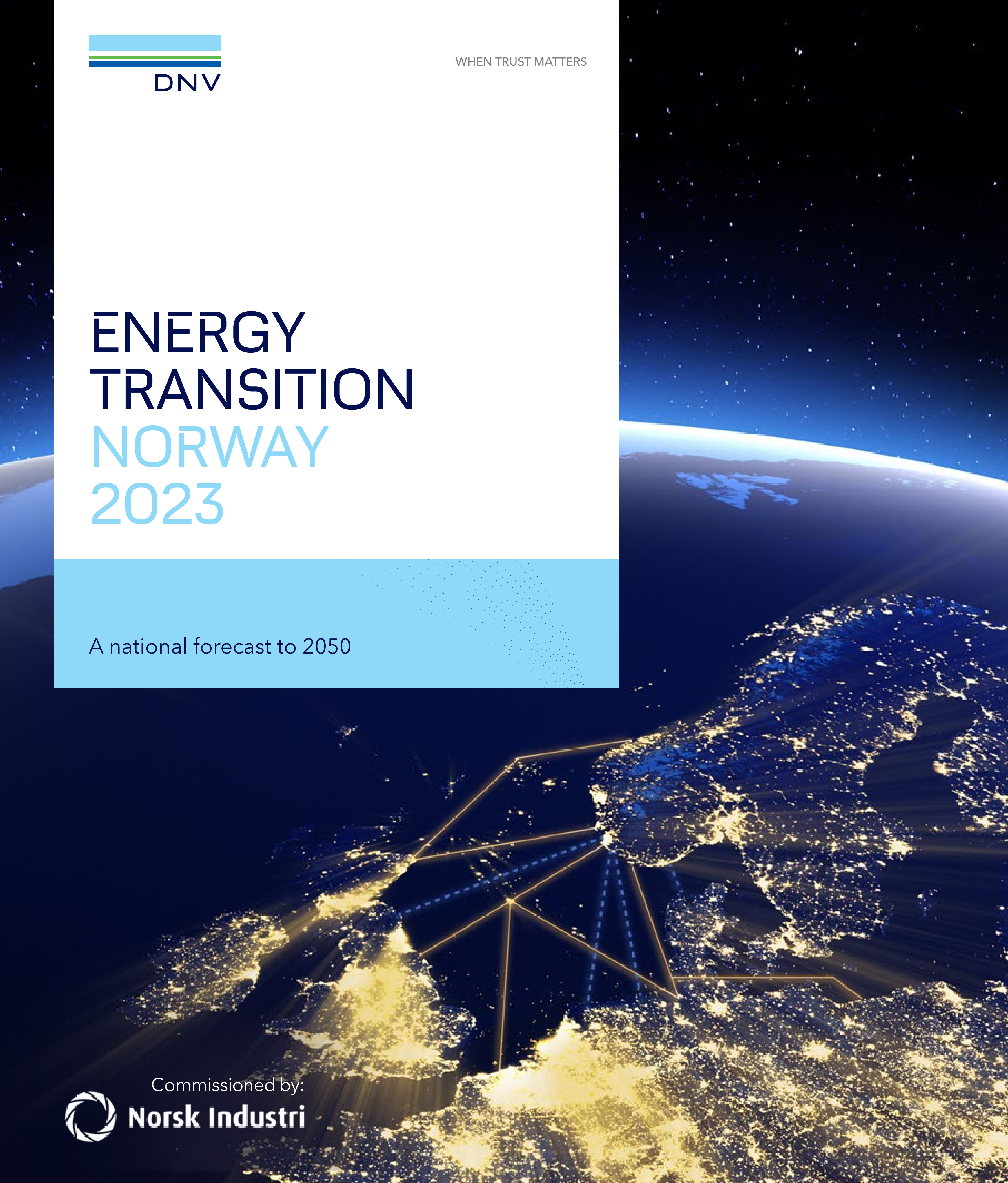


DNV

WHEN TRUST MATTERS

ENERGY TRANSITION NORWAY 2023

A national forecast to 2050

Commissioned by:
Norsk Industri

FOREWORD

The 2023 edition of the *Energy Transition Norway 2050* reconfirms that Norway is not on track to meet Paris Agreement targets for reducing greenhouse gas emissions. Despite cross-political support for 55% and 100% GHG reductions by 2030 and 2050, respectively, Norway is heading for 27% less in 2030 and 80% in 2050.

When Norway ratified the Paris Agreement in 2016, nearly all its electricity was from hydropower. We also got 140 TWh of energy from fossil fuels. To replace that fossil consumption to reach climate targets, roughly 100 TWh of additional renewables capacity for electricity and making hydrogen and ammonia was needed. The electricity grid needs strengthening across Norway, and carbon capture and storage is part of the equation. We are far from achieving this and thus face an expected net electricity deficit in 2028 lasting until 2032, that could see Norway paying European price levels or more for electricity.

This report shows the need for 390 TWh renewable power in 2050, nearly three times more than today, through converting existing fossil generation, building new green industries, and enabling hydrogen production for domestic use and export. Additional solar and hydro-power are important, especially in the short term, but make limited contributions. Onshore wind is affordable and may contribute 40–50 TWh. Offshore wind, especially floating offshore wind, will be the main contributor with more than 100 TWh near 2050.

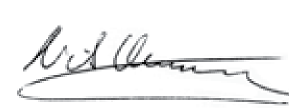
All renewables are weather-dependent, and we should expect intense supply and demand dynamics at national, regional, and local levels. Balancing the grid requires hydropower plants, huge numbers of batteries, and data-driven algorithms working in real time.

Europe depends on Norwegian gas to meet demand and stabilize the geopolitical situation. This demand is expected to increase in the short term but decline steeply in the long term. Norway can maintain its significant market share in energy supply to Europe, but through a new export mix of electricity alongside hydrogen (initially blue and then green) and ammonia as energy carriers. Again, this cannot be achieved without sufficient renewable power.

The decarbonization effort in Norway and globally is an enormous business opportunity for the Norwegian industry. Huge opportunities lie ahead in industrializing floating wind farms, setting up a complete value chain for batteries for the energy system and transport, and in hydrogen and ammonia. In addition, conventional industry products need to be carbon-neutral going forward to comply with customers' future requirements. If not, we'll lose market share.

Norway's urgent need to build a significant amount of new renewable power requires an attractive financial framework and streamlined concessions and permitting. Norsk Industri is worried that there are close to zero new applications for hydropower and onshore wind. This suggests the political framework is unattractive. New green industries as defined by the government require financial frameworks comparable to those in the EU.

Time is of the essence. We have only six years left to meet 2030 ambitions. Our politicians need to take bold decisions to get us back on track. We all have the responsibility to make a better tomorrow.



Nils Klippenberg

Chairman Electro and Energy – Norsk Industri

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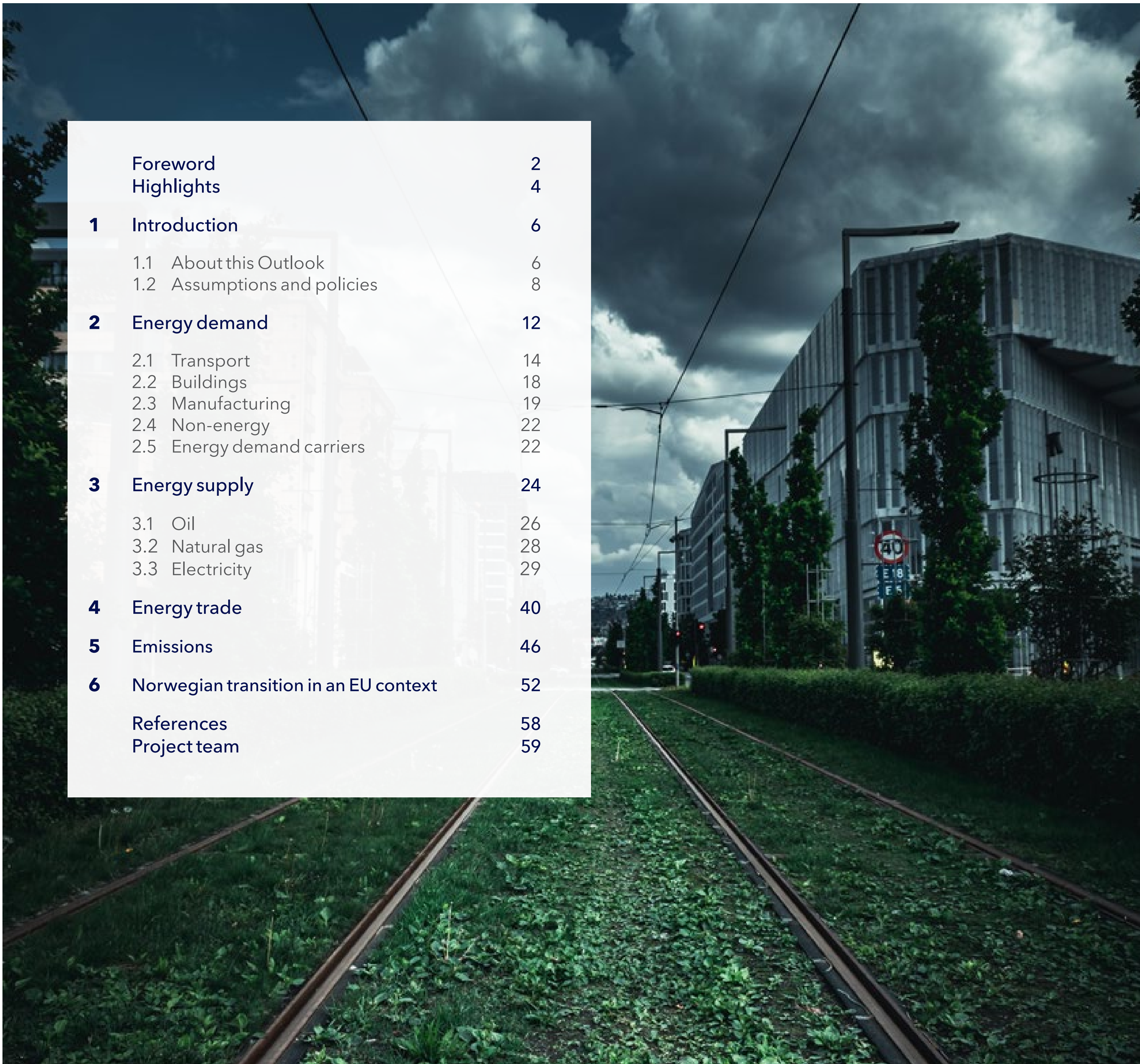


1 HIGHLIGHTS

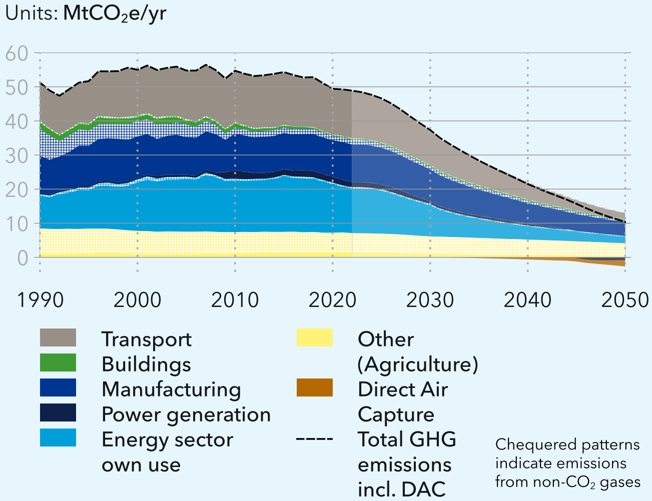
Norway not on track for 2030 and 2050 emission targets

- Implemented and planned actions are not creating the dramatic change needed to reach the short-term goals
- Norway aims to cut emissions by 55% by 2030 and 90-95% by 2050. We forecast 27% reduction by 2030 and 80% by 2050 compared with 1990
- The more urgent action is delayed, the narrower the window for reaching the targets becomes, especially the nearer-term ambitions for 2030
- Only transport and the oil and gas sector's emissions are falling close to the levels necessary to reach Norway's 2050 target
- By 2050, significant carbon capture (8 Mt) and carbon removals (2 Mt) reduce Norway's emission by half, helping to get closer to reach the target, but needs further efforts
- There is mounting pressure for high-income countries, such as those in Europe and rest of OECD, to reach net zero *well before* 2050 to allow the world to reach the ambitions of the Paris Agreement

FIGURE 1

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Historical data source: SSB (2023)

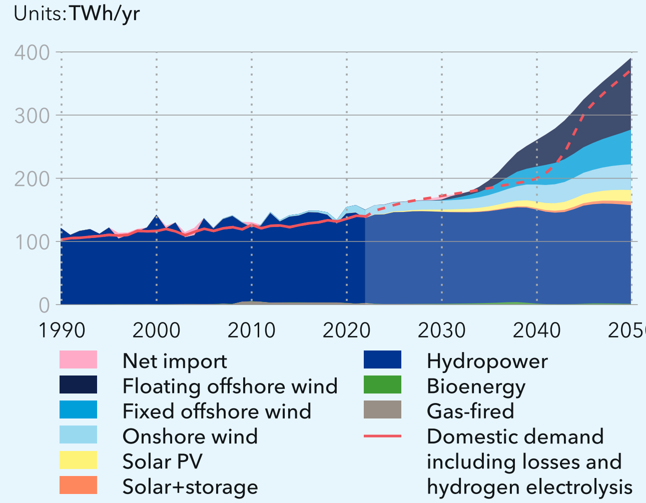
Lack of new power production places industrial development and decarbonization at risk

- The existing electricity surplus in Norway will shortly be consumed by increased electricity demand from households, industry, the electrification of transport, and electrification of several oil and gas installations
- Limited opportunities for adding new electricity generation short term will likely create an electricity deficit by the late 2020s
- The deficit is currently being managed by 'default' demand reduction: new industrial growth is being discouraged by uncertainty in future electricity prices, an unclear regulatory framework, and a lack of grid connections
- Offshore wind has the highest potential to add significant electricity to Norwegian power system in the 2030s, but delays in concessions and auctions place this potential at risk
- Grid expansion is needed to increase flexibility, remove bottlenecks and maximize the value of wind power. The current pace of grid build-out is too slow

FIGURE 2

Norway electricity supply by power station and net imports

Units: TWh/yr



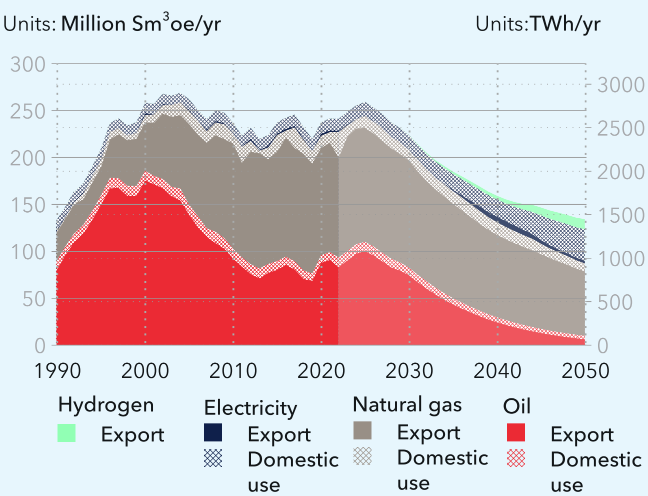
Historical data source: IEA WEB (2023), SSB (2023)

Norwegian energy exports: short-term growth, steep decline in the long term

- European demand for natural gas is falling and will fall much further than expected before the Ukraine war as a consequence of European climate and energy security considerations
- Norway's gas exports decline 35% and oil export 93% to 2050
- A growing share of Norwegian energy exports will be converted to electricity , hydrogen and its derivatives, but will only represent a fraction of today's energy export revenues
- Norway has a unique opportunity to supply blue hydrogen to Europe by the mid-2030s, switching to green hydrogen by the 2040s
- DNV forecasts 22 GW offshore wind in production by 2040 and 43 GW by 2050. Norwegian wind power generation increases to 210 TWh in 2050, of which 80% is offshore wind. Surplus wind power is likely to be used to produce hydrogen for export, while most of the electricity export will be based on hydropower and offshore wind

FIGURE 3

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs.
Historical data source: NPD (2023), IEA WEB (2023)

The energy transition creates several green industry opportunities for Norway

- The global energy transition will see a significant increase in renewable energy sources and other decarbonization technologies, offering growth opportunities for green industries
- Energy exports from Norway, especially renewable energy and low carbon hydrogen, will likely be attractive at any time during the next 30 years, but the prime window of opportunity for green industrial growth and building new value chains is the next five years
- Norway has a competitive edge in many decarbonization technologies, particularly floating offshore wind, which will see steep growth globally towards 2050
- Large-scale hydrogen value chains, initially blue but turning increasingly green leveraging surplus power generation, can generate significant export revenue complementing electricity exports
- Carbon capture and storage (CCS) will play a critical role in reducing emissions, and Norway's expertise in CCS can be leveraged for decarbonizing natural gas and creating opportunities in hydrogen and ammonia production. Storage of CO_2 on the Norwegian Continental Shelf (NCS) is a huge opportunity with limited competition, especially close to Europe
- In maritime transport, Norway's leadership in LNG, batteries, and hydrogen for short-sea shipping can be expanded to develop low- and zero-carbon solutions for global deep-sea shipping

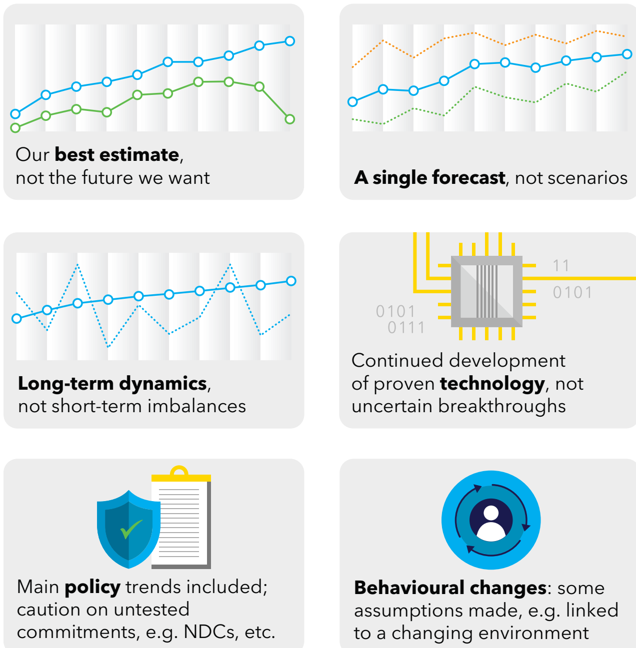
1 INTRODUCTION

1.1 About this Outlook

This *Energy Transition Norway* (ET Norway) report describes the energy future of Norway through to 2050. The analysis, the most likely model framework behind it, the methodology, the assumptions, and hence also the results lean heavily on DNV's global forecast, the *Energy Transition Outlook 2023* (DNV, 2023a) and the Energy Transition Outlook (ETO) model. This approach yields a consistent and energy-balanced result, as Norway is part of the global energy system, and the country's energy supply and demand are affected by what happens elsewhere. Similarly, what happens in Norway can affect other countries.

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 Norway's energy future, given expected economic, policy and technology developments 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 supply and demand of energy globally, and the use and exchange of energy between and within 10 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 ten regions.

