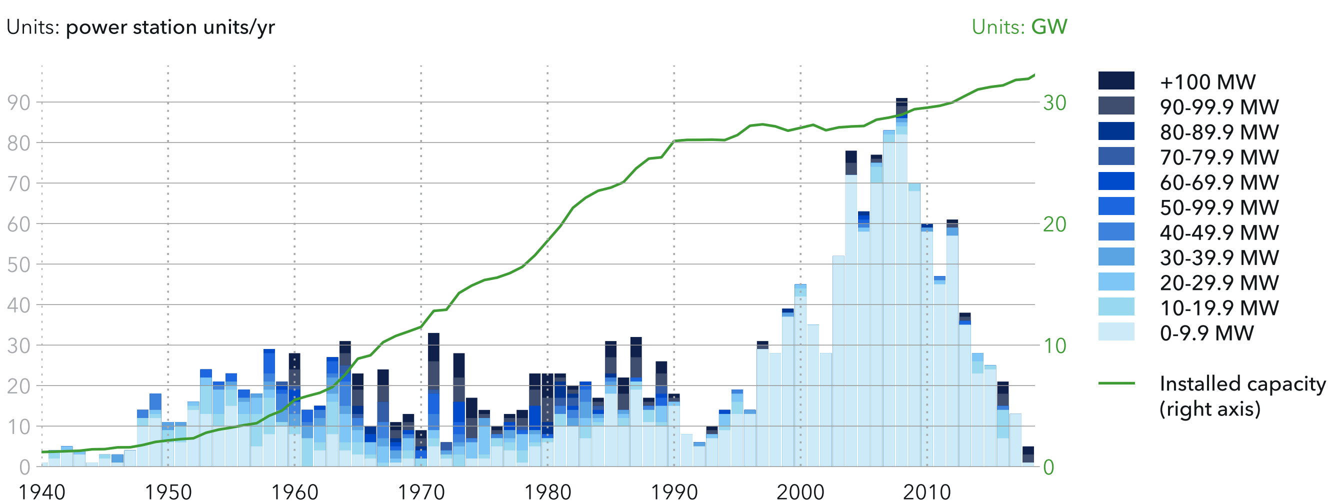
However, future onshore installations are likely to be delayed and/or scaled down by public concerns like noise, impact on birds, recreation, and a desire to preserve untouched landscape and wilderness. Unlike many Western countries with significant fossil shares in their power mix and where wind investments are regarded as essential for decarbonizing and lowering the cost of electricity generation, the Norwegian wind industry enjoys less public support. The public is also wary of arguments for building excess wind capacity for export to the European continent, fearing 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 80% of 200 TWh wind-based generation in 2050. Reduction in

FIGURE 3.10

Norway number of hydropower units added by size

Units: power station units/yr



Shows the year of becoming operational. Historical data source: Platts (2018) cost is the first factor contributing to growth. Figure 3.12 shows how the levelized cost of FOW declines in Norway until 2050, as a result of global and local developments in various cost components. For onshore wind, a fourth of the 57% 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 52-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, along with re-prioritization of shallow ocean floor space.

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 increasing 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 56% 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 exceed revenues from the domestic market.

Solar PV

Solar PV will remain a niche technology in Norway. We predict installed capacity to increase from 200 MW in 2021 to 11 GW in 2050, a 20-fold increase. We include two categories for solar: Solar PV panels connected to grid via utility scale or rooftops, and another category, solar + storage, where storage is integrated as part of the installation, producing in effect a powerplant with dispatchable power.

Even though solar co-located with storage is initially more expensive, the ability to capture a higher electricity price when solar PV is not operating will eventually lead to almost a third of the solar PV capacity integrally

FIGURE 3.11

Mean wind power density and distribution of wind farms

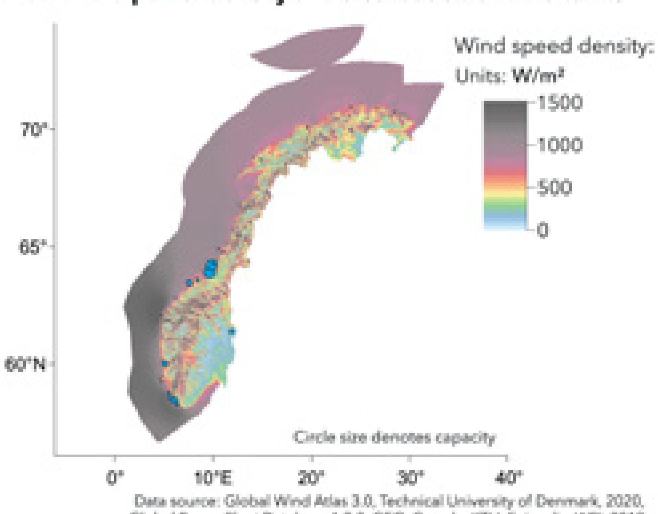
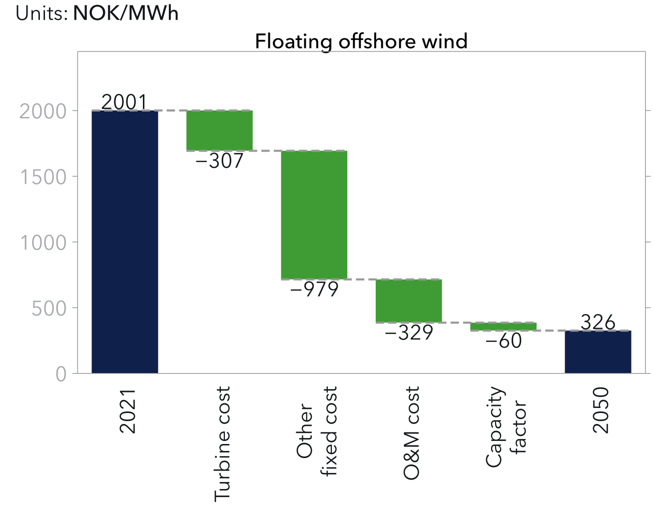


FIGURE 3.12

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

Units: NOK/MWh



including storage capacity by mid-century. Despite the low capacity factors reported for solar+storage in Table 3.1, solar+storage has its uses. While capacity factors are useful in determining how much a generation technology is used over a year, they do not give any insight as to when this generation provides the capacity. In the case of solar+storage, it is able to provide stored electricity in periods of high demand, especially in the bridging period of late 2020s and early 2030s, when the Norwegian power system is transitioning to a wind-dominated system.

The decade leading up to 2030 will see an almost equal amount of solar with and without integrated storage being installed as seen in Figure 3.13. Storage integrated solar will play a vital role in balancing the supply of solar from daytime to more demand-intensive night hours, at least locally. But, in the decade leading up to 2040, even more stand-alone solar PV capacity will be installed as rooftop solar becomes more ubiquitous while solar + storage plants lose out on cost competitiveness. However, we reiterate that solar PV will remain marginal as utility scale implementation, but rather for rooftop installations as supplementary power. The main disadvantage of solar PV is low solar irradiation in Norway.