The analysis covers the period 1990–2050, with changes unfolding on a multi-year scale that is fine-tuned in some cases to reflect hourly dynamics. We continually update our model's structure and the input data. In this report, we do not repeat all details on methodology and assumptions from *Energy Transition Outlook 2023* (DNV, 2023a), but refer to that report for further details.

We are also mindful that this analysis has been prepared while Russia's war on Ukraine is an ongoing international conflict and in the context of the unsettled economic environment at the tail-end of the COVID-19 pandemic. These factors add uncertainty to several parameters of relevance to the energy transition; first and foremost the unprecedented energy prices, but also 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, hydrogen, and ammonia. 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 and 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 a changing geopolitical landscape, energy security, job creation or global and local climate commitments. So, to better understand the most likely development in the near- to medium-term, when these issues have the biggest impact and are also easier to forecast, we have conducted interviews and discussions with politicians, advocacy groups, and business leaders to gain insights on how they view the medium-term future policy landscape unfolding. In addition to external experts, we have held internal discussions with colleagues in different parts of DNV. Much appreciation to everyone for taking the time to respond and give feedback on different topics.

> Our analysis produces a single 'best-estimate' forecast of Norway's energy future, given expected economic, policy and technology developments and associated costs.

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 most recent research and results from the Austria-based IIASA Wittgenstein Centre for Demography and Global Human Capital (WIC, 2023). These results have been updated in 2023, and the data calibrated to most recent UN data projects a global population close to the UN population estimates for 2050. Compared with previous ET Norway reports, lower fertility rates and limited immigration give Norway a slightly lower population estimate of 6.1 million (mn) in 2050 from 5.4mn today.

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 this year decided to use the long-term economic development data from OECD (2021). 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 such short-run changes, we have chosen to deviate from the OECD GDP model and instead use economic growth figures from the International Monetary Fund (IMF). The IMF data points to a GDP change for Norway that is growing from the low levels in 2020 by an average 1.6% per year until 2027, thereafter returning to the growth rates given by the OECD GDP model.

For Norway, 2022 GDP was USD 429 billion (bn), or NOK 3,800bn, while in 2050 it will be USD 667bn (NOK 5,900bn). This implies a compound annual growth rate (CAGR) of 1.6% per year. GDP per capita increases from USD 78,900 to USD 109,100 per person in the same period. All numbers are stated in 2017 purchasing power parity terms denominated in 2022 USD and therefore must be converted to get real or nominal GDP.

Technology development

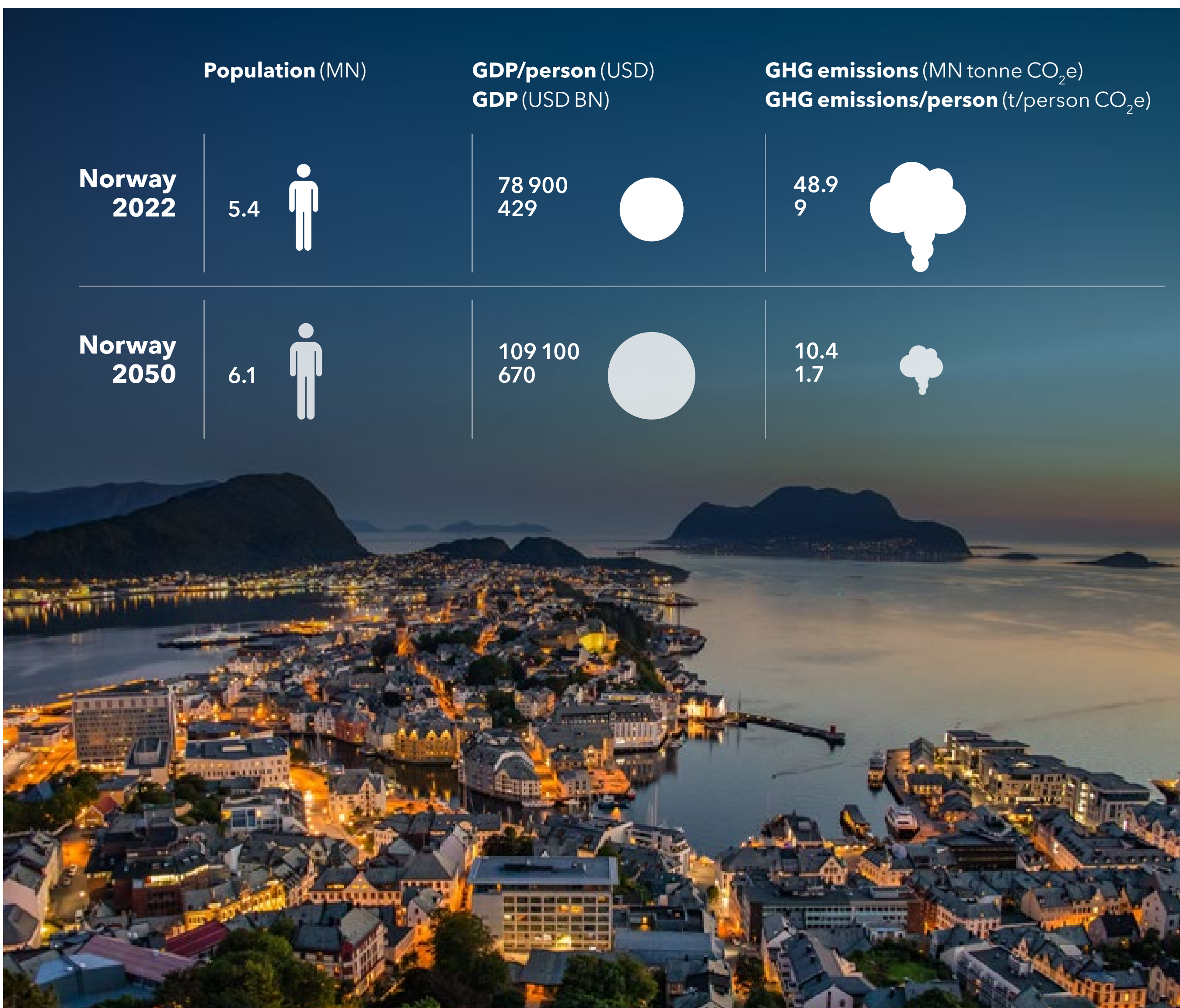
DNV bases its forecast on the continued development of proven technologies in terms of costs and technical feasibility, not uncertain breakthroughs. However, during the period covered by this Outlook, the list of those that we currently consider 'most promising' could change due to shifts in levels of financial support or changed potential for cost reduction. 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.

> Core technology 'cost learning rates' that we have used through to 2050 in our forecast include 16% for batteries, 16% for wind, and 26% for solar PV but falling to 17% later in the forecast period.

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 but 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 (e.g. solar PV panels) from supporting technologies (e.g. solar PV control systems and installation kits). Typically, the latter have a lower CLR. For example, PV core technologies and balance-of-supply (BOS) equipment have CLRs of 28% and 9%, respectively. For some technologies, like batteries, the core technology is almost all there is, and so the highest CLR dominates. For other technologies, like unconventional gas fracking, other cost components dominate.

Core technology CLRs that we have used through to 2050 in our forecast include 16% for batteries, 16% for wind, and 26% for solar PV but 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 policy changes, in turn driving 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.

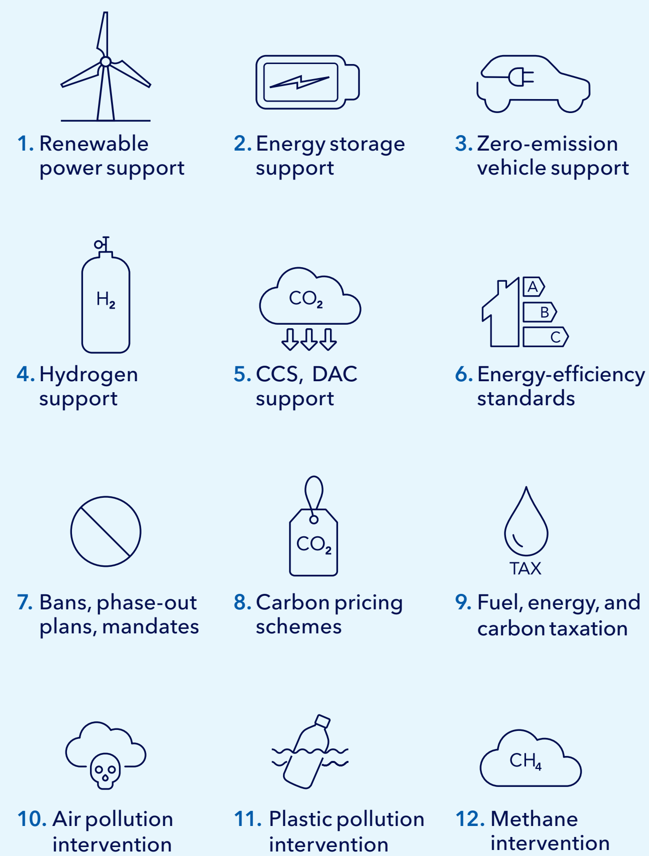
It is not a given that energy or climate ambitions and targets will be met at either national, regional, or global levels. As such, our forecast does not assume that Norway will achieve its national target of reducing greenhouse gas emissions by 55% by 2030 compared with levels in 1990.

Targets and ambition levels may or may not be translated into real policy. There are numerous examples of goals and targets not being met in Norway. However, ambitious targets are often followed by specific policy measures translating ambitions into reality influencing the emissions trajectory.

From the main ETO report (DNV, 2023a) 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

- Fixed and floating offshore wind projects will initially receive financial support to supply domestic energy demand and to establish a domestic market. As costs decrease and the proportion of electricity exported to Europe grows, offering higher profitability, financial support will gradually reduce. In addition to these sources of income, we expect there to be mechanisms to redistribute profits from high-margin energy exports, such as hydropower and green hydrogen exports, to further enhance the financial viability of offshore wind development.

Zero-emission vehicle support

- The support scheme for passenger EVs incorporate the new scheme from 1 Jan 2023, with slightly increasing costs for EV purchases of vehicles above the 500,000 NOK price point as these are ineligible for the 25% VAT exemption.
- For EVs in the commercial vehicles segment, support schemes will continue as today then grow slowly from the late 2020s until EVs account for 90% of new vehicle sales in 2040, when we expect maximum uptake of electric drivetrains.
- We have included the government’s ambition on increased use of biofuel in transport. The fraction of biofuel use for internal combustion engines increases from 13% in 2022 to 20% in 2030 and stays there until 2040, then declines with shrinking use of internal combustion engine vehicles.

Hydrogen

- We expect some production projects to be subsidised to compensate for high hydrogen prices where carbon dioxide (CO_2) pricing still makes hydrogen uncompetitive. The level of support is expected to be USD 0.30/kgH_2 for blue hydrogen and as high as USD 2.5/kgH_2 for green hydrogen, until the early 2030s.
- We expect tax and grid charges for grid-connected electrolysers to be only 25% of the levels that apply to other industrial consumers. This is the combined result of two factors. One is active government support. The other is that some grid-connected electrolysers will be renewable electricity producers deciding, based on price, between selling electricity to the grid or for hydrogen production; if they withhold selling, they do not need to buy electricity.
- We expect the cost of natural gas for steam methane reformers to be lower than the industrial gas price, due to the expectation that many reformers will be supplied directly to gas producers without going through the transmission network and the market. We assume the gas price for methane reformers to be 25% of wholesale price to retail price, on average.

Carbon capture and storage

- The Longship project with CCS from Brevik is included with phase-in by 2025/2026. Also included is CCS at Klemetsrud with phase-in from 2027/2028.
- The CCS operations at the Sleipner and Snøhvit fields on the Norwegian Continental Shelf (NCS) are expected to be phased out. The carbon captured at Sleipner is not expected to be replaced by an alternative operation. However, we expect that CO_2 will need to be removed at liquefied natural gas (LNG) liquefaction installations, thus replacing CO_2 captured at Snøhvit, where operations will be phased out in the late 2030s.
- All other CCS will be developed on a commercial basis, albeit taking increasing carbon prices into account.

Carbon price

- Carbon prices are reflected as costs for fossil fuels in the power and manufacturing sectors. In these areas, Norway is part of the EU emissions trading scheme (ETS), and carbon prices equivalent to the rest of Europe (reaching USD 250/tCO_2 in 2050) are used.
- A Norwegian carbon price reaching 2,000 NOK/tCO_2 by the 2030s is included in 'energy sector own use', such as for oil and gas extraction.
- In other areas of the model (e.g. agriculture, household emissions) carbon price is not used directly, but taxation of fuels, energy, and carbon is incorporated, causing additional costs.

Fuel tax

- Fossil-fuel tax increases at a quarter of the carbon-price growth rate for the road transport subsector.

Power capacity limitations

- For political reasons, Norway is unlikely to make large capacity additions for onshore wind, hydropower or solar PV for export – even if profitable.
- For offshore wind (bottom-fixed and floating), we do not expect any similar power capacity limitations, and capacity will be added when profitable, also for export.
- Norway is expected to add generating capacity to support increasing demand for domestic energy use. Since hydropower and wind production 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 interconnection capacity of 5 GW, and assume its gradual introduction during the 2030s. Total interconnector capacity in 2050 is 4.2 GW to the UK and 14 GW to Europe.
- We do not expect hydrogen export to be limited by pipeline capacity, but it can be exported when needed either through new pipelines or repurposed natural gas pipelines.

Agricultural (Other sector) practices reducing methane

- Reduction of methane emissions from livestock through feed supplement. Improved manure management delivered to biogas production, increasing to 10% of utilization in 2030 and growing to 30% by 2050. Reduced emissions from food waste and emissions from land use.
- All combined practices result in a reduction by 2030 of 14% from 2022 or a decline of 39% compared to 1990.

2 ENERGY DEMAND

Norway's energy consumption depends on a supply/demand balance. Historically, it has had sufficient energy resources to meet domestic demand and export. Electricity has the largest share (44%) in the country's energy mix, and efficiency measures and decarbonization are expected to drive this to 66% in 2050.

Historically, energy demand has grown in lockstep with population growth and improvements in standards of living. Norway's population growth is slowing but will still reach 6.1 million people in 2050. Economic growth will average 1.6% from 2022 to 2050, when the economy will be 55% bigger than today's USD 429bn (NOK 3,800bn).

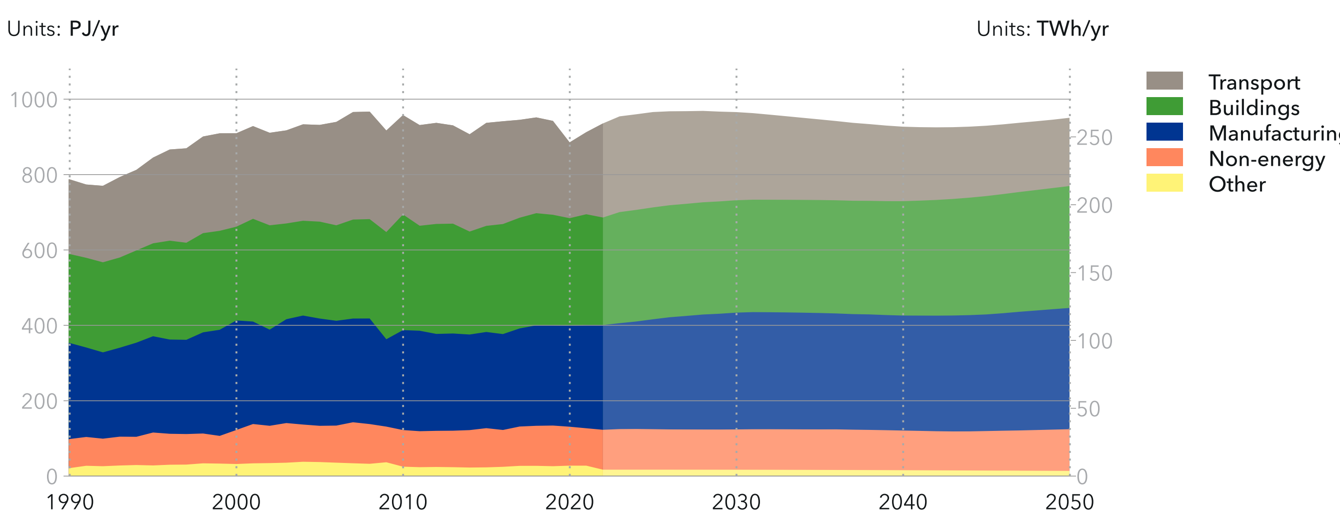
More people requiring more energy services for transportation, heating, lighting and consumer goods typically means increased energy demand. This was so until around 2008, when demand growth began to level off due to impressive developments in energy efficiency achieved, for example, through advances in lighting and heat-pump technologies.

The energy mix will change in the coming decades, driven by energy security and efforts to meet emission-reduction targets. In 2022, 47% of the mix was fossil-based; by 2050, this will be halved. We expect electricity consumption to rise in the future and foresee electrification across many end-uses, such as transport, manufacturing, and petroleum industries. Additional electricity demand will also come from new industries and data centres and hydrogen production.

We see a slight increase in Norway's energy demand (Figure 2.1) from 936 PJ in 2022 to 951 PJ in 2050. Despite the usual drivers such as population and GDP growth increasing energy demand, the marginal

FIGURE 2.1

Norway final energy demand by sector



Historical data source: IEA WEB (2023), SSB (2023)

increase can be attributed to efficiency gains enabled by electrification. Energy demand is expected to decrease in transport with a significant transition to electric vehicles (EVs), but will grow in the manufacturing and buildings sectors.

Energy efficiency is a key driver of the transition over our forecast period. It is important for the Norwegian power system, especially going forward with high electricity prices and a pressed energy supply in Europe. Energy efficiency is also usually the most cost-effective way to reduce emissions and should be at the top of the list when public authorities and companies consider emission mitigation.

For many countries, the main drivers of energy-efficiency improvements include electrification of the energy system and the rapidly growing share of renewables in power 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. It is also worth highlighting the evolving and more challenging power supply balance towards 2050. This is driven by rapid growth of green industries where enhanced efficiency and flexibility on the demand side will play key roles in achieving a better power balance, relieving the grid, and reducing the urgency of grid expansion.

Efficiencies come not only in energy supply but in how it is used. Electrifying end-use demand, seen already with uptake of electric passenger vehicles, yields further efficiency gains. The biggest improvement is expected in road transport as EVs will continue to edge out less-efficient internal combustion engine vehicles (ICEVs). Other measures raising efficiency in demand sectors include appliance switching, increasing insulation through improved building standards, and uptake of heat pumps for residential buildings and low-heat manufacturing processes.

2.1 Transport

Transport – including road, rail, aviation and maritime – accounted for 27% of Norwegian final energy demand in 2022, almost entirely in the form of oil as fuel (87%). We forecast that overall energy demand will decline almost 28% from 250 petajoules (PJ) in 2022 to 181 PJ by 2050 (Figure 2.2).