Hydrogen

Despite only needing water and energy as inputs, producing hydrogen through electric current requires costly electrolysis equipment and undergoes substantial energy losses. The main alternative production method is via steam methane reforming (SMR), where hydrogen is derived from hydrocarbons. This is currently the preferred option due to existing SMR infrastructure, and despite the high fossil-fuel prices at present due to geopolitical events. However, 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 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. For this reason, SMR coupled with CCS will be the main production route for hydrogen for energy in the

FIGURE 3.13

Norway solar capacity additions and installed capacity

Units: GW/yr Units: GW

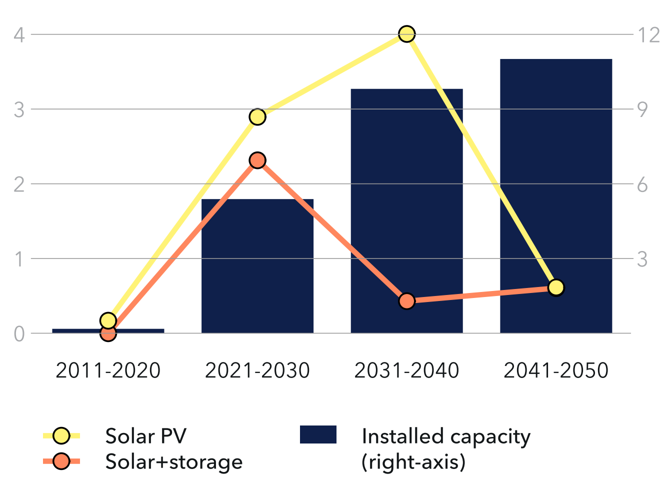
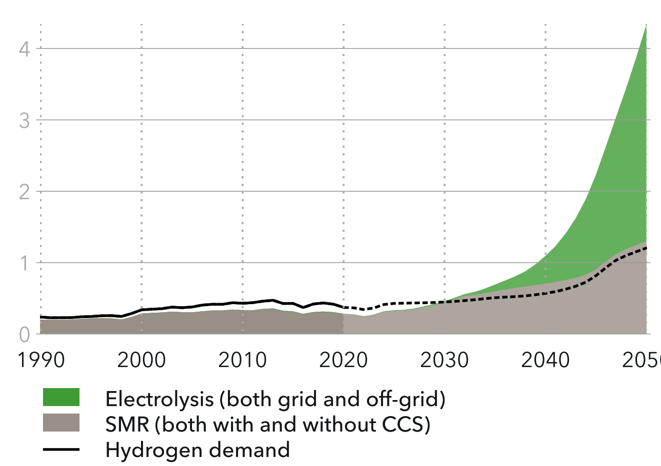


FIGURE 3.14

Norway hydrogen production by production route

Units: MtH_2/yr



Historical data source: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021). Does not include hydrogen use in residual form from industrial processes.

2030s. With more and more abundant VRES, electrolysis will start gaining traction in 2040 and by mid-century supply 80% of hydrogen as an energy carrier.

We see hydrogen as a likely zero-emission energy carrier for heat applications in manufacturing (Figure 3.15). By mid-century, 49 PJ of hydrogen will be used for industrial heat provision in manufacturing, a 20% share. Most of the hydrogen will be used in manufacturing of aluminium and other base materials, followed by iron and steel production and the construction industry.

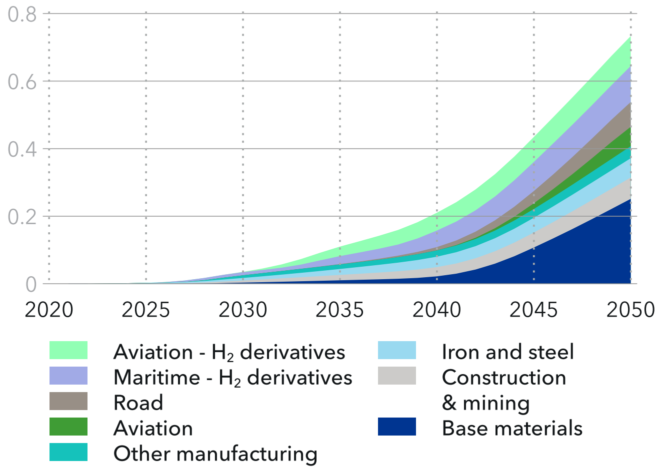
For the transport sector, hydrogen can serve as an energy-storage medium, competing with battery storage in zero-emissions usage and as a replacement for oil and gas. Long-haul, heavy road transport that cannot rely as easily as passenger vehicles on batteries for main energy storage, will turn to fuel-cell 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 but only reach 9 PJ by 2050, representing 11% of road transport energy demand.

Within maritime transport, covered thoroughly in DNV's *Energy Transition Outlook* (2022a) and in our Maritime

FIGURE 3.15

Norway hydrogen demand as energy carrier by sector

Units: MtH_2/yr



HydrogenPro taking delivery of the world's largest electrolyser at its test facilities in Herøya, Norway. Image courtesy HydrogenPro, September 2022.

companion report (DNV, 2022b), we expect low- and/or zero-carbon fuel alternatives which are derived from hydrogen like ammonia and synthetic fuels, partly implemented in hybrid configurations with diesel and gas-fuelled propulsion, having significant uptake and providing slightly more than 50% of the maritime fuel mix by 2050. We predict ammonia and synthetic fuels combined will provide 13 PJ/yr Norway's maritime sector energy demand (Figure 3.15).

Aviation is a sector where Norway is well-suited for battery electric flights on its short-haul network connecting coastal cities. However, for long-haul and international flights, synthetic fuels and pure hydrogen will play a role to decarbonize the sector. After 2030, when infrastructure has developed and costs declined , we see synthetic fuels and hydrogen starting to replace regular jet fuel and by 2050 23% (18 PJ) of aviation energy demand is covered by these energy carriers.

4 ENERGY TRADE

Norway has been, and will continue to be, a significant net exporter of energy over the next 30 years. Russia's invasion of Ukraine has placed pressure on Norway to increase energy exports, especially gas.

Although new fields will boost oil and gas exports in the immediate future, the production boost will not be enough to exceed the export peak of 2001 and the long-term trend of oil and gas exports will show a steady decline from the middle of this decade (Figure 4.1).

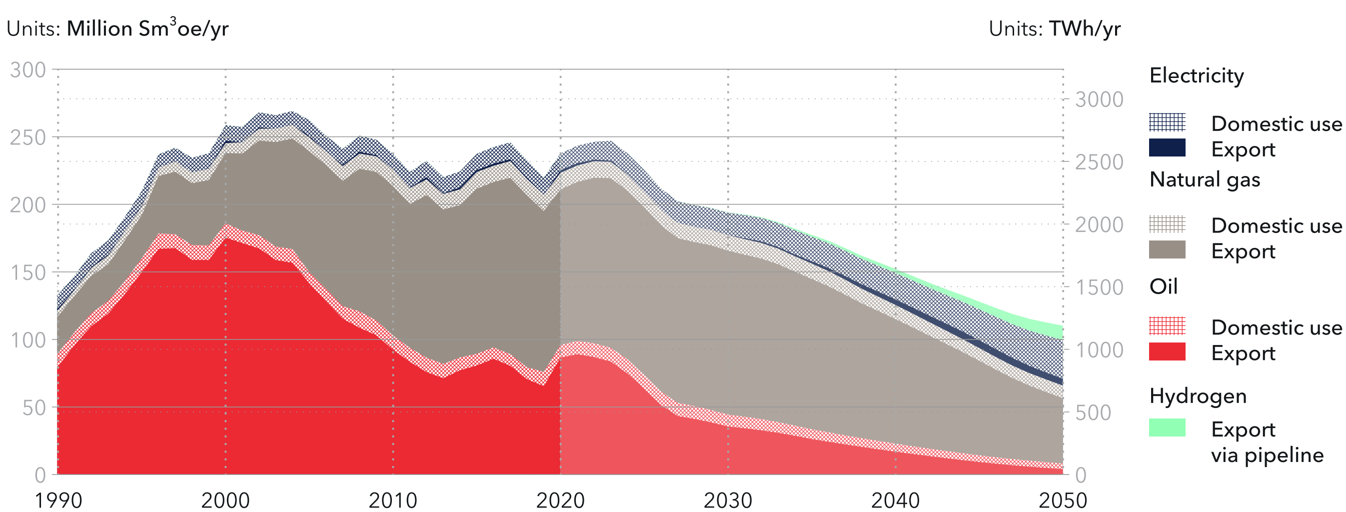
Oil exports by 2050 will be 5% of today's level, while gas exports in 2050 will be 60% lower than in 2021. Electricity and hydrogen exports will be marginal for a few years, but as power capacity increases, electricity and hydrogen exports will grow. However, volumes will remain comparatively minor, and electricity and hydrogen revenues will be unable to compensate for the lost revenue from oil and gas exports in the long-term. The value of Norwegian oil and gas exports was 490bn NOK/year on average over the last 10 years (SSB, 2022). Assuming constant prices, a 78% reduction in oil and gas export revenue by 2050 will translate into 108bn NOK in annual revenue by then. However, 60 TWh/year in net electricity exports by 2050 will only translate to an additional income of 36bn NOK/year. Hydrogen export of about 3.4 MtH_2/yr and ammonia export of 1.2 Mt/yr could yield an additional 80bn NOK/year revenue in 2050 assuming a hydrogen price of 2.2 USD/kg H_2. In other words – on present trajectory – total energy exports in 2050 will run some 260bn NOK below average annual export revenue over the past decade.

Oil and gas exports

Norway's production meets about 2% of global oil demand. As the competitiveness of Norway's oil weakens relative to other cheaper sources in a world with reduced oil demand, its share of the global oil market will gradually reduce to around 1% by 2050. As a result,

FIGURE 4.1

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs. Historical data source: NPD (2022), IEA WEB (2022)

total oil exports – including oil products – will fall to 0.6 Mbpd (36 million Sm^3oe/yr) in 2030, 0.3 Mbpd (17 million Sm^3oe/yr) in 2040 and 0.1 Mbpd (4 million Sm^3oe/yr) in 2050.

The outlook for gas is less bleak, since natural gas will maintain a strong market position in the European energy system, although lower than we forecast a year ago. This lower forecast stems directly from Russia's invasion of Ukraine and the associated decision of Europe to move away from fossil fuels, and especially away from natural gas. The continent's demand for gas has likely peaked this year and will not return to historical levels. Norway supplies close to 25% of Europe's gas demand (NPD, 2022). In parallel with the declining gas demand in Europe towards mid-century, Norway's gas exports (including NGLs) will start to decline within this decade. In 2050, Norwegian gas exports will be 48 billion m^3/yr, which is a decline of 59% compared with 2021.

Total LNG export from Norway is 6.6 billion m^3/yr, while exports to non-European countries (Turkey, South America, China, and India) constitute only 0.9 billion m^3/yr, or about 1% of Norway's gas exports (BP, 2020). We forecast LNG export to stay almost at current levels for the entire forecast period as gas demand outside Europe will be increasingly uncertain. There is potential for expansion of LNG export, but the main form of export will, however, remain by pipeline to Europe.

Installation of the NordLink cable in Germany. Image courtesy NKT.

Electricity exports

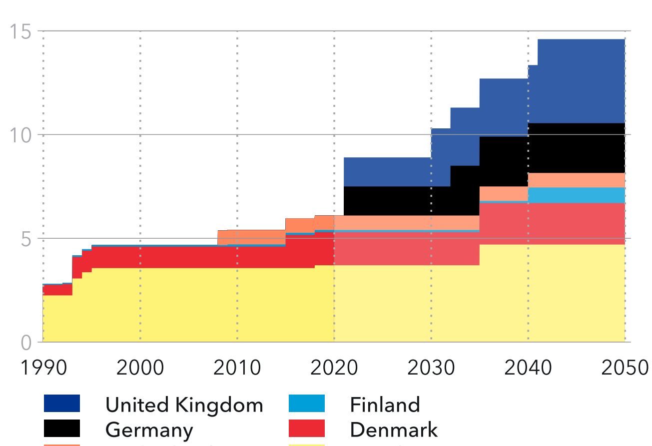
Norway's total net transfer capacity to other countries is 8.9 GW. Of this, 3.7 GW goes to Sweden, 1.6 GW to Denmark, 0.7 GW to the Netherlands and 0.1 GW to Finland (ENTSO-E, 2020). As shown in Figure 4.2, the NordLink subsea cable to Germany (1.4 GW) and the North Sea Link to the UK (1.4 GW) came online in 2021 and are operating. To facilitate its neighbouring countries' ambitions to grow renewable generation, in mid 2030s we foresee an increase in Norway's cross-border capacity to Sweden and Denmark by another 1 GW and 0.4 GW, respectively. One more 1.4 GW interconnector between Norway and Germany as well as 2.65 GW to UK is expected and finally, we assume a 650 MW cable from Northern Norway to Finland to be built by 2040.

Today, 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

FIGURE 4.2

Norway net electricity transfer capacity

Units: GW

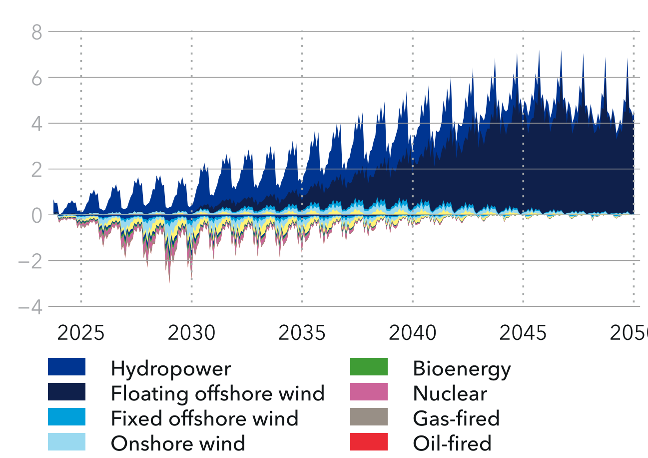


Historical data source: ENTSO-E (2022)

FIGURE 4.3

Monthly electricity export and import by power station type of source

Units: TWh/month



Positive values show exports, negative values show imports.

of Europe, based on the price differentials in each market. By using this approach, we can replicate historical trade volumes reasonably well.

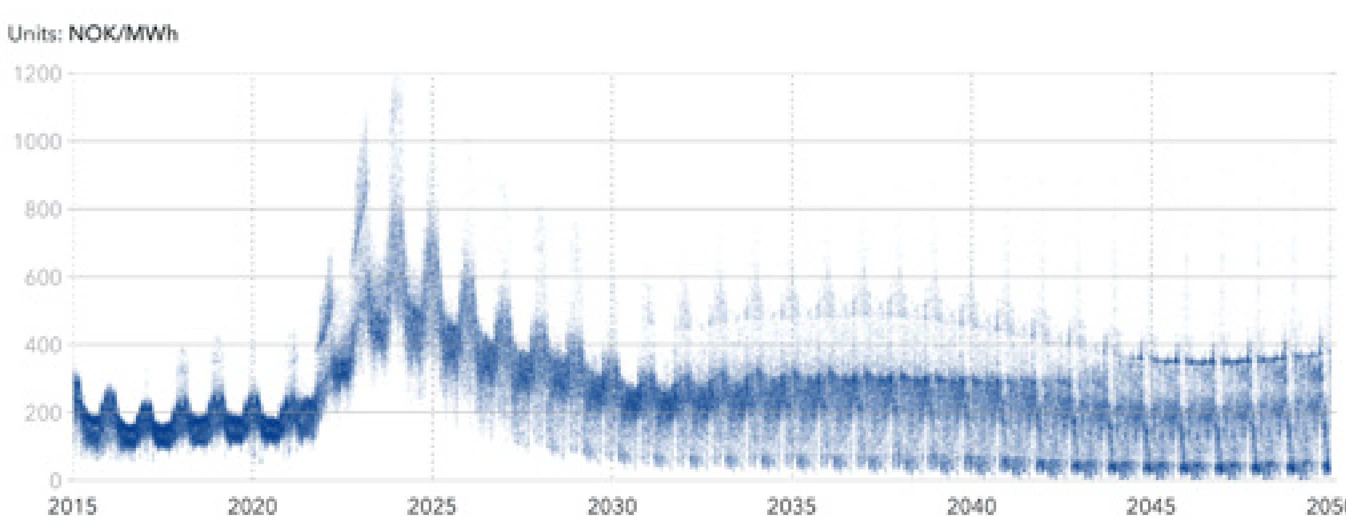
Figure 4.3 presents monthly electricity exports and imports from and to Norway until 2050, broken down by power station type of the exporting region at that month. The chart gives many clues about the future of Norwegian electricity exports. In the last 20 years,Norway's average annual net electricity exports has been 10 TWh. Annual total net exports will be lower than currently between 2026 and 2035. A significant increase in electricity demand combined with limited capacity additions increase the demand for imported electricity by up to 14 TWh/yr. From 2030, new capacity additions from offshore wind improve the balance such that Norway again is a net exporter, increasing the annual export to 44 TWh/yr by 2040 and further increasing to 55 TWh/yr by 2050. This increase is only partially linked to an increase in net transfer capacity, because Norway's ability to export electricity during the summer months – the time of year hitherto associated with most exports – does not expand as fast as capacity additions. The real change happens in the winter months. In the past, Norway has been a net importer in winter months. But, with ample generation capacity especially from new wind investments, from mid-2030s Norway will become a net electricity exporter, also during winter months.