Passenger and commercial vehicles combined are the largest sources of energy demand, constituting 61% of total energy demand in 2022. With road transport set to be largely electrified by 2050, its share in energy demand reduces to 41%. Overall, transport's transformation will include oil's share in its fuel mix dropping to 29% 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

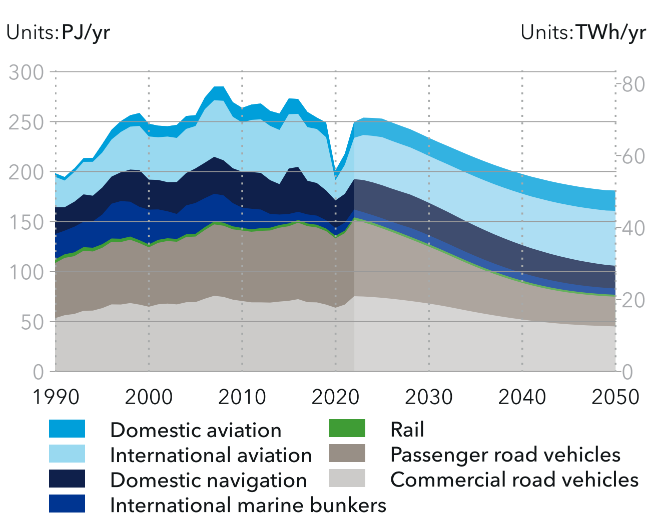
The Norwegian Parliament has decided on a national goal that all new cars sold by 2025 should be zero-emission. We therefore anticipate ongoing policies aimed at reducing emissions from road traffic to continue with significant incentives to companies and individuals encouraging switching from ICE vehicles (ICEV) to EVs through purchase and operational benefits. Over time, battery cost-learning rates will render such policies superfluous – at least for passenger vehicles where we foresee a significant decline from today's levels. Vehicle manufacturers are adapting their strategies to cope with the looming market dominance of battery EVs in the passenger segment, driving uptake and further lowering cost. For most uses, EVs will soon become more cost effective than ICEVs; EVs typically consume less than a third of the energy that ICEVs do and cost much less to maintain.

To continue the substantial EV uptake, both the average range of EVs and the density/number of charging stations need to increase and will grow in the future. In Norway, the average battery capacity per passenger vehicle is expected to increase from the current 61 kWh to approximately 94 kWh in 25 years, resulting in extended vehicle range and making EVs even more appealing (Figure 2.3).

However, EV uptake in the near term hinges on continued policy support. Our forecast factors in a significant level of such support, even if costs will slightly increase owing to a progressive decline of support that started with the new scheme from 1 Jan 2023 for the most expensive EVs. While new vehicle sales in 2023 are expected to be lower than in 2022, policies should focus not only on the

FIGURE 2.2

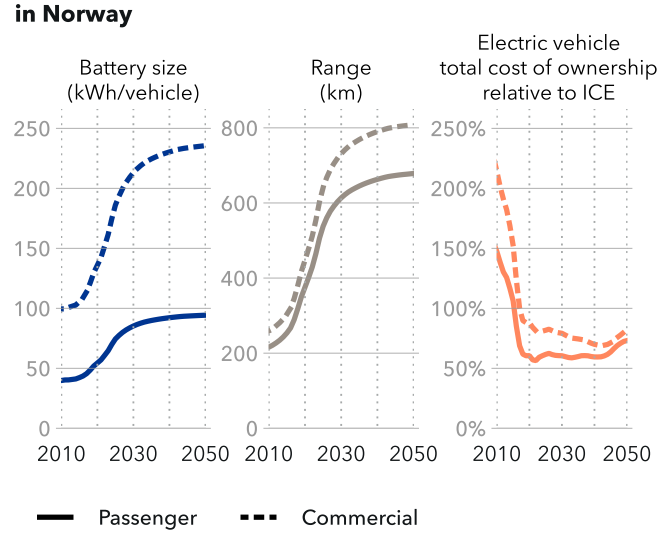
Norway transport sector energy demand by subsector



Historical data source: IEA WEB (2023), SSB (2023)

FIGURE 2.3

Development of key parameters of electric vehicles in Norway



proportion of new vehicle sales being EVs, but also on replacing existing fossil-fuelled vehicles.

EVs will account for 91% of new passenger vehicle sales in Norway in 2025, and 97% by 2030 (Figure 2.4). EV uptake will be somewhat slower for commercial vehicles, which includes everything from smaller trucks and utility vehicles to municipal buses and long-haul heavy road transport. Battery cost and driving range are the key determinants in the competition between batteries and internal combustion engines, and hence on the electrification opportunities of various vehicle segments. We expect 18% of commercial vehicles to continue using a mix of fossil- and bio-based fuels in 2050. We have also increased biofuel use in transport in line with Government's ambition to reduce transport emissions, but not completely fulfilling the goal of 30% by 2030. Biofuel's share in fuelling internal combustion engines increases from 13% in 2022 to 20% in 2030.

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 ratio is not achieved for commercial vehicles until late 2030s (Figure 2.5). Note also that we do not see the total number of vehicles in Norway growing significantly between now and 2030. By the mid-2030s, ridesharing and automation will start to make an impact and will slowly reduce the total number of vehicles to about 3.3 million by 2050, 16% below 2022 levels.

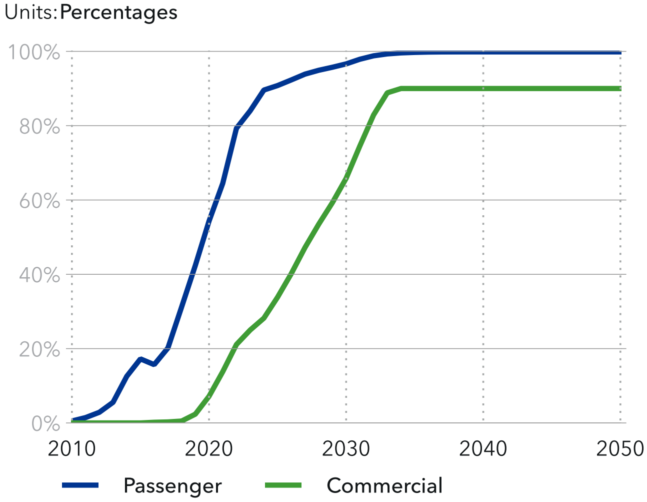
While the total number of vehicles will decline, their utilization will be higher, so neither the related energy services required, nor the total number of kilometres travelled will necessarily reduce. Total kilometrage will increase 20% by mid-century. A similar dynamic is anticipated for commercial vehicles, but the number of vehicles in this segment will rise 17% by 2050. However, even with this vehicle growth and rising overall demand for vehicle-kilometres driven, Norway will not experience a similar growth in energy demand.

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.

FIGURE 2.4

Norway market share of electric vehicles

Units: Percentages

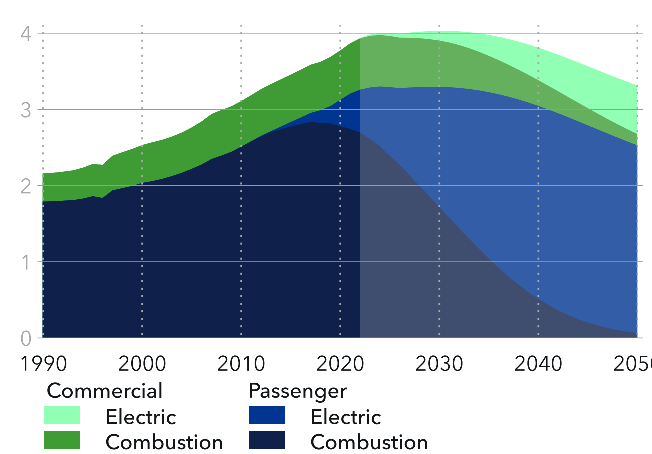


Historical data source: SSB (2023)

FIGURE 2.5

Norway number of road vehicles by type and drivetrain

Units: Million vehicles



Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs.
Historical data source: SSB (2023)

Figure 2.6 shows road transport energy demand nearly halving from 152 PJ in 2022 to 75 PJ in 2050, mainly because of the shift from internal combustion engines to electric drivetrains. The subsector's energy demand for oil declines 89% while demand for energy from electricity grows more than 10-fold. In 2050, 93% 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

Air travel has substantially increased since the pandemic and is expected to return to pre-COVID levels by 2025 with continued growth towards mid-century. The annual number of passenger flights (Figure 2.7) is projected to reach 44 million by 2050, 58% more than pre-pandemic levels.

Fuel use will not grow at the same pace. This is due to energy-efficiency gains from higher load factors and developments in engines and aerodynamics. Currently, 72% of the subsector's energy demand in Norway is for international aviation, which we expect to continue using traditional combustion engine technology. The remaining 28% is for Norwegian domestic aviation, part of which is well-suited for electrification. The government plans to electrify domestic flights by 2040, meaning Norway could be a front-runner globally in the electrification of short-haul flights. Avinor anticipates the possibility of commencing trials for electric aircraft of up to 19 seats on scheduled services from 2027-2028, followed by continued testing for larger aircraft (50–90 seats) (Avinor, 2022).

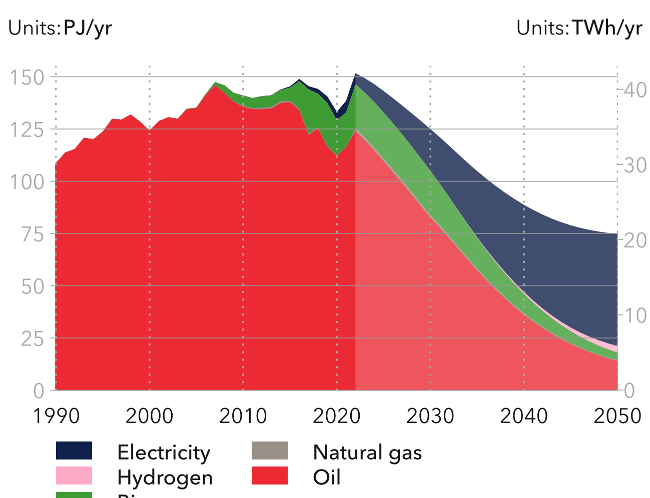
That said, we forecast that sustainable aviation fuels (SAF), particularly biofuel blends, will be the main contributors to aviation emission reductions, especially for international and long-haul flights. Which low-carbon or zero-carbon solution, or mix of fuel solutions, will dominate is not yet known as the alternatives are currently fairly evenly matched on cost and availability. By 2050, 48% (36 PJ) of Norwegian aviation's fuel mix will still depend on oil, but the share of biofuels will increase to 21% (16 PJ). Hydrogen and synthetic low-carbon fuels account for 20% (15 PJ) and electric aviation 11% (9 PJ), as in Figure 2.7.

Maritime

Maritime transport is by far the most energy-efficient mode of transport in terms of energy per tonne-

FIGURE 2.6

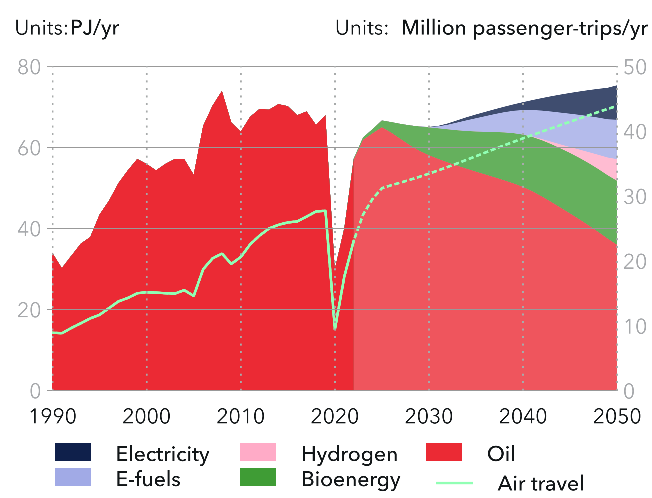
Norway road subsector energy demand by carrier



Natural gas includes LPG. Historical data source: IEA WEB (2023), SSB (2023)

FIGURE 2.7

Norway aviation subsector energy demand by carrier



Historical data source: IEA WEB (2023), SSB (2023)

kilometre. Almost 3% of world final energy demand, including 7% of oil, is consumed by ships today, mainly international cargo shipping. Norwegian energy demand from maritime activities is for national shipping and from international shipping bunkering in Norwegian ports. In 2022, the total demand was 38 PJ, 80% of it for domestic use. There is a fast recovery from the pandemic, and this demand will grow by 2030. By 2050, however, it will be a quarter (24%) less than in 2022.

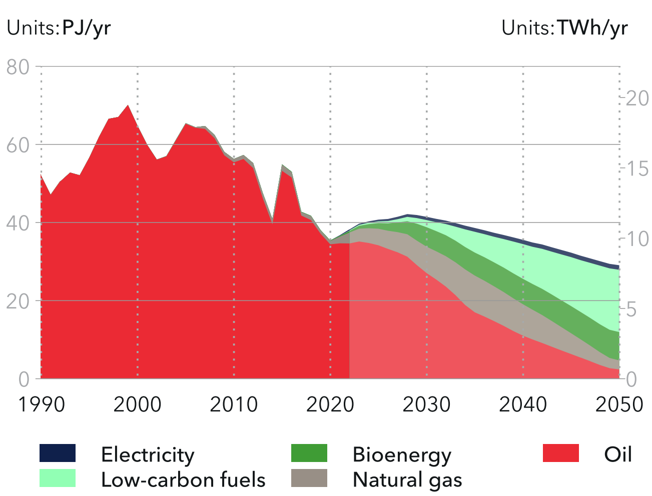
In 2023, the IMO updated its GHG strategy for global shipping, aiming for:

- A reduction in carbon intensity of international shipping by at least 40% by 2030 compared to 2008.
- Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by 2030.
- GHG emissions from international shipping to reach net zero by or around, i.e. close to, 2050.

Globally, a lack of sufficient enforcement mechanisms means that the maritime industry may fall short of these strengthened ambitions. But Norway is on track to meet the decarbonization goals through improved utilization and energy efficiencies combined with massive fuel decarbonization, which will involve switching from fuel oil to gas and ammonia and other low- and zero-carbon fuels. Norway has been at the forefront of adopting liquefied natural gas (LNG) and batteries for hybrid and all-electric solutions. With short-sea shipping and local ferries utilizing a combination of electric propulsion and electric shore power, the energy demand for electricity will increase. Initially though, gas and later low-carbon fuels (ammonia, methanol) will be the main alternative fuel sources for shipping (Figure 2.8).

FIGURE 2.8

Norway maritime subsector energy demand by carrier



Natural gas includes LNG and LPG. Fuel mix given by best-estimate assessment, not model output. Historical data source: IEA WEB (2023), SSB (2023)

Rail

The Norwegian rail subsector consists of all tracked transportation including urban rail transport, such as subways and trams. Presently, 1% (2.6 PJ) of Norway's total transport energy demand is for rail, of which 77% is based on electricity and 23% on oil. Towards 2050, rail will still account for 1% of total transport energy demand, but electricity will rise to 85% of the fuel mix.

2.2 Buildings

In 2022, almost a third (30%) of Norway's energy was consumed by buildings, making it the largest energy demand sector. 78% of building energy demand is supplied by electricity and the rest by biomass, direct heat and, to a lesser extent, oil. We foresee growth in buildings energy demand by 2050, driven by increasing GDP per capita and floor area. This will be offset by increased efficiencies in appliances and heating. We also see energy-efficiency improvements in the structure of buildings, driven by stricter regulations.

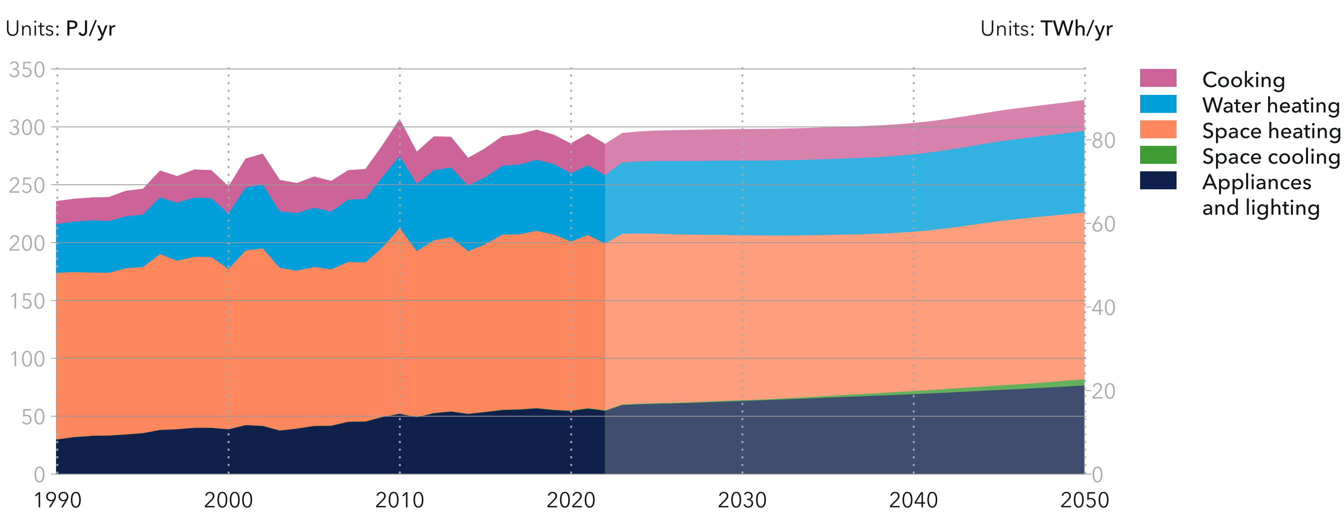
We estimate final energy demand for appliances and lighting, cooking, space cooling, space heating, and water heating. Space and water heating are the sector's largest energy uses, accounting for 50% and 21% of demand, respectively (Figure 2.9).

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, per capita electricity use for appliances and lighting also rises. Norway is at the high end of this relationship, and high-income levels manifest themselves, for example, in home entertainment systems, second refrigerators, or keeping indoor and outdoor lights on all night. However, recent high electricity prices have sharpened focus on energy savings, and with support from ENOVA for household efficiency improvements. We forecast that energy demand for appliances and lighting for both residential and commercial buildings will increase 40% between 2022 and 2050.

Space heating accounts for 50% of all the sector's energy demand and is the segment with the biggest expectation of efficiency gains. Heat energy demand will remain stable over the next decades compared to 2022 (144 PJ), even while heating a growing number of buildings. Measures enabling this transformation will include more insulation; mandatory energy performance certificates and connections to district heating systems; improved automation through digitalization; and greater heating efficiency by phasing out oil-fired heating and widespread use of heat pumps.

FIGURE 2.9

Norway buildings sector energy demand by end use



Historical data source: SSB (2023), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2023)

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 conversion, are accounted for under 'Energy sector own use' (Chapter 3). Manufacturing in our Outlook covers four subsectors:

Construction and 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, including paper, pulp, and print.

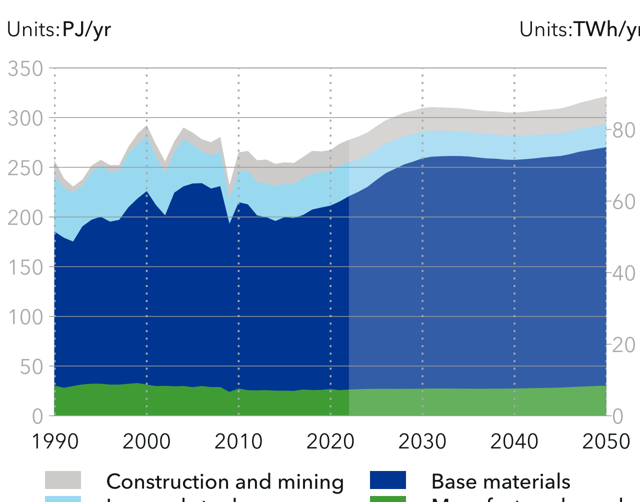
Iron and steel – includes the production of iron and steel.

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

Hydro Norse aluminium production facility at Sundalsøra

FIGURE 2.10

Norway manufacturing energy demand by subsector



Historical data source: IEA WEB (2023), SSB (2023)

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 energy can be found in ETO 2023 (DNV, 2023a). In Norway, the industrial sector and especially the base material subsector is a large contributor to manufacturing sector GDP.