We have assumed that new floating offshore wind capacity will not only be driven by domestic demand and revenue from Norway's own electricity market, but also by increasing European electricity demand and opportunities for high export revenue. We see this happening in a self-reinforcing process, where year-round export opportunity triggers new floating offshore wind investments, and the availability of this new capacity allows for up to 60% of floating offshore wind's annual generation to be exported. Most of the remaining capacity will be used to produce electrolysis-based hydrogen or to re-charge long term storage.

One important aspect of increased annual net electricity imports between 2026 and 2030 is bigger fluctuations in future electricity prices. Our analysis (Figure 4.4) shows that electricity prices initially will increase and face bigger fluctuations. As both capacity and export/import volumes increase, not only will average electricity prices decline, but price fluctuations within the year will also reduce. The price stability is linked

FIGURE 4.4

Norway wholesale electricity price distribution



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

to increased flexibility resources in the power system, brought by new interconnections, availability of EV batteries through vehicle-to-grid systems, new utility-scale storage capacities, and better demand response afforded by widespread adoption of smart grids. One limitation not accounted for in Figure 4.4 is the impact of grid constraints, which are not reflected in our model's design. 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 higher than that predicted by our model.

Hydrogen exports

In the present decade, hydrogen as an energy carrier will remain too expensive to be widely used and the demand will instead be created through policy support and incentives from governments, e.g. in Europe. In the 2030s, the average price of hydrogen will reduce by half compared with the early 2020s and hydrogen's role in industrial heating will become more widespread, though global use of hydrogen as an energy carrier will remain smaller than its non-energy use. The 2040s will be the decade of demand diversification as more hard-to-electrify sectors will be forced to use hydrogen or its derivatives to decarbonize, e.g. through the uptake of ammonia and e-fuels as maritime fuels. Europe, with its strong hydrogen support policies, will lead global hydrogen uptake with 11% hydrogen and its derivatives in its 2050 final energy mix. Europe is one of four leading world regions that together will consume two-thirds of the global hydrogen demand for energy purposes, a figure that also reflects regions' shares in international maritime and aviation energy consumption in line with the size of their economies.

Norway is in a very good position to support this transition in Europe. Today, Norway uses predominantly natural gas and coal as sources for hydrogen production for use in its domestic feedstock market. By mid-century, Norway's domestic hydrogen demand will triple, but its hydrogen production will grow by a factor of 10. This opens possibilities for hydrogen export to Europe, as the region's demand will exceed its supply in the early 2030s. By then, Norway will export about 0.3Mt hydrogen to Europe. This will grow to 3.4 Mt hydrogen by 2050.

Already installed and future pipelines both to UK and mainland Europe will enable hydrogen transport from Norway to Europe. Blue hydrogen from natural gas coupled with CCS could provide a steady flow of hydrogen using Norway's natural gas resources and CCS knowledge effectively, supplemented by green hydrogen from renewable energy sources such as offshore wind or Norway's grid electricity. The export based short- to medium-term focus is on blue hydrogen accounting for about a half of Norway`s hydrogen production by 2035. Another third will still come from unabated natural gas-based hydrogen production. However, by mid-century this ratio changes: two thirds will be green, and one third based on natural gas mostly decarbonized (85%) with CCS. Big uptake markets in Europe such as Germany favour hydrogen from renewable power over hydrogen from natural gas, even if coupled with CCS. However, the current turmoil in gas markets and supply could change this view, at least in the medium term.

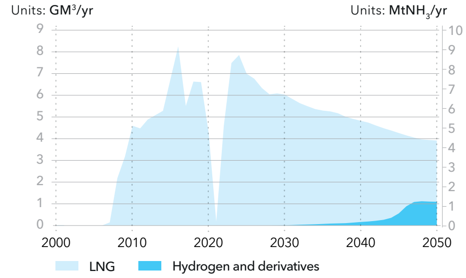
Norwegian natural gas can be converted to blue hydrogen and exported to Northern Europe for a cost somewhat higher than subsidised green hydrogen from Southern Europe. With equal subsidies blue hydrogen from Norway will have similar costs, and the competitive situation will be decided by degree of reuse of existing gas infrastructure. It is absolutely possible Northern Europe will need both these two sources of hydrogen.

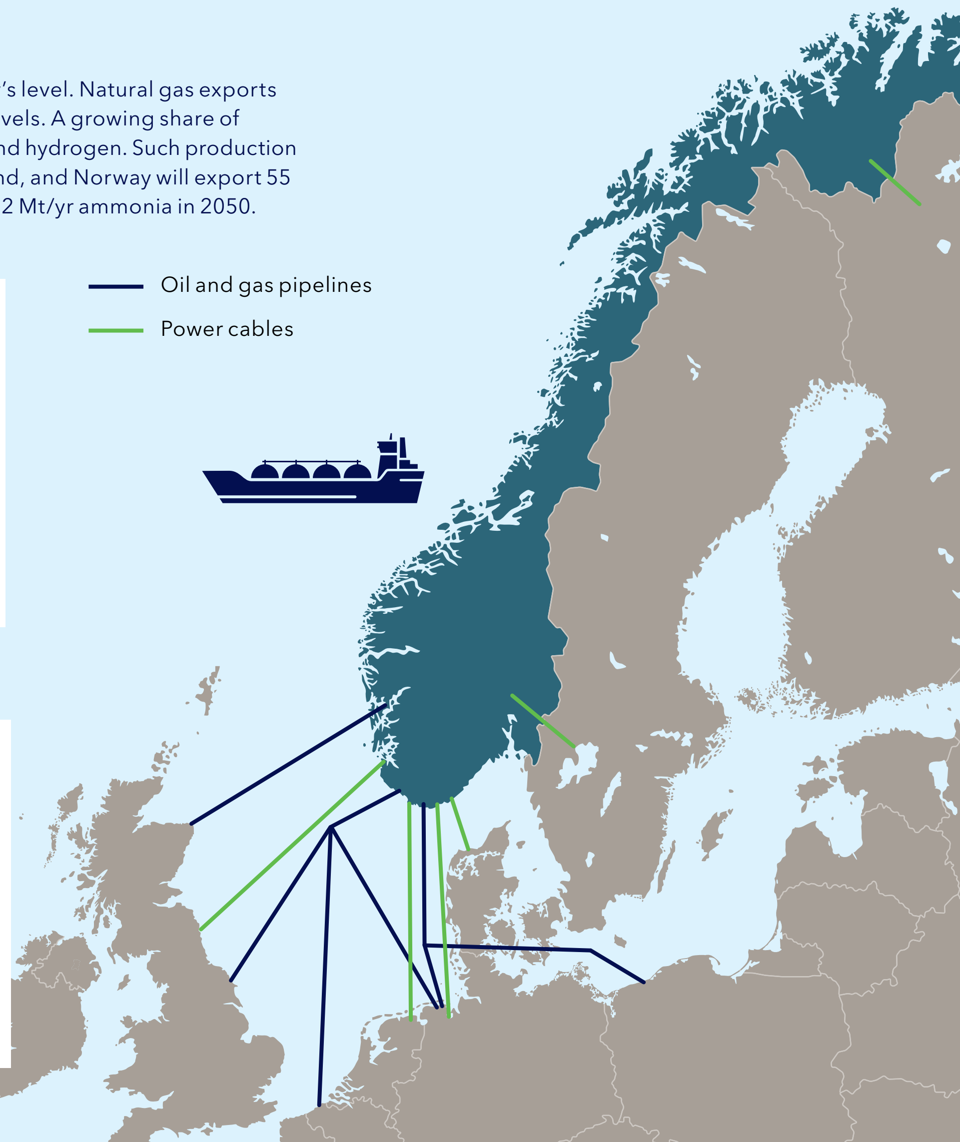
While we forecast significant amounts of hydrogen to be exported to Europe via pipelines, low-carbon ammonia is going to be traded on keel from Norway. In the late 2040s, low-carbon ammonia exports from Norway will reach about 1.2 Mt per year, to be shipped mainly to European (80%) and British (15%) ports, as well as to other regions in much smaller amounts (5%).

Energy trade

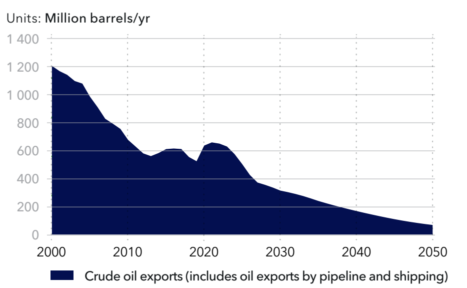
By 2050, Norway's oil export will be 5% of today's level. Natural gas exports will be at 55bn m^3 in 2050, 60% below today's levels. A growing share of energy exports will be converted to electricity and hydrogen. Such production will increasingly be larger than domestic demand, and Norway will export 55 TWh/yr of electricity, 3.4 Mt/yr hydrogen and 1.2 Mt/yr ammonia in 2050.

Maritime export

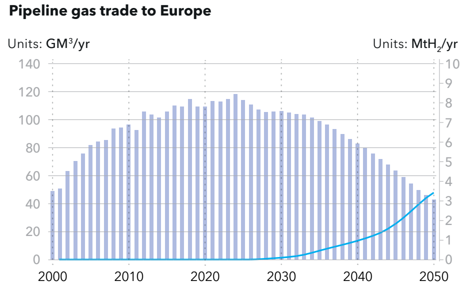




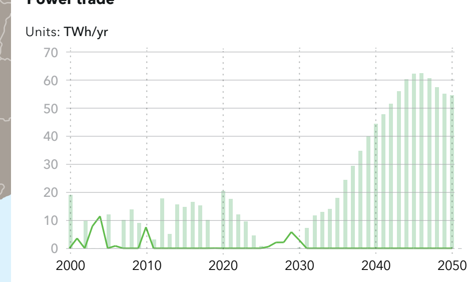
Crude oil exports



Pipeline gas trade to Europe



Power trade



Oil and gas pipelines, power connectors and ship location are simplified

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 Norway's emissions. We begin with the estimated energy-related CO_2 emissions derived from our forecast, and then list the remaining GHGs and their origin. Since our modelling focuses mainly on the energy system, we make 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

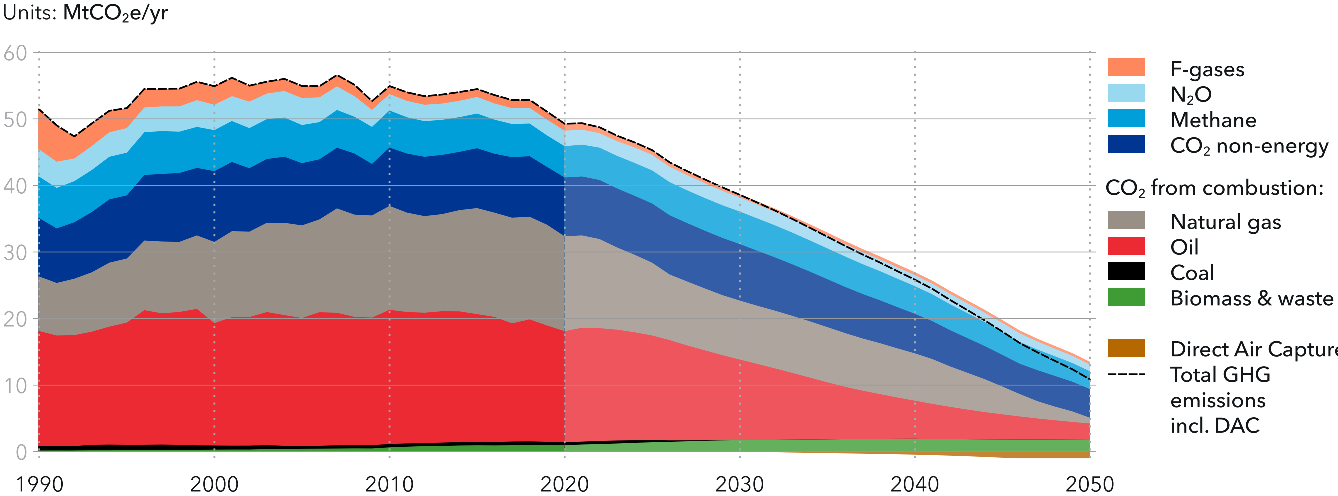
Energy-related CO_2 emissions have increased steadily in Norway for three decades, and a decline has only been observed in the last 5 years. In addition to CO_2 emissions from combustion of fossil fuels, a large share of Norwegian CO_2 emissions comes from non-energy related emissions. A high quantity of these emissions derives 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 16% of the total GHG emissions in 2021 and will grow to represent 38% in 2050.

Our forecast indicates that GHG emissions will continue to decline over the entire forecast period. Emissions in 2021 were slightly lower than in 1990 and by 2030 will

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 (2022) have declined 25% compared with 1990 levels. By 2050, we expect an emissions decline of 79% compared with 1990, to 10.8 million tCO_2e (Figure 5.1), hence falling way short of both the 2030 (55% cut) and the 2050 net zero ambitions.

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 a general decline in oil and gas production combined with the removal of natural-gas driven turbines during production in favour of cleaner grid connected electricity, and changes in heat-intensive processes in the manufacturing sector. As our energy transition model does not include non-CO_2 GHGs, we have 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 are included in the model.

Emissions by sector

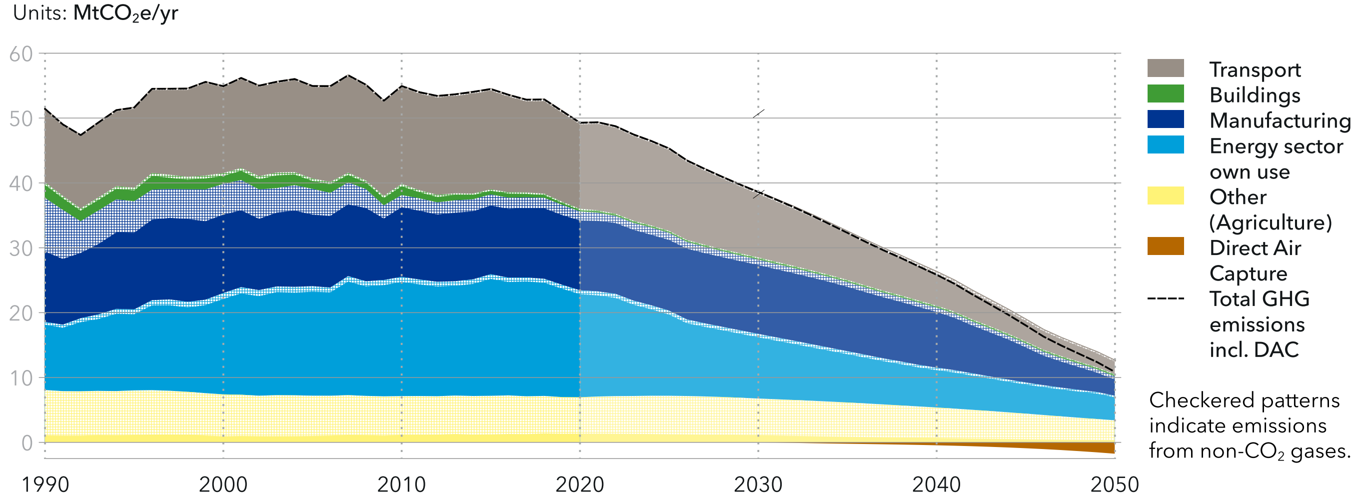
From a sectoral perspective, all emissions have been associated with the main sectors described in our energy systems model. Emissions from CO_2 dominate in all sectors, with the exception of the 'Other' category which in this context equates mainly to agriculture,. In the agricultural sector, emissions 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 ambitions in the sector, which extrapolated to 2050 declines by 57% for 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.