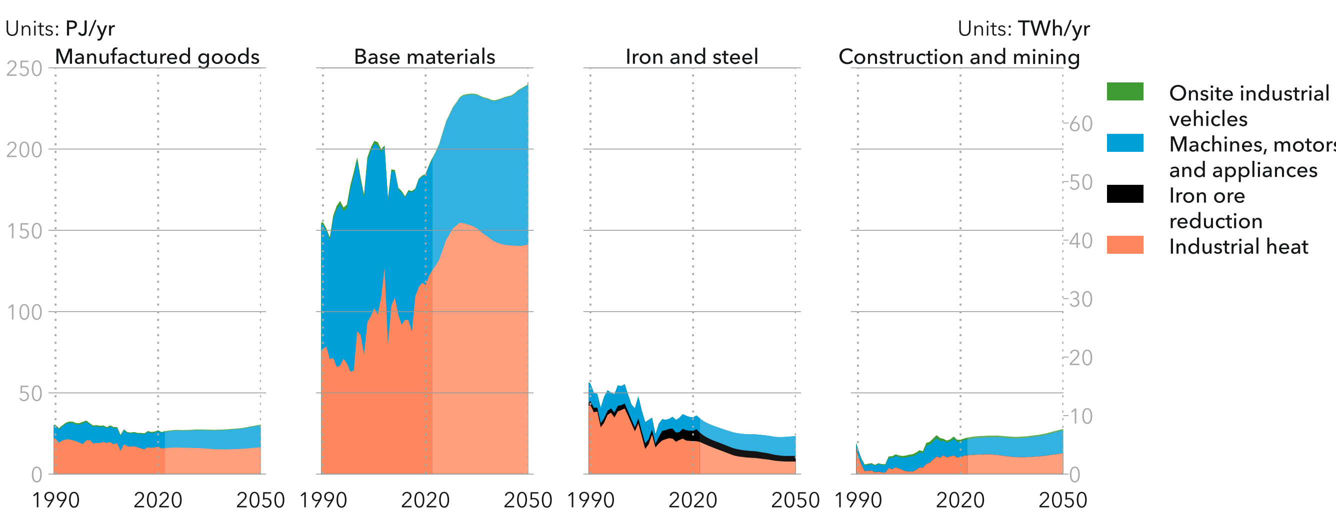
Norway's manufacturing sector consumed 278 PJ in 2022, accounting for 30% of the country's final energy demand. Base materials account for more than two-thirds (70%) of the total manufacturing energy demand (Figure 2.10) and are primarily characterized by production of non-ferrous metals (e.g. aluminium and manganese), and petrochemicals. Energy demand from construction and mining continues to grow towards 2050, while iron and steel decreases. We expect manufacturing energy demand to grow to 322 PJ/yr by 2050.

Energy demand for the base materials subsector was 195 PJ in 2022. It 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 (35%), as in Figure 2.11. Energy demand is expected to grow sharply towards 2030, after which growth eases to 240 PJ in 2050. This overall growth of 23% from 2022 levels is driven largely by increased electricity demand from expanding industrial sectors such as battery manufacturing, aluminium, and hydrogen production. Cement, plastics, and other chemicals' energy use will see an increase towards 2040, before slowly declining towards 2050.

Most of the Norwegian iron and steel subsector's current energy demand is for heat, the rest being for machinery, equipment, and iron ore reduction during steel production (Figure 2.11). Currently 34 PJ (12% of manufacturing energy demand), iron and steel's energy demand will be a third (32%) less in 2050 as coal is phased out and electricity and hydrogen are used more (Figure 2.12). Globally increasing shares of recycled steel in steel production will also contribute

FIGURE 2.11

Norway manufacturing subsectors energy demand by end use



Historical data source: IEA WEB (2023), SSB (2023)

to decreasing the energy demand with reduced need for virgin iron ore.

Energy demand from the manufactured goods subsector has steadily declined since 2000 and represents 10% (26 PJ) of manufacturing demand. We expect this subsector's energy demand to remain steady until the mid-2040s then gradually increase to 30 PJ in 2050. Electricity presently has the largest share in the subsector's energy mix, and we see this growing towards 2050 as, together with hydrogen, it replaces natural gas. A large share (61%) of final energy for manufactured goods is used for heat. Another 38% is used to operate machines, motors, and appliances (MMA). Driven by automation and digitalization, energy demand for MMA in the subsector will grow towards 2050 (Figure 2.11). By then, close to half of the subsector's energy demand will derive from MMA while efficiencies in heating keep energy demand steady around 2022 levels.

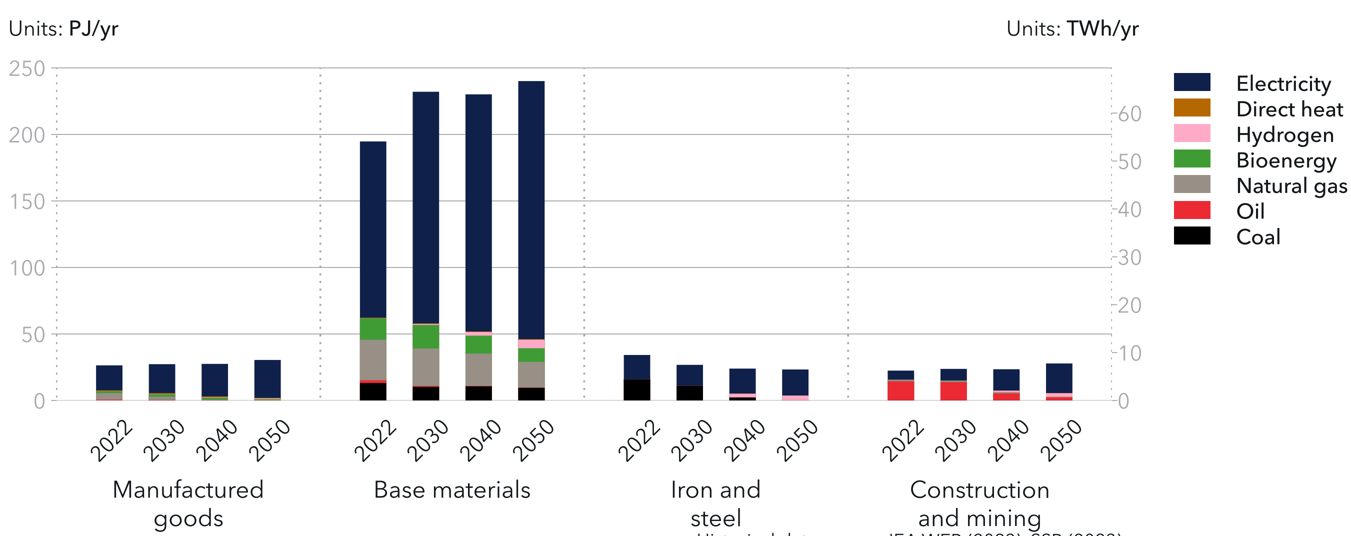
Energy demand for construction and mining was 22 PJ in 2022, slightly increasing towards 2050. Towards 2050 there is a noticeable shift away from oil, replaced by increasing shares of electricity and hydrogen (Figure 2.12).

Most Norwegian construction and mining current energy demand is for heat and MMA, with a small share for onsite industrial vehicles (Figure 2.11).

Changes in Norwegian manufacturing's energy mix depend on technological innovation, resource availability, and on policies and incentives. With 63% of the sector already electrified, further electrification offers only limited efficiency gains, so change between now and 2050 in sourcing energy is most likely in high-heat processes. From the 2030s, we expect decarbonized hydrogen to increasingly replace coal and natural gas as the energy carrier for manufacturing processes. We forecast growth from 0.3% of the energy mix in 2030 to 4% in 2050 for hydrogen. Direct electrification will continue to dominate the manufacturing energy mix, with an 82% share by 2050, driven by increasing adoption of electricity in activities such as battery manufacturing and data centres, and by electrification of processes to mitigate emissions. With the increasing share of electricity and high electricity prices, we have seen and foresee industries struggling with high operational costs, potentially affecting their competitiveness in global markets, or even their continued viability.

FIGURE 2.12

Norway manufacturing subsectors energy demand by end use



Historical data source: IEA WEB (2023), SSB (2023)

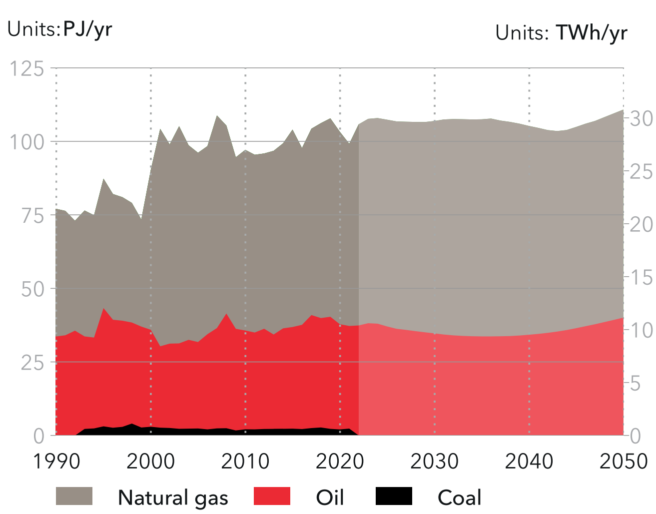
2.4 Non-energy

In 2022, 11% or 106 PJ of primary fossil-fuel consumption was used for non-energy purposes. This category represents the use of coal, oil, and natural gas as industrial feedstock. Much of the energy in the form of natural gas goes to petrochemicals as the largest consumer (65%) 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 2022, with the rest going to making fertilizers, paints, and other chemicals. To align with the EU target of recycling 55% of all plastic packaging by 2030, Norway's rate of plastic recycling needs to improve, necessitating a more comprehensive management of the recycling value chain within the country. The rate of plastic recycling will be boosted by more efficient (and potentially circular) chemical recycling methods supplementing or replacing traditional mechanical recycling. Plastics production will continue to increase to a peak in 2038 to meet growing demand, but then declines towards 2050.

FIGURE 2.13

Norway non-energy demand for energy carriers



Historical data source: IEA WEB (2023)

2.5 Energy demand carriers

By combining energy demand for the sectors covered, we forecast Norway's final energy demand by energy carrier (Figure 2.14). 'Final' here means energy delivered to end-use sectors. It excludes energy losses and energy sector own use in power stations, oilfields, refineries, pipelines, and so on.

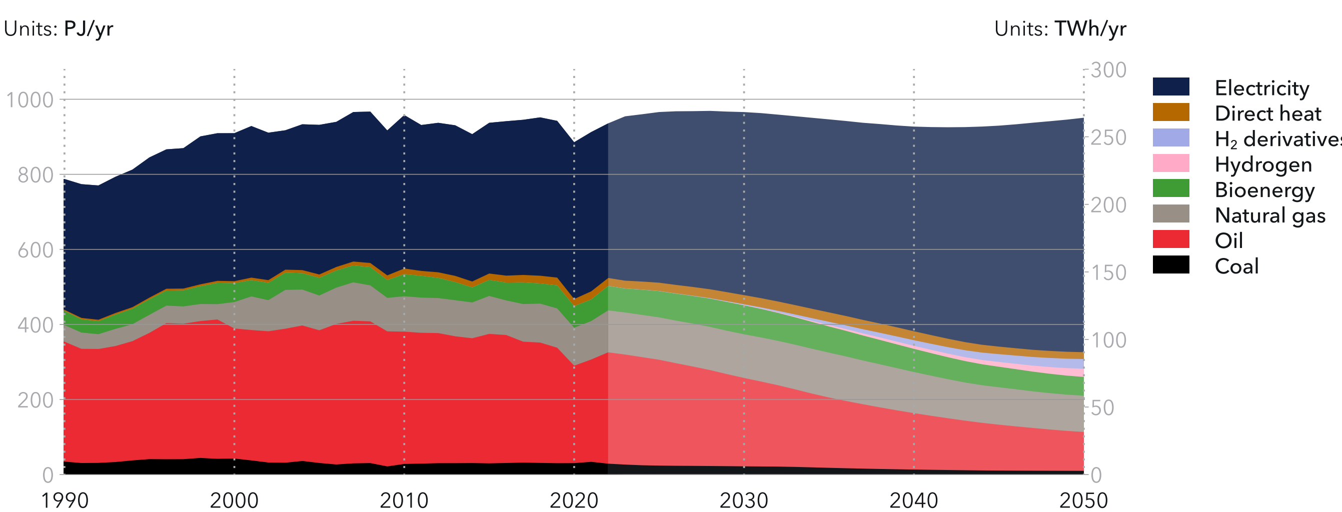
Even for Norway, with one of the world's most renewable energy-based power systems, the ongoing transition will further increase the share of electricity in final energy demand. In 2022, electricity represented 44% (412 PJ) of the country's final energy use. In 2050, it will account for 66% (625 PJ). Cheap renewables, technological advances, and policy are together driving steady electrification of energy demand. Onshore wind, limited-scale solar PV, and (eventually) offshore wind backed by policy, will support growth in demand for electricity for domestic use, and for export, which will account for a rising 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. We foresee electricity increasingly replacing 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.

Cheap renewables, technological advances, and policy are together driving steady electrification of energy demand.

FIGURE 2.14

Norway final energy demand by carrier



Historical data source: IEA WEB (2023)

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.

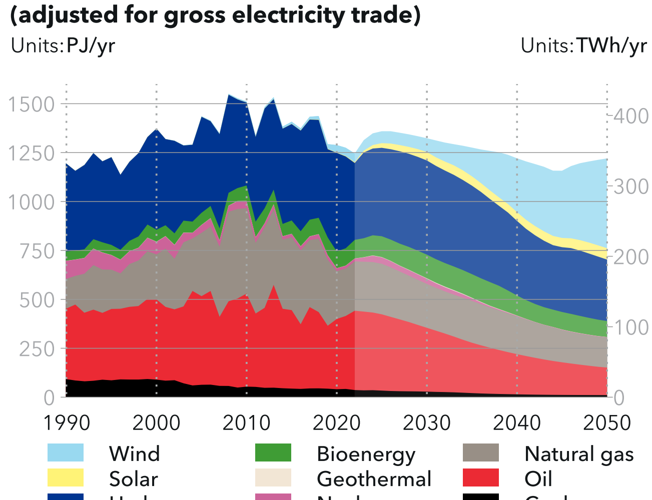
The global energy mix is also changing rapidly. For Norway, this creates challenges for continued fossil-energy export but opens opportunities to supply low-carbon electricity and hydrogen to Europe, mainly through existing hydropower and the future expansion of offshore wind.

Primary energy supply is the total amount of energy needed to meet energy demand. Figure 3.1 illustrates Norway's historical and projected energy consumption originating from diverse primary energy sources, considering gross electricity and hydrogen trade. The figure shows that the country's primary energy supply declined by over 10% from 2018 to 2019, reaching 1,220 PJ, and we anticipate it will remain relatively stable until mid-century.

In addition to its domestic consumption, Norway exports substantial amounts of energy, mainly oil and gas, as described in Chapter 4. The country 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 increasing in Europe. The flow to and from Norway will thus impact the Norwegian grid mix, which is shown in Figure 3.1 as including electricity production from, for instance, nuclear, as part of the European grid mix.

FIGURE 3.1

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



Adjusted for gross electricity trade, using average European electricity mix
Historical data source: IEA WEB (2023), SSB (2023)

> Apart from exceptionally dry years, the annual balance has traditionally been a net export, which will change in the future

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. By 2050, renewable primary-energy supply will represent 76% of the domestic energy mix, up from the 44% in 2022.

Thanks to the aggressive adoption of EVs in Norway, and to a certain extent in the rest of Europe, primary oil use will reduce 3.8% year on year in Norway. To counteract this reduction in oil use in transport and other sectors such as oil and gas production, primary energy from wind will grow 9% year on year from 45 PJ in 2022 to 460 PJ in 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 2022, from 325 PJ to 311 PJ, with spikes and troughs between. While historical highs saw numbers up to 396 PJ in 2007, demand was at an unprecedented low-point of 276 in 2020 due to the COVID-19 pandemic. As Figure 3.2 shows, we forecast a 66% drop in domestic oil demand, relative to 2022, with a decrease to about 107 PJ towards mid-century. This decline is similar to developments projected for Europe, where we forecast a reduction of 64% compared with 2022. On a global scale, we forecast oil demand to decline 38% compared to the current consumption level by 2050.

More than three-quarters (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 2022 when it started to decline. In 2022, about 57% of the transport sector's 216 PJ of oil demand came from road vehicles. Going forward, passenger vehicles segment will experience the most extensive conversion to electricity, boosted by Norway's leading position in electric mobility. The decline in oil demand from commercial vehicles will be slower. By 2050, the road subsector's oil demand will have reduced by almost 89% compared with 2022, a decline like that in Europe (-84%).

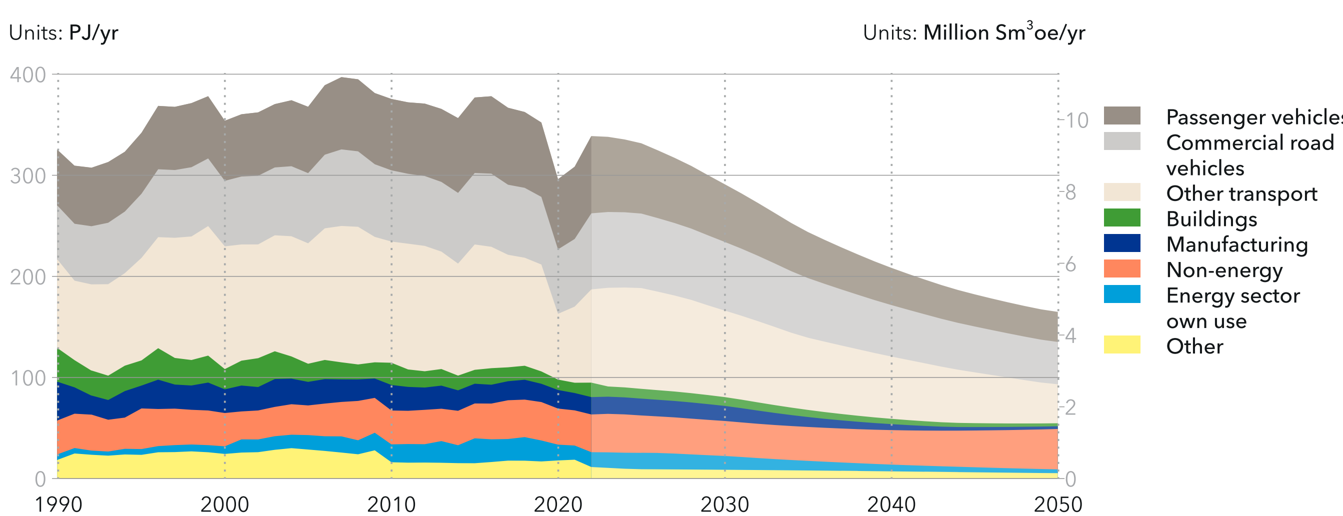
Maritime will see an even faster reduction, declining to less than 6% of current oil demand by 2050, from 35 to 2 PJ. The strong growth of alternative fuels for shipping, such as electricity, natural gas, and low- and zero-carbon fuels in combination with changes in maritime energy demand will drive the reduction. Aviation's dependence on oil will be more protracted, we project its oil demand will increase by 8% in the next two to three years before it declines to 36 PJ in 2050, 40% less than in 2022. In aviation, synthetic fuels, biofuels, and other low- and zero-carbon fuels, rather than electrification, will drive decarbonization.