By 2050, we expect an emissions decline of 79% compared with 1990, to 10.8 million tCO_2e, thus falling way short of both the 2030 (55% cut) and the 2050 net zero ambitions.

FIGURE 5.2

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Emissions from power generation are allocated to end-use sectors. Historical data source: SSB (2022)

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, and installations without electrification reach end of life, emissions will decline gradually towards 2030 by 40% compared with 2021 levels. By 2050, the energy sector's own use reduction is 77% at 3.8 $MtCO_2e$ due to declining activities on the NCS and an electrification rate of just over 50%.

The manufacturing sector currently emits 12 $MtCO_2e$ – a quarter of total GHG emissions. 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 have only slightly declined (by 6%) due to an expected growth in industrial output. However, by 2050, emissions will be down to 3 $MtCO_2e$, a decline of 76% mainly due to fuels switching to cleaner sources in industrial heat (electricity and hydrogen) and more CCS to capture process emissions.

In 2021, the transport sector was responsible for 27% (13.6$MtCO_2e$) of total emissions. These emissions will drop significantly towards 2050 but are not on track to fulfil Norway's 2030 ambition of reducing transport emissions by 55% compared with 1990 levels. Today, the road transport sector emits 8.8 $MtCO_2e$. By 2030 this will decline to 5.6 $MtCO_2e$, a reduction of 24% compared with 1990 and 36% compared to 2021 levels. The main contributor to this reduction is the electrification of the road sector, especially passenger vehicles, where emissions decline 50% from 1990 levels to 2030. By 2050, road transport emissions will decline by 87% 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 37% 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 70% from 1990 to 2050 and end up at 1.2 million tCO_2e, with the help of synthetic fuels, biofuels, and hybrid electric solutions.

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 370$ktCO_2e$. Even with an expected increase in building mass and floor space, these emissions will decline further due to building standards 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 40% leaving 320$ktCO_2e$.

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 requirement to follow technical specifications. We forecast 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 850$ktCO_2$/yr is removed from gas and injected into an offshore sandstone reservoir (GCCSI, 2022). At the Melkøya LNG facility, an additional 700$ktCO_2$/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 16.1 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 model, along with an increasing CO_2 price. The effect is an increase of emissions captured starting in 2025 and slowly adding CCS capacity in new sectors ending up capturing a total of 11.2 MtCO_2/yr by 2050 (Figure 5.3).

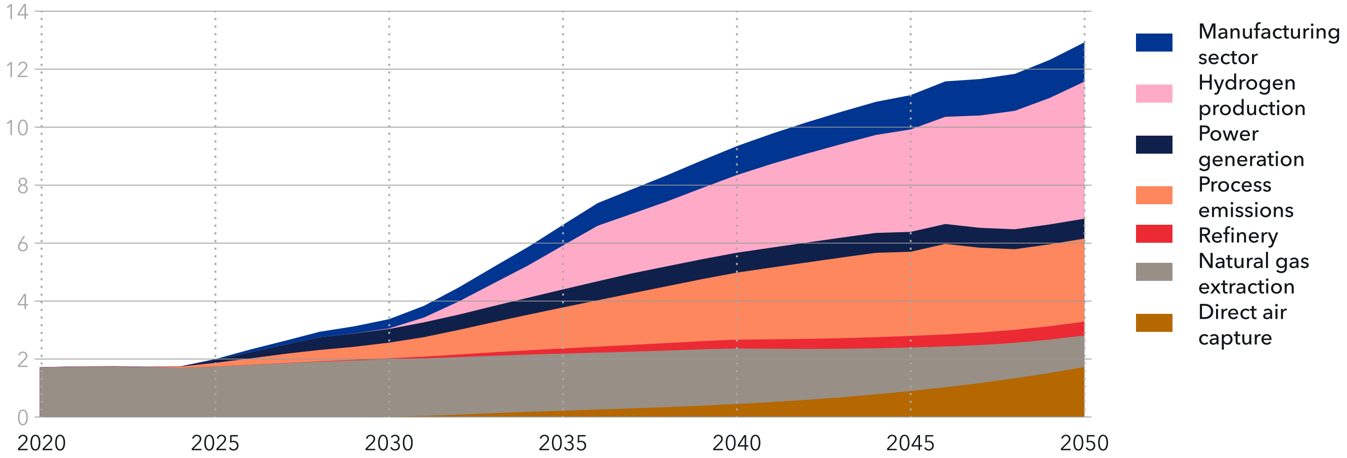
Direct air capture (DAC), which involves the direct capture of CO_2 from the atmosphere and then sequestering the captured CO_2, is still an emerging technology. It shows great promise for decarbonization but will only make a meaningful difference by 2040. It is nevertheless a much-needed technology to limit global warming to 1.5°C and could be very meaningful for individual companies to

The waste-to-energy plant at Klemetsrud in Oslo is implementing CCS technology to capture up to 400,000 tonnes of CO_2 each year from 2026. More information about the project and technology can be found here. Image courtesy of Fortum Oslo Varme AS

FIGURE 5.3

Norwegian CO_2 emissions captured

Units: MtCO_2/yr



offset their existing emissions. In Norway, there are several interesting initiatives attracting attention of investors leading to an early uptake of DAC in Norway and reaching almost 2 Mn t/CO_2 by 2050, representing 18% of global DAC capacity.

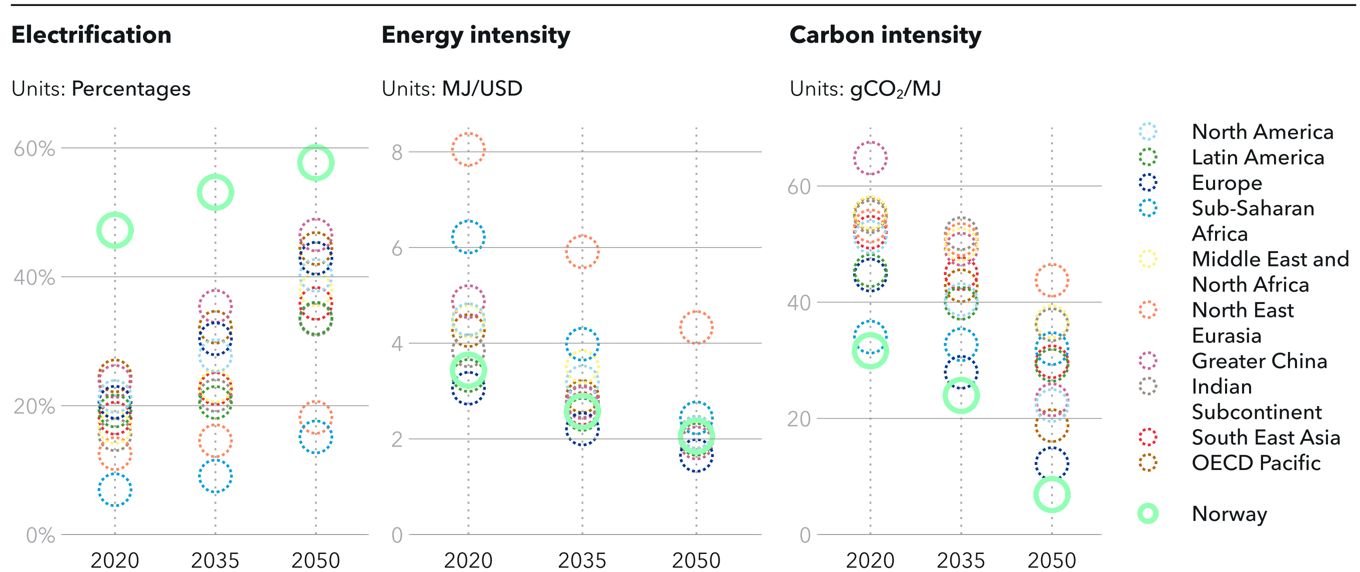
Combining CCS on point sources with direct capture from the atmosphere, we expect a total capture of 13 $MtCO_2$/yr, amounting to 60% of all Norwegian CO_2, leaving 6.8 $MtCO_2$ uncaptured in 2050. Remaining CO_2 emissions stem from sectors such as transport, where emissions are difficult to capture, as well as from other point sources where capture remain expensive and complicated. Remaining Non-CO_2 emissions (4$MtCO_2$e) are mainly found in the agricultural sector which will be increasingly difficult to avoid or remove without considerable disruption to food production.

Energy transition indicators

Norway's energy system is unique compared with those of other regions. It has abundant natural energy resources and a relatively small population; a large energy export; and a power sector already among the most decarbonized globally. Figure 5.4 presents Norway's development against three main energy-transition indicators: Electrification, energy-intensity improvements and decarbonization in comparison to other developed regions. Norway's share of electricity in final energy demand will reach 58% 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 1.7 MJ/USD in 2050. Carbon intensity significantly declines between 2030 and 2050, reaching a final value of 7gCO_2/TJ. This level is much lower than in Europe, where we see a 73 % decline to 12 gCO_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, and which place Norway with an advantage when considering carbon intensity.

In Norway, there are several interesting initiatives attracting attention of investors leading to an early uptake of DAC in Norway and reaching almost 2 Mn t/CO_2 by 2050

FIGURE 5.4



6 NORWEGIAN TRANSITION IN AN EU CONTEXT

The geopolitical situation has changed dramatically since last year's *Energy Transition Norway* report. Energy systems resilience is now a significant concern given the EU's historic reliance on Russian oil and gas, and energy prices have spiralled in the wake of Russia's invasion of Ukraine. Governments across Europe are struggling to balance the energy trilemma (security / affordability/ sustainability) in the energy transition while securing short-term energy needs.

Norway is similarly in a situation where it needs to strike a balance between attending to domestic price spikes, fostering technology and industrial ventures for the green transition, delivering on decarbonization commitments, and being a secure supplier of energy to its European neighbours.

Shared decarbonization ambitions

Norwegian climate commitments are aligned with those of the EU. Common climate objectives and common regulatory frameworks, founded on the Agreement on European Economic Area (the basis of EU-ETS participation since 2008), are to achieve an overall reduction of GHG emissions by 55% by 2030 compared with 1990 levels and achieving carbon neutrality by 2050. The EU is showing no signs of reversing its climate commitments despite the war in Ukraine and security of supply challenges. To the contrary: the EU has intensified policy initiatives and its package of policy measures ('Fit for 55') to advance decarbonization. Norway has agreed to additional cooperation with the EU through 2021-2030 to fulfil the 2030 climate targets, and Norway is thus committed to 40% emissions reduction in non-ETS sectors, broken down into annual binding cuts. EU internal flexibility mechanisms are accepted, in terms of allowing implementation of emission reductions either domestically or in another EU/EEA country, but use of global flexibility mechanisms is not (Guldbrandsen et.al, 2022). However, our forecast finds Norway's emissions declining 25% by 2030 compared with 1990 levels and 79% by 2050, hence pressure will mount to implement supplementary national measures during the remaining 8-year period to deliver on targets.

Unprecedented clean energy policy acceleration

The Russian war on Ukraine has raised the profile of renewables as distributed and abundant energy sources that are hard to weaponize. Comparatively brief development lead-times to bring renewable plants on stream are tilting policy in their favour in the short term, with long-term energy security as a key motivation. The European Commission's REPowerEU Plan outlines a host of initiatives aimed at ending the dependence on imported Russian fossil fuels by 2027. It builds on the full implementation of the Fit-for-55 proposals, and proposes going further, with higher energy savings (binding energy efficiency target of 13%, an increase from previous 9%) and a 2030 renewable energy target of 45% (share in European energy use), up from the previous 40% (EU Commission, 2022). To speed up the deployment of renewables, dedicated 'go-to' areas for renewables will be established with shortened and simplified permitting processes in areas with lower environmental and social risks. The Commission's analysis indicates that REPowerEU entails additional investment of €210bn between now and 2027, framed as a down-payment on independence and security. The EU is front-running the transition by building a nexus of climate and trade policies to sustain low-carbon investment and employment with a carbon-border adjustment mechanism (CBAM).

The 'secure supplier' – short to medium term

As the biggest producer of oil and gas in Europe, and with Europe as the main export market for gas and oil products, Norway is playing a crucial role in helping to secure EU's energy supplies in the current geopolitical context and in efforts to substitute and phase out dependency on Russian gas. Companies on the Norwegian Continental Shelf are on track to deliver 122 billion cubic meters of gas in 2022, an historically high level, up 8% from 2021, and the equivalent of close to 1/3 of total gas consumed in the EU in 2021 (Government.no, 2022). Hence in the near-term future, the EU is deepening its energy cooperation with existing suppliers, but neither regional natural gas nor oil production, mostly in Norway and the UK, can cover Europe's needs, and the EU is developing new hydrocarbon alliances with e.g. the US, Middle East, and South America.

Long-term EU developments, however, are pointing in a direction of oil and gas becoming less attractive, adding uncertainty to demand for Norwegian gas. Our main *Energy Transition Outlook* (ETO) 2022 (Section 4.2) forecasts international oil demand to be 32% lower than today in 2050 (from 82 Mb/d to 56 Mb/d), largely driven by falling demand in road transport. Not only will oil demand fall even faster than the world average in Europe (dropping 61% by 2050) as a result of the EU's accelerated transition efforts, but natural gas demand will also fall precipitously in the EU – down 64% by 2050 relative to 2020. Moreover, the geography of oil and gas production will concentrate ever more strongly in the Middle East and North Africa, given abundant reserves there and lowest-per-barrel extraction costs.

Fossil-fuel risks – medium to long term

The long-term prospect of declining fossil-fuel demand from the progressing energy transition, and in Europe from an extraordinary transition acceleration, is not dampening interest in fossil-fuels, either in Norway or globally. Supply constraints, high fossil-fuel prices, and producer windfall profits are boosting exploitation of hydrocarbons across the world. New fossil infrastructures are flagged in producer countries, positioning themselves to fill the supply gap and alleviate the energy shortfall caused by sanctions on Russian energy sources.

However, new field investments, which take years to come into production, will not solve today's acute energy crises or high prices in Europe nor domestically for Norway. To reduce the financial risk of stranded assets, investment decisions need careful consideration, taking into account the market situation and prices at the point in time of entering operations *and* throughout the technical lifetime of assets. New infrastructure built today creates the risk of locking in investments that will meet fierce competition from other fossil-fuel producers with lower production costs.

In the Norwegian context, this risk of stranded assets is further amplified by the favourable tax package introduced in June 2020 to encourage investment following a crash in oil prices caused by the COVID-19 pandemic. The Wisting project is an illustrative case in point in which several politically charged transition dilemmas are manifest. Presently, the project's decision basis is developed by Equinor to qualify for tax breaks available until end of 2022. Operational by 2028, the project has a 30-year life; it also requires a 340 km, 100 MW cable carrying renewable power across Finmark land, impacting Sami communities and livelihoods.

Several studies have concluded that developing *new* oil and gas fields is incompatible with the 1.5°C target (DNV, 2021; IEA, 2021; IISD, 2022). Beyond assumptions about climate action and consideration for structural decline in oil and gas demand, Norwegian deliberations will also have to consider how new fossil field investments set up competition with energy and infrastructure investment needs for other power-intensive industries, as well as competence transfer and labour transition needed from the oil and gas sector into green industry ventures, e.g. the offshore wind sector. Such transfers are needed to build future Norwegian export revenue potential, achieve reduction of Norwegian emissions, and contribute to Europe's energy transition to renewables; but this can be delayed if policies favour petroleum exploration and exploitation and lead to incoherent cross-governmental climate and energy transition planning.

Increasing renewable electricity capacity – the key transition enabler

Norway shares the European Commission's European Green Deal vision of transformation to a sustainable, low-carbon economy. Like their counterparts in EU member states, Norwegian industry players and policy-makers are aiming to advance transition-related technology and value creation through decarbonization efforts. The Norwegian 2021 Climate Plan targets a green transition aligned with economic development, with renewable energy playing the key role.