The share of oil in energy demand for buildings will decline from 5% in 2022 to 1% in 2050, representing an absolute reduction from 14 to 3 PJ. The primary application of oil in buildings, specifically for space and water heating, is expected to transition toward electrification.

A very similar outcome is expected in manufacturing. Here, the current 6% share will decline 9-fold to represent

FIGURE 3.2

Norway oil demand by sector

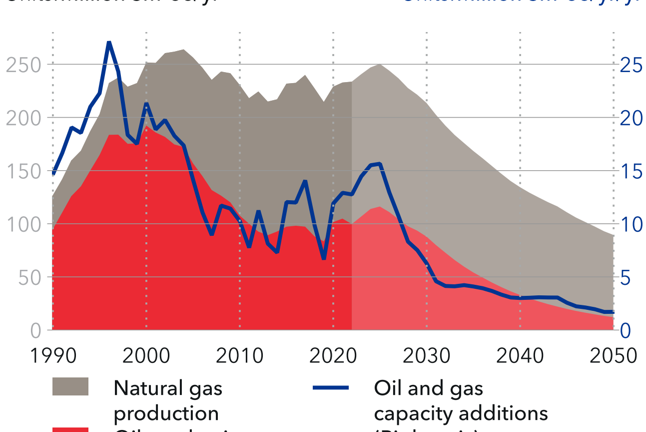


Does not include natural gas liquids and bioliquids. Historical data source: IEA WEB (2023), SSB (2023)

about 0.8% of oil demand by 2050. The main driver here is less oil use in industrial heat processes where it is replaced by electricity.

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 (2023), IEA WEB (2023)

Production increases are expected over the next two to 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 downward pressure on oil prices, and relatively few new discoveries are expected to be developed. Reduced oil demand will make it less attractive for the industry to expand production into challenging environments, such as deep water and/or Arctic locations.

Globally, as oil fields are depleting faster than global demand for oil declines, continued investment in new capacity is expected. But incoming capacity additions in Norway will not replace the capacity being shut down, because no new oil fields will be developed after 2030. That said, oil production in Norway in 2050 will be at about 0.2 Mbpd (see Figure 3.3) which is still twice more 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 175 EJ to 149 EJ by 2050, a 15% reduction. By mid-century globally, natural gas will overtake oil in primary energy consumption. In Europe, which receives almost all of Norway's gas export, consumption will gradually decline to 61% of the 2022 level in 2050, aided by the natural gas supply choke brought on by Russia's invasion of Ukraine.

Overall natural gas demand in Norway will only reduce 39% towards mid-century from 2022 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 2010 at about 320 PJ. Natural gas consumption will continue for a few more years before declining steadily through to 2050, reaching 216 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 on offshore installations.

But, despite this 60% reduction in own use, the natural gas demand for hydrogen production will somewhat counteract the demand reduction in Norway. By 2042, 133 PJ/year of natural gas will be consumed to produce hydrogen in Norway, representing a 39% share of total demand for the gas.

The second largest consumption of natural gas is as petrochemical feedstock, representing 20% in 2022, a share that is expected to grow to 33% 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 9% 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.

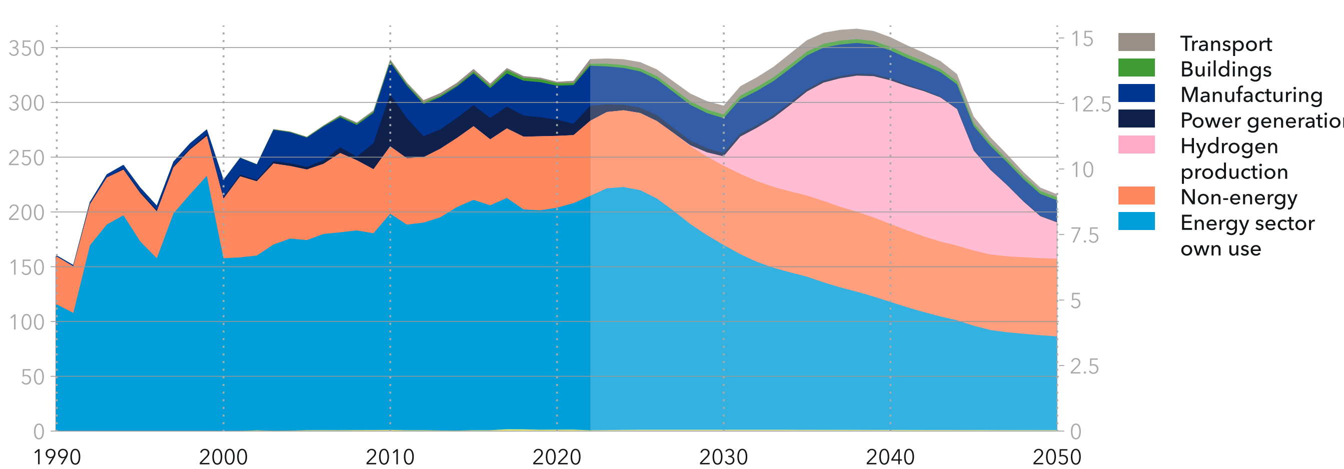
On a global scale, gas production will remain stable and move to new locations around the world. In terms of absolute output, the three dominant players in 2020 were North East Eurasia, the Middle East and North Africa, and North America. But the Ukraine war has led

FIGURE 3.4

Norway natural gas demand by sector

Units: PJ/yr

Units: Billion Sm^3/yr



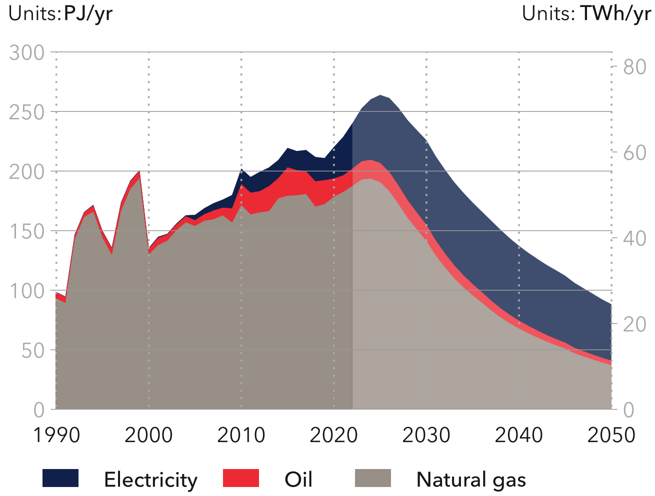
Includes natural gas liquids. Historical data source: IEA WEB (2023), SSB (2023) to severe curtailment of North East Eurasian natural gas supply, at least in the period up to 2030.

Figure 3.3 shows Norway's natural gas production in 2022 was about 134 Bn m^3 and it is projected to be about the same until 2026 before it declines to 77 Bn m^3 in 2050. Throughout this time span, Norway will maintain an export share of around 95%. We forecast that Norway's LNG liquefaction capacity, currently at around 5 Mt per year, will remain the same.

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 by 80% as gas-fired onsite power production on offshore installations is replaced by electricity from the mainland or from offshore wind (Figure 3.5). 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 54% share of electricity in the supply of NCS energy needs (Figure 3.5).

FIGURE 3.5

Norwegian continental shelf energy demand by carrier



Historical data source: IEA WEB (2023), SSB (2023)

3.3 Electricity

Electricity demand

In 2022, Norway's annual electricity consumption per person was 25.8 MWh. This is one of the highest per capita electricity consumptions in the world, thanks to Norway's electricity-intensive industries such as aluminium production; high penetration of electricity use in heating of residential and commercial buildings and in powering the oil and gas extraction industry; and the country's leading role in the electrification of road and marine transportation. Ample supply of relatively cheap electricity from hydropower plants have been the main contributor to this development. This per capita consumption is set to increase almost 2.5-fold to 2050, with explosive growth in new demand categories.

Total electricity demand in Norway, including net electricity imports (gross imports minus gross exports in every year) is expected to increase from 145 TWh in 2022 to 373 TWh in 2050. Four sectors will spur this growth: hydrogen production, transport, oil and gas production, and to a lesser extent, space cooling.

We will see the electrification of all transport segments, but first and foremost road vehicles, with 15 TWh/yr consumed by 2.5 million passenger and 640,000 commercial EVs in 2050. Electric short-haul flights will consume 2.4 TWh in 2050. As hydrogen and e-fuels start to replace gas in manufacturing and marine gas oil in transport, respectively, from the late 2020s, electricity consumption from electrolysis plants will grow significantly, reaching 1.6 TWh/yr in 2040 and 136 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 18 TWh in the mid-2030s then decline in line with reduced activity towards 2050 while representing 54% of segment energy demand.

Total electricity use in buildings will increase about 28%, from 65 to 83 TWh from 2022 to 2050. Growth in provision of heat (space, water, and cooking) is expected to be only 21% due to more efficient heat pumps, better insulation, and a warming climate.

Meanwhile, the appliances and lighting segment will grow by about 40%, 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 bring higher summer temperatures, which results in higher electricity demand for space cooling in Norway. From 91 GWh consumed in 2022, space cooling electricity demand will grow to about 1.5 TWh in 2050.

Electricity supply

Historically, Norway's electricity supply has been dominated by hydropower (Figure 3.7), and up to 2005, over 99% of domestic electricity was supplied by this source. At that point, other technologies started to make inroads, such that in 2022 non-hydro electricity generation was 14%, split as 8% from wind, 1.5% from gas, 0.3% from biomass and 0.2% each from coal and solar PV. The rest comes from imported electricity.

In the future, we foresee an even more diverse production mix. Grid-connected electricity will triple from 2022 to 2050 while hydropower generation grows by only 16%. The remainder of the gap will be closed mostly by wind. Onshore wind has seen significant growth. However, public and in some cases judicial opposition (Supreme Court of Norway, 2021) 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 6% solar PV, <0.5% gas, 10% onshore wind and 42% offshore wind (mostly exported). The remaining 39% will be hydropower-based. While stand-alone Li-ion battery storage including vehicle-to-grid supplies only 2% of the electricity in 2050, it also plays an important part in balancing demand and supply in Norway in the future.

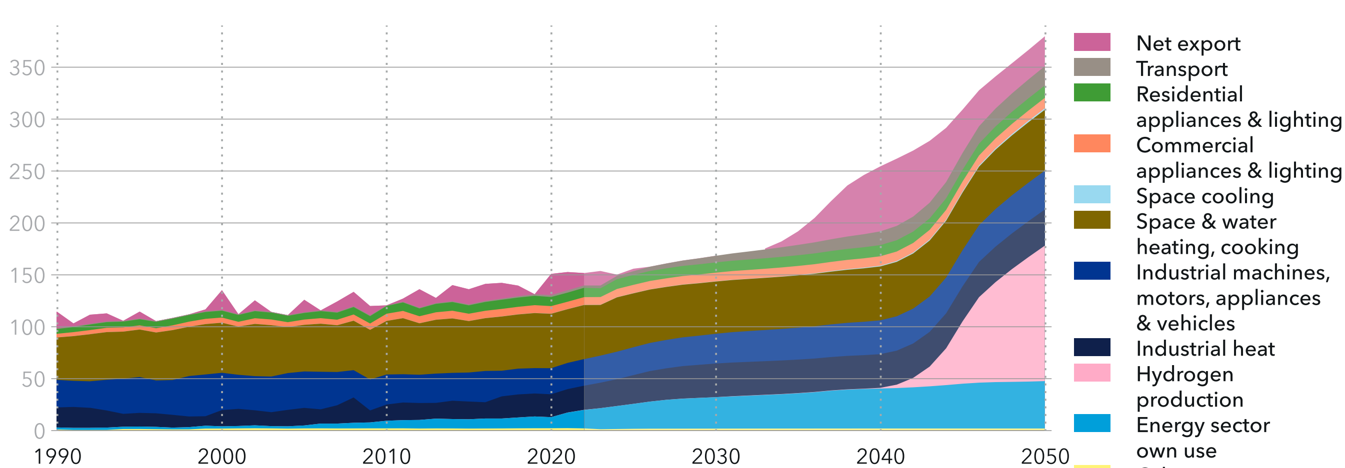
Electricity generation

Although it is possible to control how much power is generated from hydropower stations, their operations

FIGURE 3.6

Norway electricity demand by sector

Units: TWh/yr



Historical data source: SSB (2023), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2023) 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, 2023), 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 the 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 the 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.

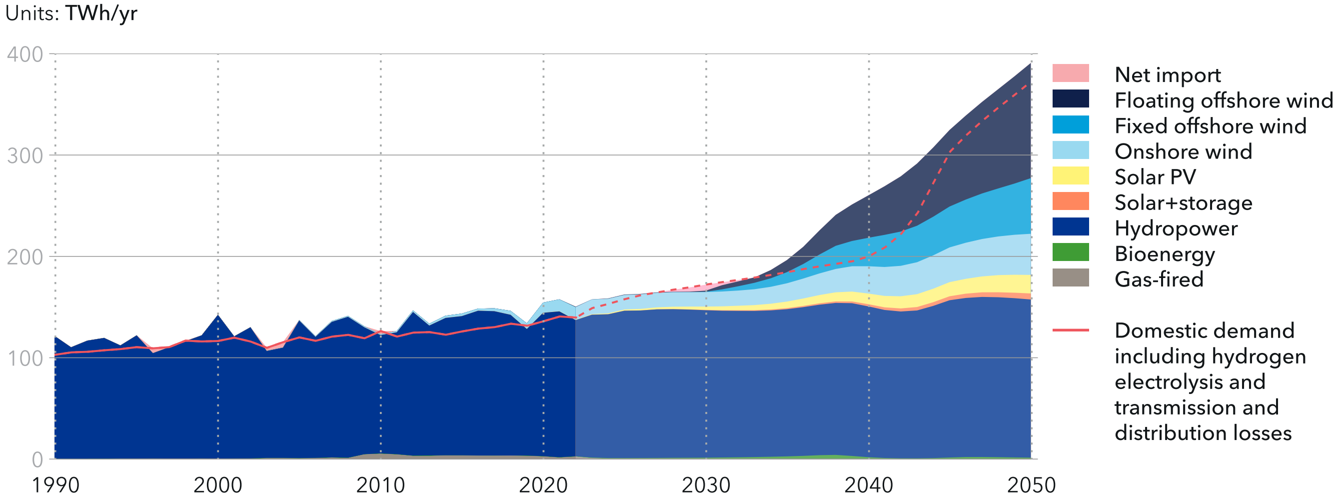
The ETO's power market operates on an hourly scale and finds the market equilibrium at each hour by adding up the potential supply and demand at different prices and calculating the price at which total supply equals total demand.

The graphic overleaf summarizes the operation of our model's power-market module, and the dynamics of power supply and demand over the same typical winter week in 2028, 2038, and 2048. Our hourly model ignores any grid constraints, meaning that within the model any demand can be met by any generator in the country or region, regardless of location. For Norway, we do not distinguish between the bidding zones and treat the whole country as a single market.

FIGURE 3.7

Grid-connected electricity generation by power station type

Units: TWh/yr



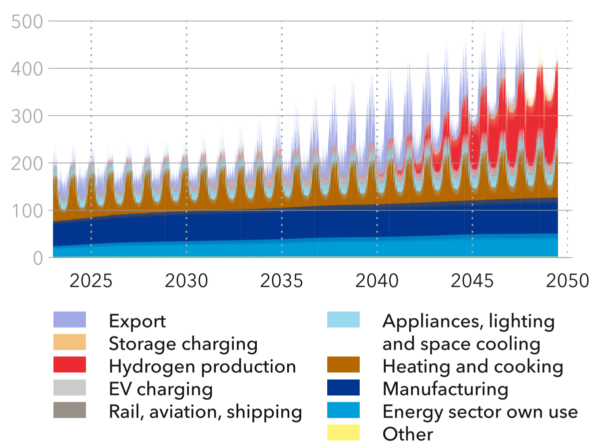
Historical data source: IEA WEB (2023), SSB (2023)

Norway's hourly supply and demand

The Norwegian power system will transform from being a net importer of power in the near term to become a net exporter, with offshore wind capacity build-out, and supply and demand balanced through grid-connected electrolysers. We illustrate this dramatic change by forecasting hourly demand for the same winter week in three different years (2028, 2038, 2048).

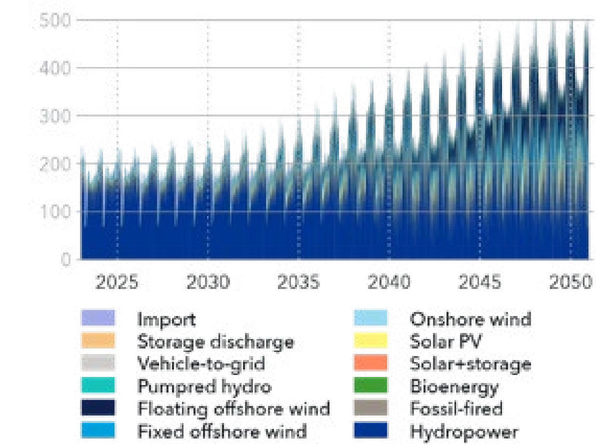
Norway electricity demand by segment; 2023-2050

Units: TWh/yr (daily readings)



Norway electricity supply by source; 2023-2050

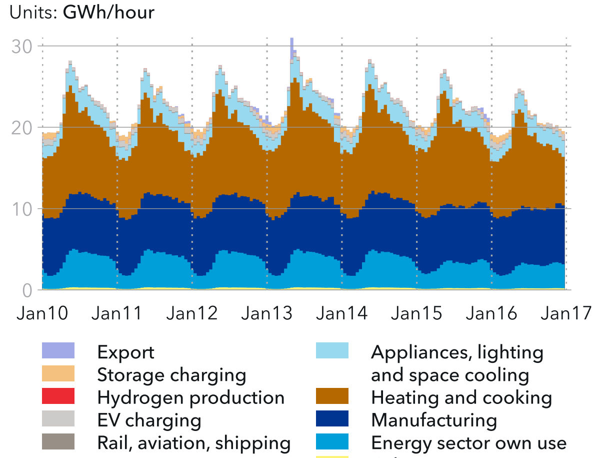
Units:TWh/yr (daily readings)



2023 – 2050: Figure above shows the evolution of demand and supply in the Norwegian power system, cumulated daily and presented annually. The peak demand and supply starts increasing considerably from 2035, with capacity build-out of offshore wind in the North Sea, in conjunction with Norway's ability to export this cheap power. From the 2040s, we forecast considerable amounts of grid-connected power being used to produce hydrogen, again for export purposes.