The Confederation of Norwegian Enterprise (NHO) and partners in the 'Green electrical value chains' project (NHO, 2020) outlined export-oriented industry development in 6 priority areas (renewable energy, offshore wind, batteries, hydrogen, maritime transport, power system optimization incl. smart charging infrastructure) with an estimated revenue potential of €32bn/yr in 2030 and at least €76bn/yr by 2050. Recently, the government presented the Green Industrial Initiative (NFD, 2022), a roadmap envisioning similar priority areas, in addition to forestry and forest bioeconomy, and petroleum value chain CO_2 management. The realization of the green re-industrialization potential rests on public policy, incentives, and regulatory frameworks to advance investments.

With the forecast drop in oil and gas export revenue (78% to 2050), clearly time is running short for positioning and build-out of transition and decarbonization-related competences and industry. Tuning research and development towards these ends are key ingredients, and the recent delay of the Ocean Space Centre (Forskning.no, 2022) could be construed as undermining ambitions. Supportive government funding should be meaningfully and rapidly steered in the direction of development and deployment for these ambitions. The current and future importance of clean tech service-based exports (finance, technology, and advisory) should not be discounted, particularly *if* skills and experience are acquired at a faster rate in Norway than elsewhere as the country pursues aggressive decarbonization plans to meet its 2030 commitments.

Decarbonization efforts and the establishment of green industrial value creation are intrinsically linked to Norway's domestic electricity sector. While historically a frontrunner in electrification of energy consumption, founded on access to and surplus of clean abundant hydropower offering low power prices to power-intensive industry, abundance has been replaced by growing price and security of supply concerns in 2022.

Access to stable, predictable, and reasonably-priced renewable electricity will be a precondition for enduring developments in new, green industries. The present power price advantage enjoyed by northern bidding zones in Norway fall way short of what is required in terms of the sheer scale of access and availability required. The national challenge is to make sufficient investments in renewable power to supply growing demand centres (new industries), offshore petroleum production, and for possible export. The deficit outlined in this forecast (Highlight 3) underlines the criticality of increasing renewable electricity generation capacity near term, beyond upgrade and expansion initiatives of hydropower capacity and including investments in grids. Failing to do so risks eroding the competitive advantages for power-intensive industries and will likely derail the establishment of energy transition-related green industry ventures.

REFERENCES

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

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

DNV (2021) *Pathway to net zero emissions.* https://www.dnv.com/energy-transition/pathway-to-net-zero-2021.html

DNV (2022a) *Energy Transition Outlook 2022 – a global and regional forecast to 2050.* Available at: eto.dnv.com

DNV (2022b) *Maritime forecast to 2050 - Energy Transition Outlook 2022.* Available at: eto.dnv.com

Energifaktanorge (2021) *Energy facts in Norway.* Available at: https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon

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

Equinor (2020) *Utbygging og drift av kraft fra land til Sleipner.* Available at: https://www.equinor.com/content/dam/statoil/documents/impact-assessment/sleipner-kraft-fra-land/equinor-vedlegg-1-repm712-00011-01-dokumentasjon-av-konsekvenser-ved-utbygging-og-drift-av-kraft-fra-land-til-sleipner.pdf

European Commission (2022) *REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition.* Press release, 18. May, Brussels. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

Forskning.no (2022) *Havforskningssenteret Ocean Space Centre i Trondheim utsettes.* May. https://forskning.no/havet-ntb-om-forskning/havforskningssenteret-ocean-space-centre-i-trondheim-utsettes/2025115

GCCSI (2022) *Global CCS facilities database*. Available at: https://co2re.co/FacilityData

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

Global Wind Atlas 3.0, Technical University of Denmark (DTU) (2020) *World Bank Group, Vortex, Energy Sector Management Assistance Program (ESMAP).* Available at: https://globalwindatlas.info

Government.no 2020, *The government launches 'Longship' for carbon capture and storage.* Available at: https://www.regjeringen.no/en/historical-archive/solbergs-government/Ministries/smk/Press-releases/2020/the-government-launches-longship-for-carbon-capture-and-storage-in-norway/id2765288/

Government.no (2022) *Prime Minister Jonas Gahr Støre`s statement at the European Political Community meeting in Prague. 6. October, Prague.* https://www.regjeringen.no/en/aktuelt/prime-minister-jonas-gahr-stores-statement-at-the-european-political-community-meeting-in-prague-6-october-2022/id2933269/

Gulbrandsen, Lars H., Hermansen, Erlend A.T. (2022) *Ever Closer Union? Norges tilknytning til EUs klimaregelverk*. Årgang 80, nummer 1, Juni. https://tidsskriftet-ip.no/index.php/intpol/article/view/3674/6538

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

IEA ETP (2016) *Energy Technologies Perspective, International Energy Agency.* Available at: https://www.iea.org/topics/energy-technology-perspectives

IEA – International Energy Agency (2021) *Net Zero by 2050 – A Roadmap for the Global Energy Sector.* May, Paris https://www.iea.org/reports/net-zero-by-2050

IEA WEB (2022) *World Energy Balances*. International Energy Agency. Available at: http://www.iea.org/statistics/relateddatabases/worldenergybalances.

IISD – International Institute for Sustainable Development (2022) *Navigating Energy Transitions – Mapping the road to 1.5°C*. October. https://www.iisd.org/publications/report/navigating-energy-transitions

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

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

NFD – Nærings- og fiskeridepartementet (2022) *Veikart – Grønt Industriløft.* https://www.regjeringen.no/no/dokumenter/veikart-for-gront-industriloft/id2920286/

NHO – Confederation of Norwegian Enterprise (2020) *Norske muligheter i grønne elektriske verdikjeder.* ©2020. Styringskomiteen for Grønne Elektriske Verdikjeder. https://www.nho.no/siteassets/prosjekter-og-samarbeid/gronne-elektriske-verdikjeder.pdf

NPD (2022) *Exports of oil and gas.* Available at: https://www.norskpetroleum.no/en/production-and-exports/production-forecasts/

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

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

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

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

SSB (2022) *Statistisk sentralbyrå Statistikkbanken.* Available at: https://www.ssb.no/statbank

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

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 model were made by DNV. We are deeply grateful to those who took the time to make themselves available for interviews. Listed below in alphabetical order with their assigned affiliation:

Magnus Krogh Ankarstrand Yara Clean Ammonia, **Alexander Strøm Arnesen** Elkem, **Gudmund Bartnes** Vårgrønn, **Hildegunn T. Blindheim** Offshore Norway, **Håkon Borgen** Statnett, **Andreas Bjelland Eriksen** Statssekretær, **Anja Farstad** Statnett, **Åslaug Haga** Norwea, **Nils Klippenberg** Siemens, **Ulrik Olbjørn** Equinor, **Christian Rynning-Tønnesen** Statkraft, **Lars Rørsægg** Yara

In addition to these external experts, we have held numerous internal discussions with colleagues in different parts of DNV. Much appreciation to our colleagues for taking the time to respond and give feedback on different topics.

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: Frida Berglund, Thomas Horschig, Anne Louise Koefoed, Sujeetha Selvakkumaran, Adrien Zambon

Editor: Mark Irvine

Communications: Anne Vandbakk, Therese Sanni

Published by DNV AS. **Design** SDG/McCann Oslo **Print** Aksell. **Paper** Arctic volume white 130/250 g. **Images** Cover image: Dennis Schroeder / NREL, p. 3, p. 8, p. 10, p. 15, p. 31, p. 41, p. 53: Getty Images, p. 23: FREYR Battery, p. 39: HydrogenPro, p. 42: NKT p. 49: Fortum Oslo Varme AS.

Historical data

This work is partially based on the World Energy Balances database developed by the International Energy Agency, © OECD/IEA 2022 but the resulting work has been prepared by DNV and does not necessarily reflect the views of the International Energy Agency. For energy related charts, historical (up to and including 2021) numerical data is mainly based on IEA data from World Energy Balances © OECD/ IEA 2022, www.iea.org/statistics, License: www.iea. org/t&c; as modified by DNV.

WHEN TRUST MATTERS

About DNV

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.

dnv.com/eto

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