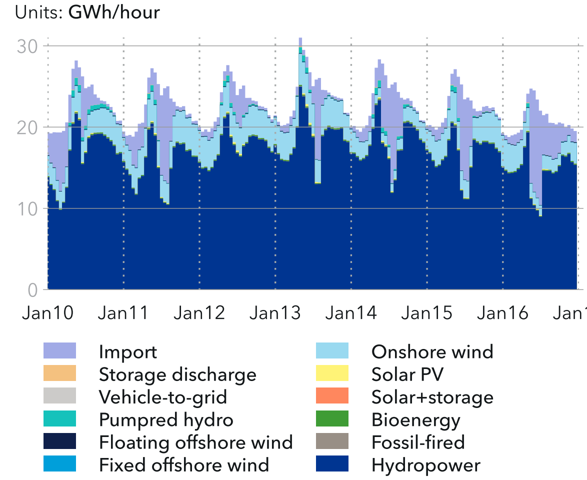
Norway electricity demand by segment; week 2; 2028

Units: GWh/hour



Norway electricity supply by source; week 2; 2028

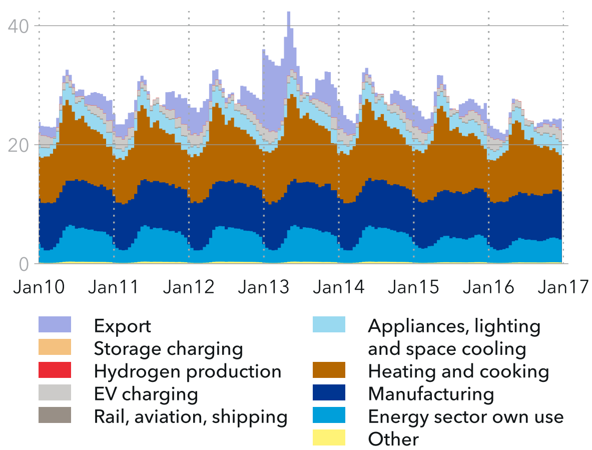
Units: GWh/hour



2028: Norway is a net electricity importer in every single hour of this week due to limited offshore wind capacity build-out, and high winter heating demand, which peaks during mid-day. In the critical evening hours, there is considerable power import into Norway as the system faces inflexible and sustained demand. Limited capacity and storage build-out hinders adequacy; and given the lower prices in the rest of the European market compared to the marginal price of hydropower, adequacy is achieved through electricity imports.

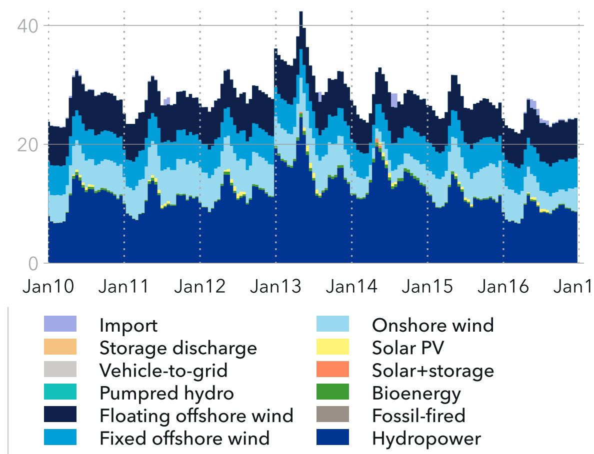
Norway electricity demand by segment; week 2; 2038

Units: GWh/hour



Norway electricity supply by source; week 2; 2038

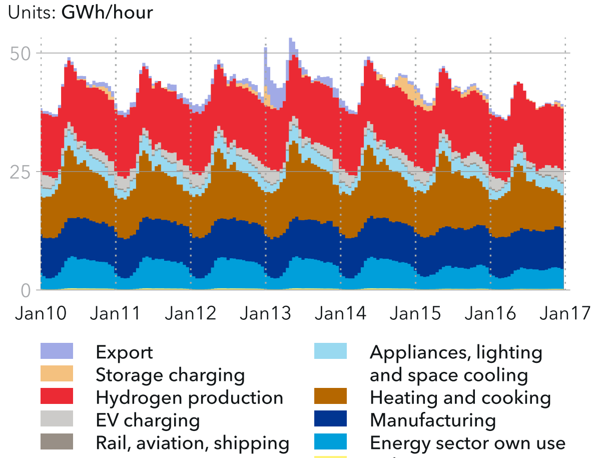
Units: GWh/hour



2038: There is a complete reversal of the supply and demand situation found in 2028, and Norway is a net electricity exporter, even in winter by 2038. The fixed and floating offshore wind capacity build-out ensures that there is spare power to be exported during 90% of the hours in this week, due to the price advantage offshore wind has, given very low marginal costs. Floating offshore wind has also overtaken onshore wind power generation because of higher capacity factors in the North Sea. Due to the possibility of export, curtailment of wind power is quite minimal, even without the presence of significant storage capacity in the grid.

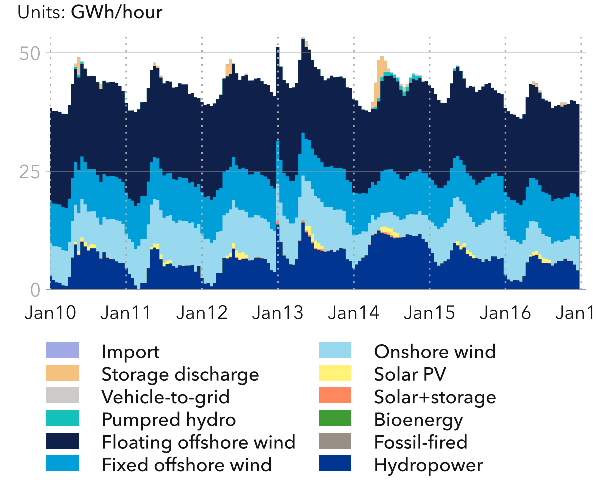
Norway electricity demand by segment; week 2; 2048

Units: GWh/hour



Norway electricity supply by source; week 2; 2048

Units: GWh/hour



2048: Power supply and demand are completely transformed compared with 2028 and 2038 by 2048. Grid-connected electrolysers overtake heating demand, even in winter, throughout the week. While Norway exports power during a similar number of hours as in 2038, exports are reduced due to the sustained demand for power from electrolysers. The presence of both dedicated grid-connected storage and vehicle-to-grid power are critical, as they provide power during mid-day, peak-demand hours, and hence maintain supply adequacy. During windy periods, when wind power prices are low, the same storage is charged with cheap offshore wind electricity, thus ensuring minimal curtailment.

Capacity developments

Power systems with considerable shares of variable renewable electricity sources (VRES) such as wind and solar face the 'capture price' problem. That is, since these technologies have near-zero marginal running costs, electricity prices tend towards zero during hours when electricity production from wind and solar are significant and plentiful. As more and more solar and wind enter the power system, the number of hours where electricity prices are zero tend to increase. This implies that the electricity prices these sources can capture, or demand tends to be low, thus leading to developers being uninterested in investing in these sources when revenue prospects diminish.

But we do not foresee this being a showstopper for Norway. The reason for this is that hydropower and pumped hydro, which have higher and stable variable costs, will counteract the variability of wind and solar and set the price in combination with the European electricity market. In 2050, hydropower will still have a non-trivial 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, hydropower. In 2049, we foresee offshore wind capacity, both grid-connected and off-grid, overtaking hydropower capacity in Norway. We forecast a higher uptake of floating offshore wind (FOW) compared with fixed offshore wind, despite the lower levelized cost of the latter. The main reason is 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.

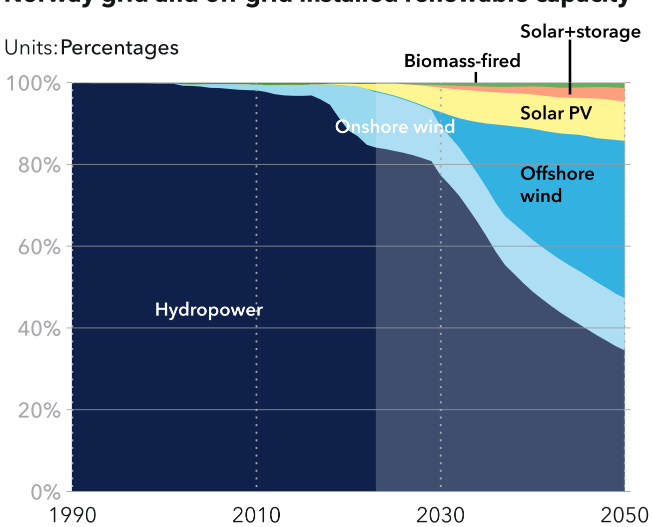
Our hourly comparative analysis of Norwegian and European power systems indicates that up to 50% of annual output from Norwegian FOW can be exported to Europe. Most of the rest is used to produce electrolysis-based green hydrogen, also for export purposes.

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

FIGURE 3.8

Norway grid and off-grid installed renewable capacity

Units: Percentages



Historical data source: IEA (2023); GlobalData (2023)

FIGURE 3.9

Norway capacity additions becoming operational by power station type

Units: GW/yr

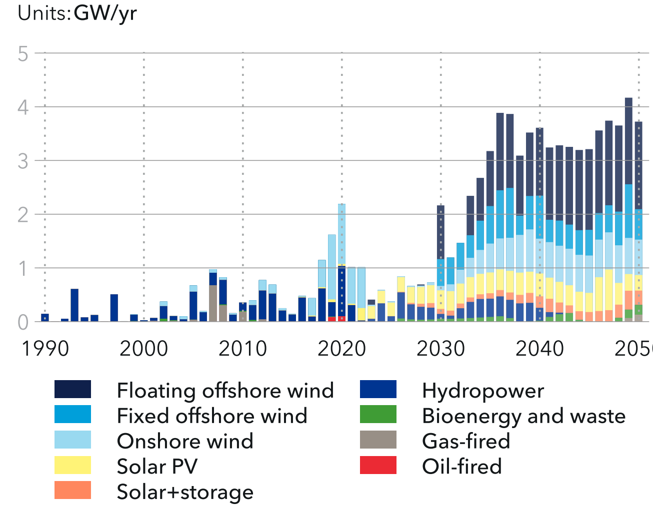


TABLE 3.1
Installed capacity and the annual average capacity factor of power stations

	Installed capacity (GW) by the end of year				Capacity factor			
	2022	2030	2040	2050	2022	2030	2040	2050
Hydropower	34.1	35.9	38.7	38.8	45%	46%	44%	46%
Onshore wind	5.5	5.5	9.9	14.3	29%	30%	32%	33%
Floating offshore wind	0.01	1.1	10.1	25.2	50%	50%	51%	53%
Fixed offshore wind	0.0	0.5	6.8	12.2		49%	49%	52%
Solar PV	0.4	2.7	6.6	10.8	15%	15%	19%	20%
Solar+storage	0.0	0.3	1.5	3.7		15%	18%	19%
Thermal	1.0	1.1	0.9	1.7	28%-43%	5%-53%	8%-38%	2%-35%
Onshore wind onshore off-grid capacity for hydrogen production	0.05	0.05	0.1	0.1				
Fixed offshore wind off-grid capacity for hydrogen production	0.00	0.00	3.3	4.0				
Floating offshore wind off-grid capacity for hydrogen production	0.00	0.00	1.4	2.0				

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.

After these power stations come online, investments will slow down in the mid-2020s. The 2030s will be the last decade with significant hydropower additions. With almost full exploitation of hydropower with flexibility and ramping up/down capability already by 2023, the capacity additions in the future will be of smaller plants or upgrades in their power capacity capable of generating output over short periods, but not more energy per year.

From the mid-2020s, solar PV additions take place, motivated by electricity deficits during mid-day peaks and the desire for local energy security. After 2040, we foresee the majority of new capacity to be in wind power, dominated by a large share of FOW, to the point where Norway will boast 9% 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 1.4 GW of pumped hydro storage and 36.5 GW of stand-alone Li-ion battery storage in the Norwegian electricity grid in 2050.

Hydropower

With more than 1,769 plants (Energifaktanorge, 2023), 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 87 TWh across the country (Energifaktanorge, 2023). 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.

Hydropower will continue to play a central role in Norway's electricity system. However, the existing 34 GW installed capacity will expand only slightly before 2050, to reach 39 GW. Although the technical potential for Norwegian hydropower is estimated to be around 46 GW (NVE, 2011; Cleveland & Morris, 2013), we predict capacity additions to halt well before that owing to factors related to preservation of habitats, 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 the 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 2022, the total installed capacity was more than 5.5 GW, almost all in the form of onshore projects, with less than 100 MW of floating offshore wind projects. However, most onshore wind turbines are on the southwest, west, and north shores. Favourable wind conditions exceeding 1,000 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

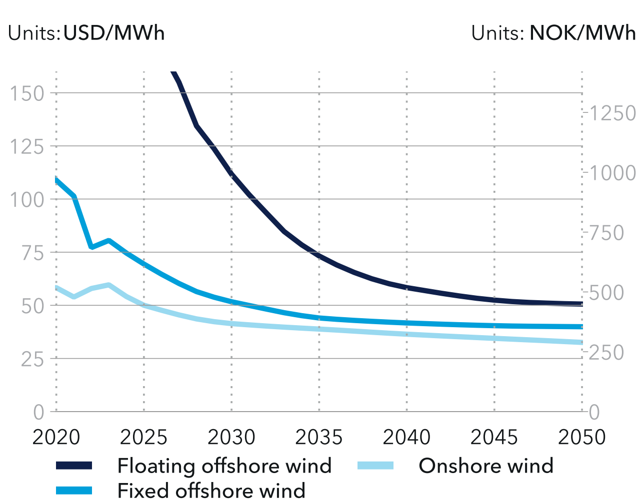
preserve untouched landscapes and wilderness. Unlike many countries with significant fossil shares in their power mixes and where wind investments are regarded as essential for decarbonizing and lowering the cost of electricity generation, the Norwegian wind industry enjoys less public support. The public is also wary of arguments for building excess wind capacity for export to the European continent, 'incorrectly' fearing it may cause domestic electricity prices to increase.

Given that mitigating climate change also preserves natural habitats, we predict that growth in Norway's wind capacity will be mostly offshore, constituting 81% of 210 TWh wind-based generation in 2050. This is despite the headwinds and challenges the global offshore wind industry has faced in the last 12 months in many mature economies such as the US, the UK, and other European countries (DNV, 2023a).

As seen in Figure 3.10, the increase in levelized cost of energy (LCOE) for wind power also impacted the industry in Norway, with LCOE increases in 2022 and 2023 after almost a decade of continuous reductions. But some reasons for the cost increases are indeed temporary, such as supply-chain snarls and labour shortages and are due a course-correction by 2030.

FIGURE 3.10

Norway levelized cost of wind energy



2022 international USD. Exchange rate as per OECD 2022, 8.9 NOK/USD
Historical data source: GlobalData (2023), DNV analysis

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.

By 2030, the global volumetric learning effect would halve the LCOE of FOW and reduce the LCOE of fixed offshore wind by a third (33%) (Figure 3.10). The always higher non-turbine and installation costs of FOW imply that even in 2050, the LCOE of FOW will be about 27% higher than that of fixed offshore wind. 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. So, the drastic cost reductions to be expected in offshore wind are one of the major drivers of the uptake of wind power in Norway. Regardless, the success of offshore wind also hinges upon it sharing the ocean space with other domains and uses, such as fisheries, aquaculture, shipping, and recreation going into the future (DNV, 2022).

Another major 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 an additional driver for offshore wind. With the electricity consumed by offshore platforms increasing to cover up to 54% of their energy demand in the coming 30 years, FOW 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 FOW operators from exports will exceed revenues from the domestic market.

Solar PV

We predict installed capacity to increase 36-fold from 420 MW in 2022 to 15 GW in 2050, as seen in Figure 3.11. We include two categories for solar: solar PV panels connected to grid from utility-scale or rooftop arrays, and 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 including storage capacity as integral by mid-century.

Despite the low-capacity factors reported for solar+storage in Table 3.1, the combination has its uses. While capacity factors are useful in determining how much a generation of 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 can provide stored electricity in periods of high demand, especially in the bridging period of the late 2020s and early 2030s, when the Norwegian power system is transitioning to a wind-dominated system.

Despite this usefulness, stand-alone solar PV will always be installed more than solar+storage. But in the decade leading to 2040, the gap between the two will widen. 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 utility-scale solar PV will remain marginal, with the main use of solar PV panels being in rooftop installations as supplementary power. The main disadvantage of solar PV is low solar irradiation in Norway.

Hydrogen

Hydrogen is usually produced either through the electrolytic breakdown of water into hydrogen and oxygen or via steam methane reforming (SMR) natural gas. SMR is currently the preferred option due to the existing SMR infrastructure.

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.

FIGURE 3.11

Norway solar capacity additions and installed capacity

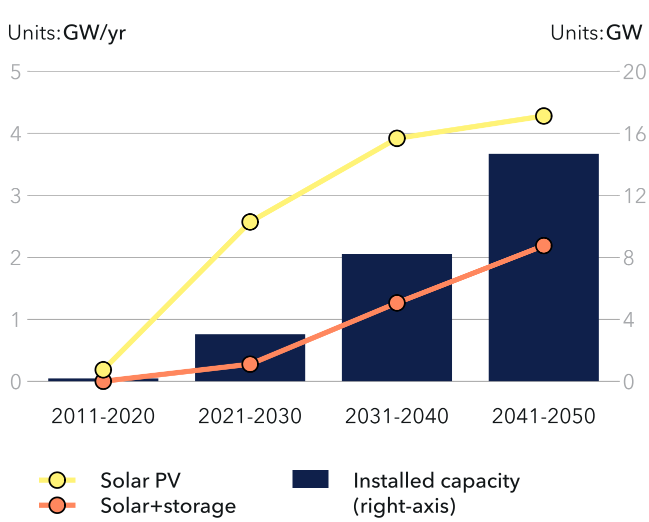
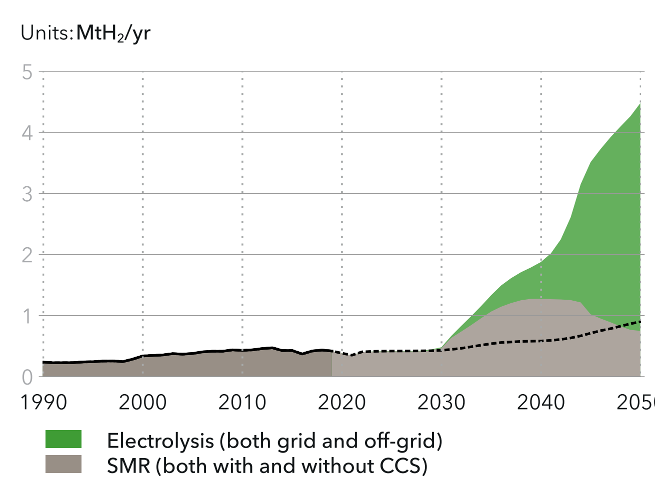


FIGURE 3.12

Norway hydrogen production by production route



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

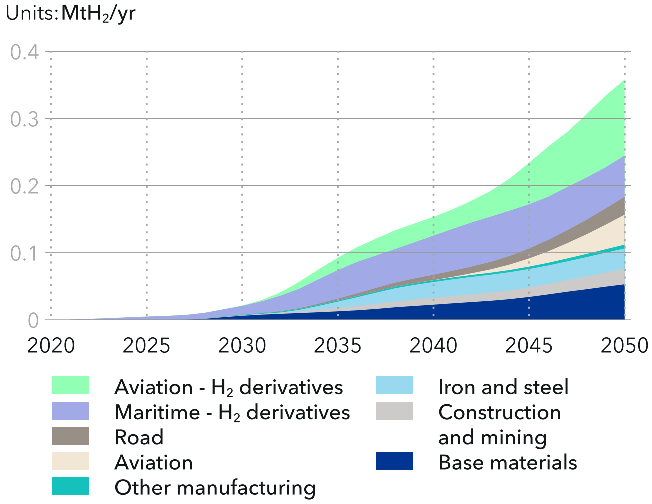
Hydrogen supplied via electrolysis is seen as one of many flexibility options to take advantage of low power prices when production from VRES is plentiful, and demand is lacking, as also shown in our hourly power demand supply infographic. However, there are many other markets for such cheap electricity; for example, for 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 2030s. The European demand for low-carbon hydrogen coupled with existing natural gas pipeline infrastructure which may be repurposed for transporting hydrogen, will incentivize blue hydrogen production in Norway.

Hydrogen supplied via electrolysis is seen as one of many flexibility options to take advantage of low power prices.

FIGURE 3.13

Norway hydrogen demand as energy carrier by sector

Units: MtH_2/yr



With increasingly abundant VRES, electrolysis will start gaining traction from the 2040s, and by mid-century will supply 95% of hydrogen as an energy carrier, and 80% of the total hydrogen production.

We see hydrogen as a likely zero-emission energy carrier for heat applications in manufacturing (Figure 3.13). By mid-century, 13.5 PJ of hydrogen will be used for industrial heat provision in manufacturing, a 7% share. Most of the hydrogen will be used in the 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 2040 onwards but only reach 3 PJ by 2050, representing 4% of road transport energy demand.

Within maritime transport, covered thoroughly in DNV's *Energy Transition Outlook* (2023a) and in our *Maritime companion report* (DNV, 2023c), we expect significant uptake by 2050 of low- and zero-carbon fuel alternatives derived from hydrogen (e.g. ammonia and synthetic fuels). They will be partly implemented in hybrid configurations combining diesel and gas-fuelled propulsion options, and will provide slightly more than 55% of the maritime fuel mix by mid-century. We predict ammonia and synthetic fuels combined will provide 16 PJ/yr of Norway's maritime sector energy demand (Figure 3.13) by then.

Norwegian aviation 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 roles in decarbonizing aviation. After 2030, when infrastructure has developed and costs have declined, we see synthetic fuels and hydrogen starting to replace regular jet fuel and by 2050, 20% (15 PJ) of aviation energy demand is covered by these energy carriers.

4 ENERGY TRADE

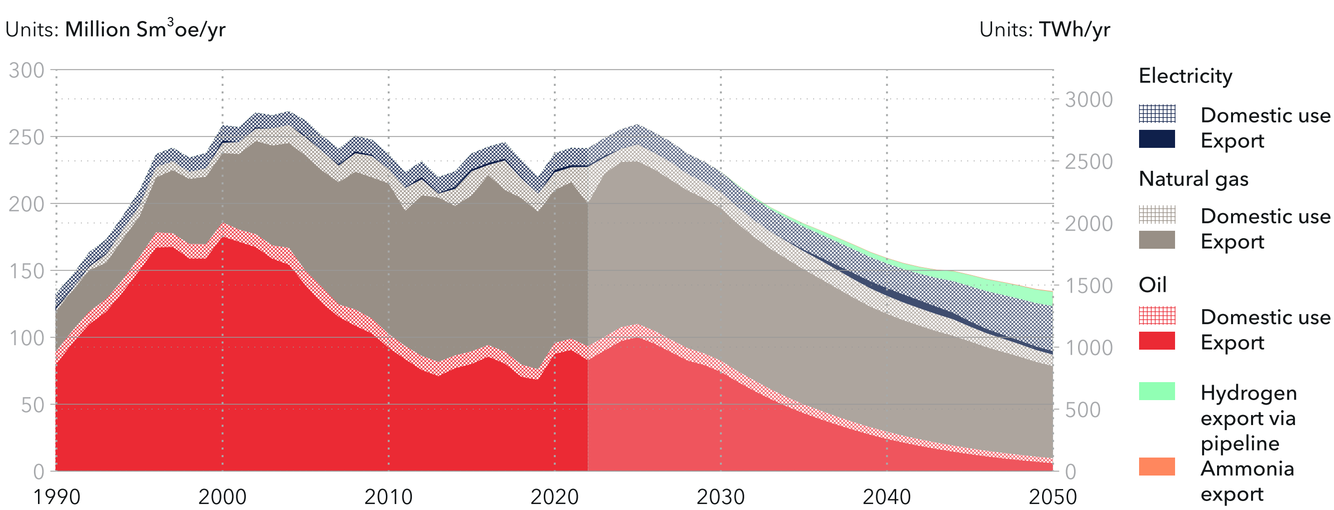
Norway will continue to be a significant net exporter of energy but at progressively lower levels over the next 30 years. This contrasts with the short-term pressure on Norway to increase exports to Europe as it weans itself off Russian fossil fuels.

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. The long-term trend of oil and gas exports will show a steady decline from the middle of this decade (Figure 4.1).

By 2050, oil exports will be 7% of 2022 level, and gas exports 35% lower than in 2022. Electricity and hydrogen exports will be marginal for a few years, but with increasing demand from Europe and power capacity increases, hydrogen and electricity 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 USD 55bn (490bn NOK)/year on average over the last 10 years (SSB, 2023) but grew to an astounding USD 214bn (1900bn NOK) in 2022 (Norsk Petroleum, 2023). Using constant prices, a combined 68% reduction in oil and gas energy export revenue by 2050 will translate into USD 17.5bn (155bn NOK) in annual revenue by then. This figure is one third of the export revenue generated by oil and gas in an average year, and 8% compared with the record year of 2022. However, there will be an increasing amount of electricity, hydrogen, and ammonia export going forward. 30 TWh/year in net electricity exports by 2050 translate to an additional income of USD 2bn (19bn NOK)/year. Hydrogen export of about 3.5 MtH_2/yr could yield an additional USD 7bn (61bn NOK)/year revenue in 2050 assuming a

FIGURE 4.1

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs. Historical data source: NPD (2023), IEA WEB (2023) hydrogen price of 2 USD/kgH_2. In other words, on the present trajectory, total energy exports in 2050 will run some USD 28bn (NOK 250bn)/yr 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 Norwegian oil weakens relative to other cheaper sources in a world with declining oil demand, its share of the global oil market will gradually reduce to around 1% by 2050. As a result, total oil exports (including oil products) will fall to 1 Mbpd (75 million Sm³oe/yr) in 2030, 0.32 Mbpd (24 million Sm³oe/yr) in 2040 and 0.08 Mbpd (6 million Sm³oe/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 and even lower than the year before. The lower forecast is a direct consequence of Russia's invasion of Ukraine and the associated decision of Europe to move away from fossil fuels, especially 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 (Norsk Petroleum, 2023). 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 69 billion m³/yr, 35% less than in 2022.

Total LNG export from Norway is around 6 billion m³/yr in a normal situation. But with the 2020 fire at Melkøya and the restored facility's start-up in June 2022, only 3.7 bn m³ of gas was exported last year, 35% to France, 62% to other European countries, and only 3% to countries outside of Europe (BP, 2023). We forecast LNG export to stay at existing levels as gas demand outside Europe will be increasingly uncertain. But over time it will decline in line with reduced demand from Europe. However, it could be that LNG export capacity will grow in the future as gas export via pipelines is also declining due to lower European demand: the main form of export will, however, remain by pipeline to Europe. It could also be, as discussed below, that natural gas is converted to hydrogen or ammonia with these new decarbonized energy sources then being exported using existing infrastructure with some retrofitting.

Electricity exports

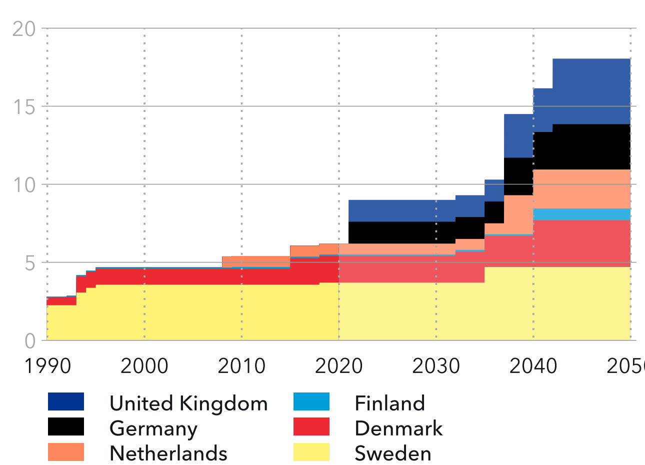
Norway's total net transfer capacity to other countries is 8.9 GW. Of this, 3.7 GW goes to Sweden, 1.6 GW to Denmark, 0.7 GW to the Netherlands and 0.1 GW to Finland (ENTSO-E, 2023). As shown in Figure 4.2, the NordLink subsea cable to Germany (1.4 GW) and the North Sea Link to the UK (1.4 GW) came online in 2021 and are now operating. To facilitate neighbouring countries in growing the renewables share of energy consumption, in the mid-2030s we foresee an increase in Norway's cross-border capacity to Sweden and Denmark by another 1 GW and 1.3 GW, respectively. Interconnectors between Norway and UK (2.8 GW) as well as Germany (1.5 GW) and Netherlands (1.8GW) is expected. 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.

FIGURE 4.2

Norway net electricity transfer capacity

Units: GW



Historical data source: ENTSO-E (2023)

Our model simplifies this structure by representing Norway and the rest of Europe as two electricity markets without any grid constraints within each market. This simplified model still operates at hourly intervals and calculates the trade between Norway and the rest of Europe, based on the price differentials in each market. By using this approach, we can replicate historical trade volumes reasonably well.

In the last 20 years, Norway's average annual net electricity export has been around 10 TWh. But going forward, this situation is going change. In the short-term, between 2025 to 2035, net imports of electricity will rise by up to 5 TWh/yr. An increase in electricity demand combined with limited capacity additions are the reasons for this.

But, the new capacity additions from offshore wind improve the balance such that Norway is again a net exporter increasing the annual export to 63 TWh/yr by 2040. This high annual exports do not continue onwards, though. With grid-connected electrolysers providing a sustained demand for power, electricity exports decline to 29 TWh/yr by 2050. Nevertheless, we expect Norway to remain a net exporter of electricity from 2035 onwards.

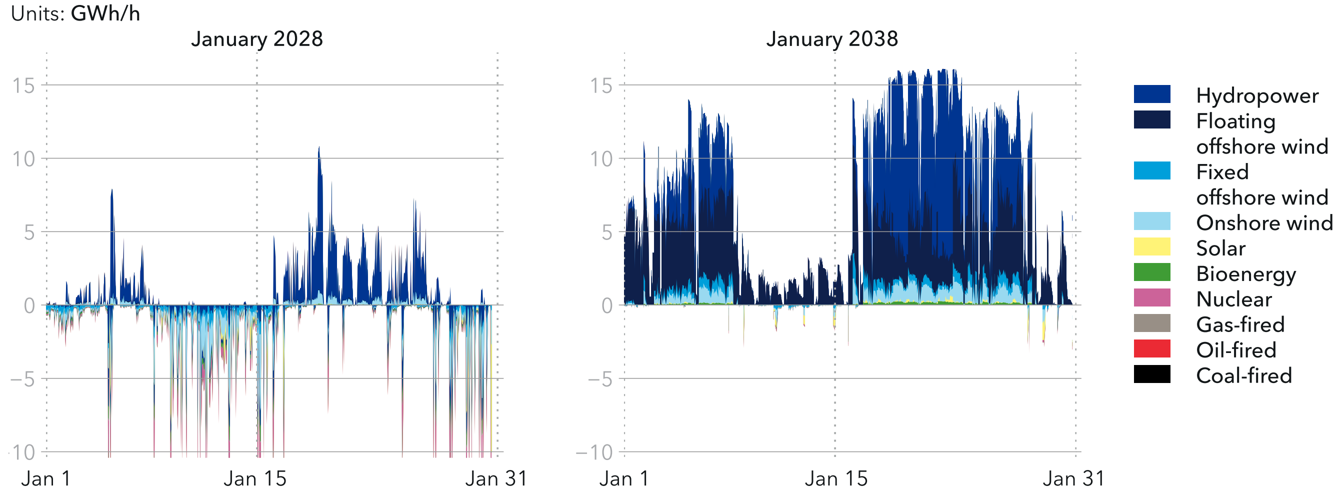
The main reason for this decline is a change from exporting electricity to producing hydrogen and exporting the gas. Additional wind capacity in Europe will make it more profitable to produce hydrogen instead of exporting electricity. The increase in export of electricity is only partially linked to 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 the mid-2030s Norway will become a net electricity exporter, also during winter months.

Figure 4.3 demonstrates how electricity trade of Norway changes in a winter month from 2028 to 2038. In 2028, for the majority of the winter month (60% of the hours) Norway imports electricity, and in the hours that it does export, most of the exports are comprised of hydropower. On the contrary, the imports in 2038 are very minimal, with Norway exporting electricity to Europe for about 90% of the hours. Among the exports, more than 50% is offshore wind, and the clear majority, FOW.

FIGURE 4.3

Norway monthly electricity export and import by power station type (source)

Units: GWh/h



Positive values show exports, negative values show imports.

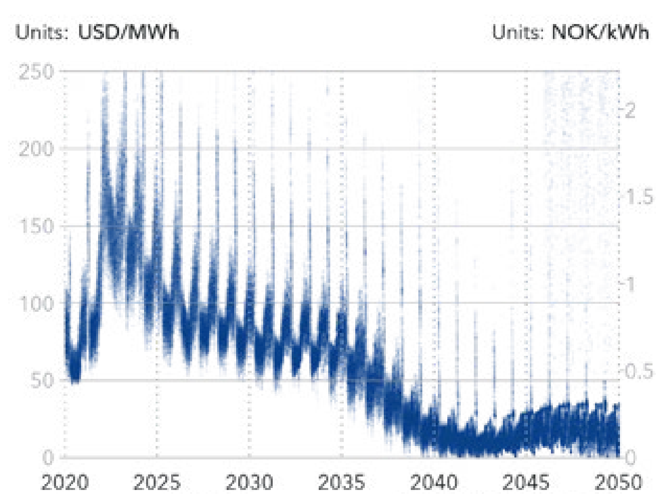
Wind turbines in Møre og Romsdal

We have assumed that new offshore wind capacity will not only be driven by domestic demand and revenue, 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 much of the floating offshore wind's annual generation to be exported. Most of the remaining capacity will be used to produce electrolysis-based hydrogen or to recharge long-term storage.

One important reason for the increase in annual net electricity imports between 2028 and 2032 is bigger fluctuations in future electricity prices. Our analysis 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

FIGURE 4.4

Norway wholesale electricity price distribution



International USD. Exchange rate as per OECD 2022, 8.9 NOK/USD
Shows simulated wholesale electricity price at a particular hour.

decline, but price fluctuations within the year will also reduce. The price stability is linked to increased flexibility resources in the power system, brought by new interconnections, availability of EV batteries through vehicle-to-grid systems, new utility-scale storage capacities, and better demand response afforded by widespread adoption of smart grids. One limitation not accounted for is 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 its 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, for example, through the uptake of ammonia and e-fuels as maritime and aviation fuels.

Europe, with its strong hydrogen support policies, will lead global hydrogen uptake with 13% hydrogen and its derivatives in its 2050 final energy mix. Europe is one of three leading world regions that together will account for 75% 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 as industrial feedstock. By mid-century, Norway's domestic hydrogen demand more than doubles, 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. Initially the production of hydrogen will be from natural gas using CCS (blue hydrogen) with exports starting in the early 2030s. By 2040, we expect an export volume over 1 Mt and growing to exceed 3 Mt hydrogen by 2050. By then 80% of the produced hydrogen will be based on electrolysis powered by renewable energy, predominantly wind.

Already installed and future pipelines to the 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 based short- to medium-term focus is on blue hydrogen accounting for 56% of Norway's hydrogen production by 2035. Another 20% will still come from unabated natural gas-based hydrogen production. However, by mid-century this ratio changes: over 70% of Norway's hydrogen will be grid-based, 14% in total from natural gas with CCS, 13% from dedicated wind, and 2% from unabated natural gas.

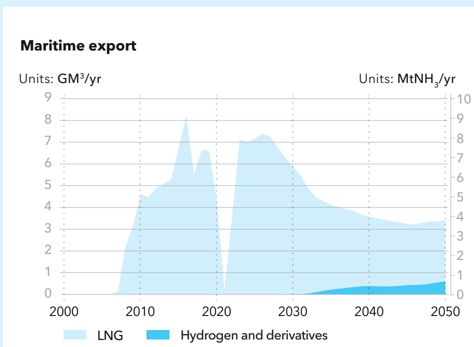
Big uptake markets in Europe. such as Germany, strongly prefer hydrogen from renewable sources over that produced from natural gas (even if coupled with CCS). However, the current turmoil in gas markets has led to a reluctant acceptance of the bridging role of blue hydrogen.

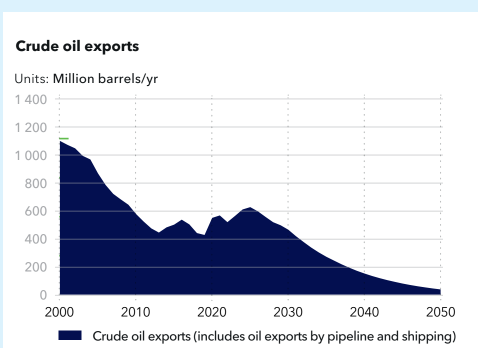
While we forecast significant amounts of hydrogen to be exported to Europe via pipelines, low-carbon ammonia is going to be traded on keel from Norway. In the late 2040s, low-carbon ammonia exports from Norway will reach about 0.8 Mt per year, to be shipped mainly to European ports.

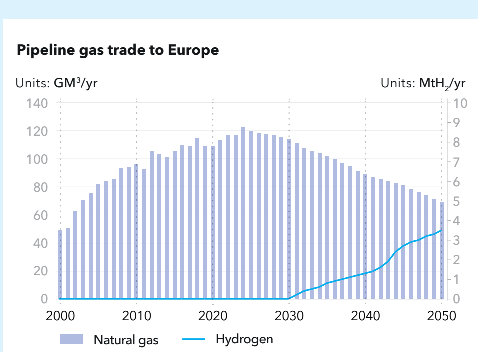
Blue hydrogen from natural gas coupled with CCS could provide a steady flow of hydrogen using Norway's natural gas resources and CCS knowledge effectively

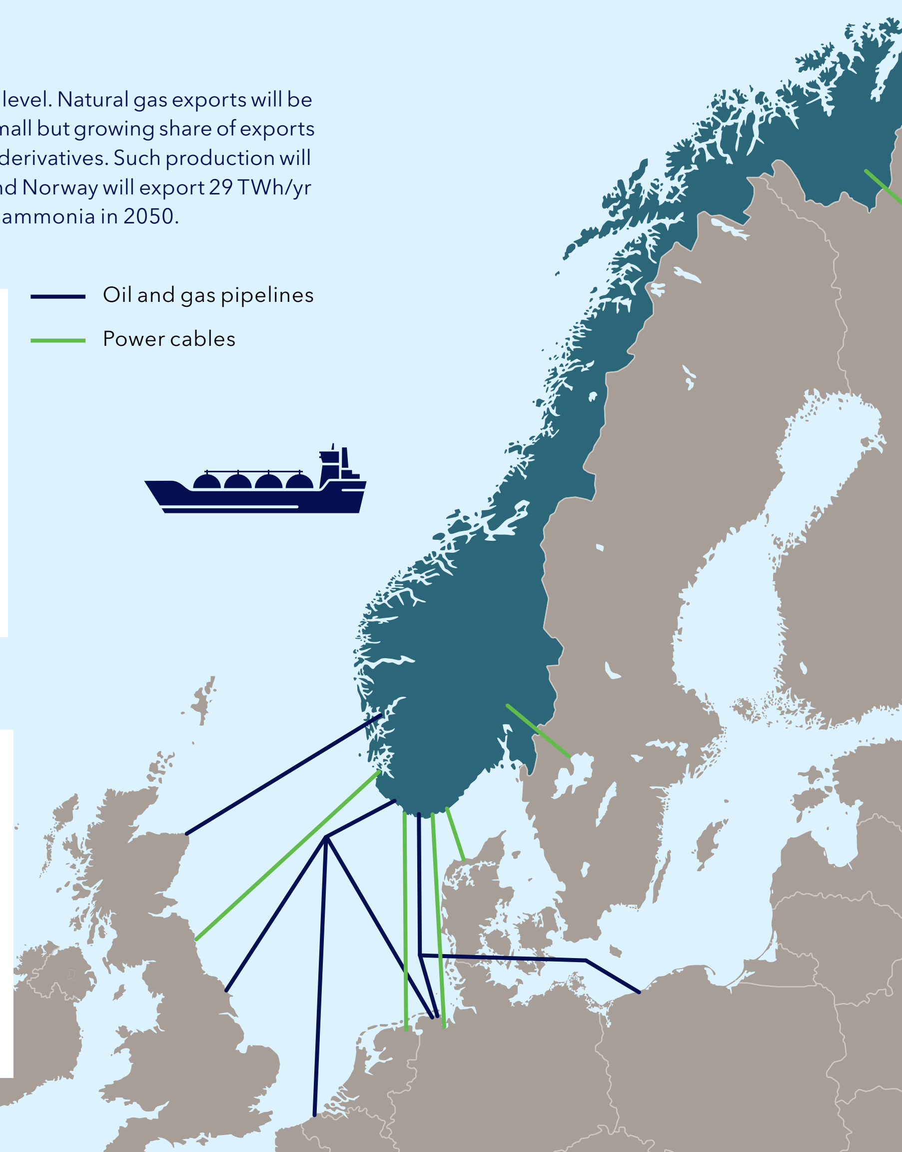
Energy trade

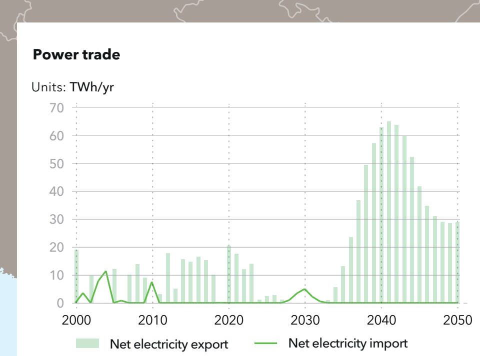
By 2050, Norway's oil export will be 7% of today's level. Natural gas exports will be at 69bn m³ in 2050, 35% below today's levels. A small but growing share of exports will be in the form of electricity, hydrogen and its derivatives. Such production will increasingly be larger than domestic demand, and Norway will export 29 TWh/yr of electricity, 3.5 Mt/yr hydrogen and 0.8 Mt/yr ammonia in 2050.











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 globally and in Norway. CO_2 is the main contributor to these emissions and comes largely from the combustion of fossil fuels.

In this chapter, we describe how we estimate Norway's emissions by source and sector to develop a full account of them. We begin with the estimated energy-related CO_2 emissions derived from our forecast, then list the remaining GHGs and their origins. Since our modelling focuses mainly on the energy system, we make assumptions on the decarbonization possibilities for other, non-energy related anthropogenic GHG emissions. We conclude with a discussion on developments relating to the capture and storage of some of these emissions.

Emissions by source

Norway's energy-related CO_2 emissions have risen steadily for three decades, and a decline has only been observed in the last seven years. In addition to those arising from fossil-fuel combustion, a large share of Norwegian CO_2 emissions are non-energy related from industrial processes. A large quantity of these come from using fossil fuels as feedstock in the steel and petrochemical industries. Non-energy emissions also arise from the calcination process in cement production and from other process-based emissions from anodes.

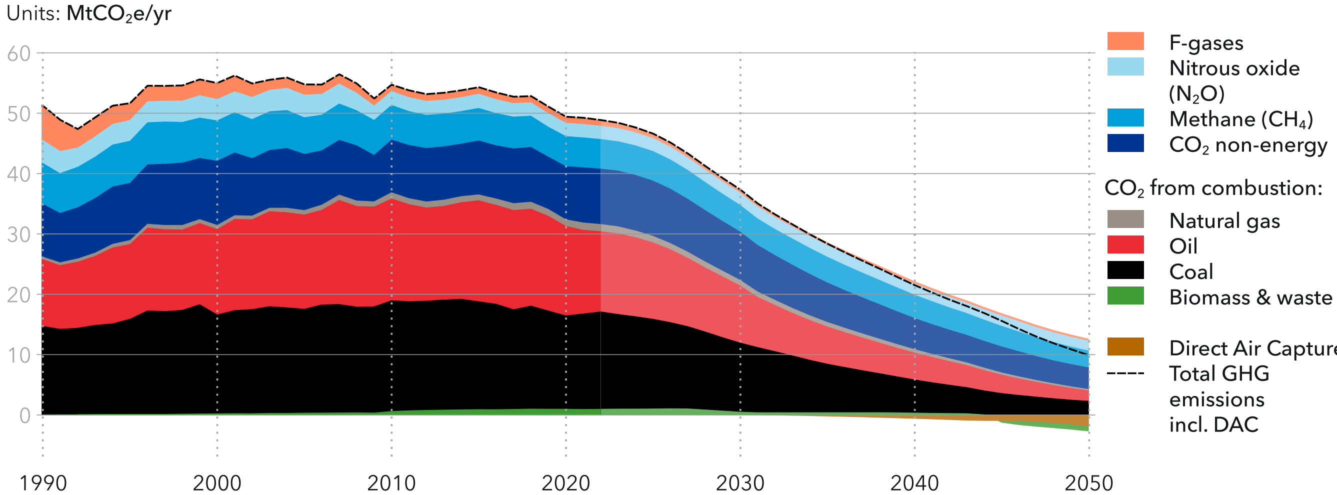
Other GHGs in Norway's footprint are methane, nitrous oxide, and industrial f-gases (fluorinated gases, i.e. HFCs, PFCs and SF6), all with much more aggressive global warming potential than CO_2. Tonne-wise, these emissions are small compared with CO_2, but converted to CO_2 equivalents, they contributed 17% of total GHG emissions in 2022 and will account for 40% in 2050.

Norway's forecast GHG emissions trajectory to 2050 is sobering. In 2022, emissions were slightly less than in 1990 and we predict their decline to reach 27% by 2030

FIGURE 5.1

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

Units: $MtCO_2e/yr$



F-gases include: HFCs, PFCs and SF6. Historical data source: SSB (2023) and 80% by 2050, when 10.4 million tCO_2e will be emitted (Figure 5.1). This falls well short of the ambitions for a decline of at least 55% by 2030 and 90–95% by 2050.

Declining emissions are linked mainly to electrification of road transport and the associated reduction in oil consumption. Other factors are a general decline in oil and gas production; using clean grid-connected electricity instead of natural-gas turbines to power oil and gas production; and changes in heat-intensive manufacturing processes. As our ETO model does not include non-CO_2 GHGs, we have used current emission levels to forecast trends for each sub-source, or have tied the emission source to an activity we model. For instance, methane emissions from oil and gas activities are tied to activity levels and calibrated to historical levels in oil and gas exploration, which are included in the model.

Emissions by sector

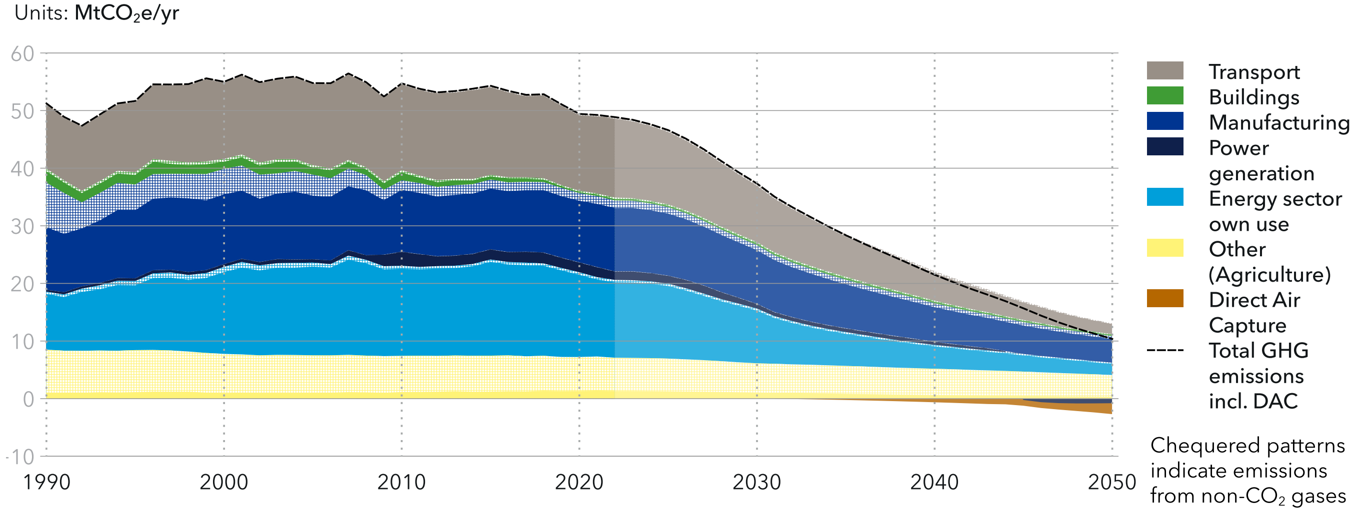
From a sectoral perspective, all emissions have been associated with the main sectors described in our ETO model. Carbon dioxide emissions dominate all sectors except the 'Other' category, which in this context is mainly agriculture. Agricultural emissions are largely methane from enteric fermentation and manure. The other major source in the 'Other' category is methane from landfills. We expect progress in reducing emissions from agriculture and animal management by 2030 and 2050, but these are tied to activity level and thus relatively difficult to reduce through technical means. We have included some progress as described in the Norwegian Government's 'Green book' (2023), resulting in 14% reduction from 2022 levels to 2030. However, we do not assume Norwegian agriculture and animal activity levels will decline. Some activities, such as mechanical machinery in the agricultural sector, will have CO_2 emission reductions comparable to those in the commercial vehicle segment.

In 2022, transport emitted 29% (14 $MtCO_2e$) of total emissions, the largest sectoral share. These will fall significantly towards 2050 but are not on track to fulfil Norway's 2030 ambition of reducing transport emissions by 55% compared with 1990 levels. The road transport subsector emitted 8.7 $MtCO_2e$ in 2022. By 2030, this will decline to 5.4 $MtCO_2e$, 26% less than in 1990, and 37% lower than in 2022. The main driver of this reduction is electrification, especially in passenger vehicles, where emissions decline 54% from 1990 levels by 2030. The government's ambition to increase biofuel use to help

FIGURE 5.2

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Historical data source: SSB (2023)

decarbonize road transport will also contribute. Between now and 2050, road transport emissions will decline 92% to represent 7% (0.7 $MtCO_2e$) of Norwegian emissions.

Aviation, rail, and maritime combustion emissions have been declining since 2000 and are currently 38% of Norwegian transport emissions. However, these subsectors' emissions will not decline as fast as those from road transport. Helped by synthetic fuels, biofuels, and hybrid electric solutions, overall GHG emissions from these transport segments are expected to fall 70% between 1990 to 2050, when they will be 1.2 $MtCO_2e$.

The second largest sectoral emissions is the 13.5 $MtCO_2e$ (28% of total emissions) from 'energy sector own use', mainly for energy extraction and production. Most (62%) of this is CO_2 from gas turbines generating electricity on the Norwegian Continental Shelf (NCS). As the NCS continues to electrify more production, as efficiencies increase, and as installations without electrification reach end of life, emissions will decline by 30% between 2022 and 2030. By 2050, emissions from 'energy sector own use' will have reduced 84% to 2.1 $MtCO_2$ since 2022 due to declining activities on the NCS and an electrification rate of just over 54% of the energy used.

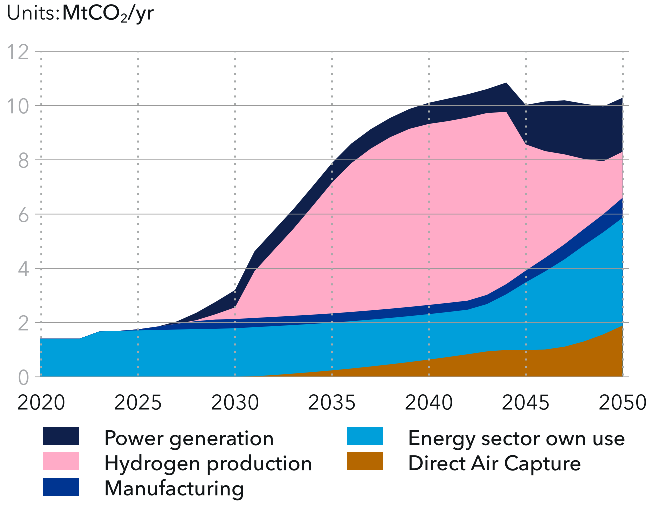
Manufacturing currently emits 12.3 $MtCO_2e$, a quarter of Norway's total GHG emissions. Just over half of manufacturing emissions are from process-related CO_2 emissions in heavy industry, and the rest comes from combustion of fossil fuels. By 2030, emissions will have declined by only a sixth (17%) due to expected growth in industrial output. By 2050, however, emissions of 4.6 $MtCO_2e$ will be nearly two-thirds (63%) less than 2022 levels. This is due mainly to fuel switching to cleaner sources (electricity and hydrogen) in industrial heat, and to greater use of carbon capture and storage (CCS) of emissions from waste streams.

Buildings energy use in Norway is largely linked to electric heating. Some fossil fuels are still used for space and water heating in commercial buildings. The remaining emissions are methane from burning biomass for heating. Currently, the buildings sector represents only 1% (around 500 $ktCO_2e$) of Norwegian emissions. 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, emissions will have further declined by 33% to 340 $ktCO_2e$ per year.

FIGURE 5.3

Norway CO_2 emissions captured

Units: $MtCO_2$/yr



The developments we are aware of today and have modelled are not happening at sufficient scale to make a significant contribution to the emissions reduction required to achieve Norway's climate ambitions.


The Johan Sverdrup field. Image ©Equinor/Lizette Bertelsen, Jonny Engelsvoll

Carbon capture and storage

Carbon capture and storage (CCS) is currently almost solely applied in processes related to oil and gas extraction, where there is a viable business case or need to follow technical specifications. We forecast that in the future, large point sources, mainly in manufacturing, will increase carbon capture from their waste streams. Collectively, however, the developments we are aware of today and have modelled are not happening at sufficient scale to make a significant contribution to the emissions reduction required to achieve 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, 2023). 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 Sleipner being 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.

Our modelling also includes 400 ktCO_2/yr carbon capture at Brevik cement plant and 400 ktCO_2/yr from the Klemetsrud waste-to-energy plant, with both capture streams anticipated to come online gradually from 2025 to 2028.

The Norwegian government approved state funding of NOK 16.1 billion as part of the Longship CCS initiative in 2020 (Government.no, 2020). Such a significant investment incentivizes increased CCS activity, which we include in our model, along with a significant increase in CO_2 price. The effect is an increase of emissions captured, starting in the late 2020s and slowly adding CCS capacity in new sectors to be capturing a total of 8.4 MtCO_2/yr by 2050 (Figure 5.3). A large share of the captured CO_2 will be from blue hydrogen production – 6.6 GtCO_2/yr by 2040. Capture will then decline towards 2050 as green hydrogen production grows and outcompetes blue hydrogen.

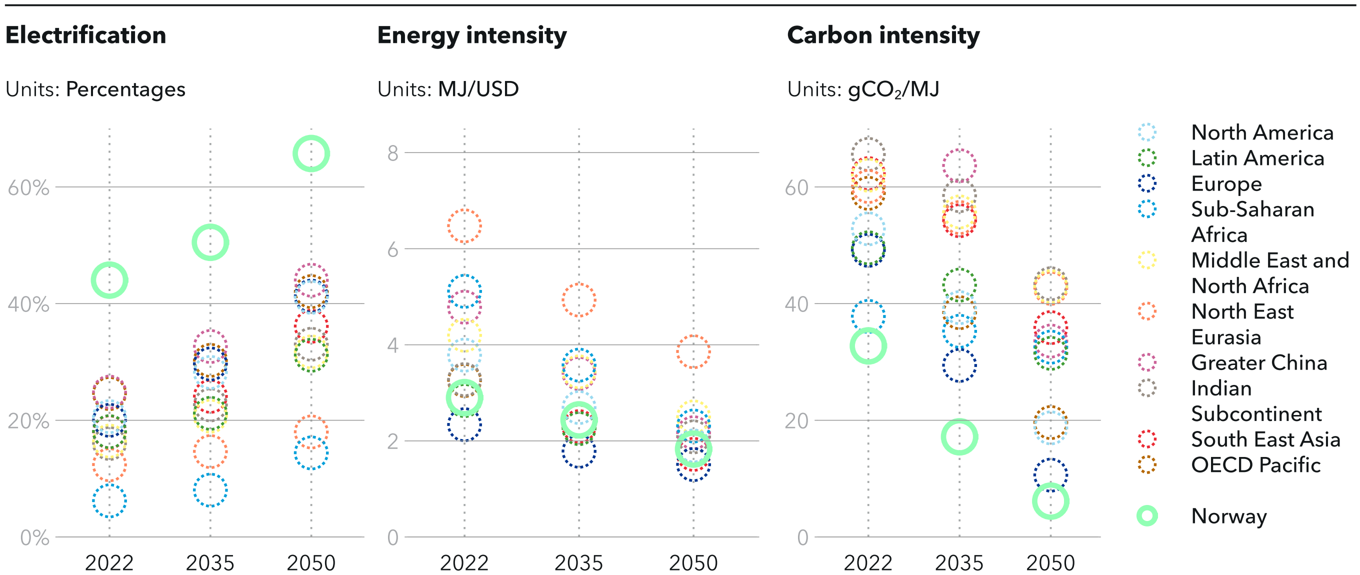
Direct air capture (DAC) – direct capture and sequestration of CO_2 from the atmosphere – is still an emerging technology. It shows promise for further decarbonization but is currently only in pilot state and will need to prove it works in large-scale installations. In our forecast, DAC will only make 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 offset their existing emissions. Several initiatives attracting investor interest will likely lead to early uptake of DAC in Norway and capture reaches 1.9 $MtCO_2$/yr by 2050, 1% of global DAC capacity.

Combining CCS on point sources with DAC, we expect a total capture of 10.3 $MtCO_2$/yr in 2050, leaving 10.4 $MtCO_2$ uncaptured. 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 in 2050 (4.6 $MtCO_2e$) are found mainly in the agricultural sector (82%) and 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 countries. 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 carbon intensity in comparison to other regions. Norway's share of electricity in final energy demand will reach 66% in 2050, far higher than in any of the regions in our global forecast. Energy intensity is reduced to 1.8 MJ/USD in mid-century, slightly more than in the rest of Europe, where it is expected to reach 1.5 MJ/USD. Carbon intensity significantly declines between 2030 and 2050, reaching a final value of 6.2 gCO_2/MJ (81% reduction). This level is much lower than in Europe, where we see an intensity of 10.6 g gCO_2/MJ, 78% less than 2022 levels. The main reason for these differences is that emissions in Europe stem mainly from transport and buildings. These are sectors that Norway has electrified significantly, giving Norway an advantage when considering carbon intensity.

FIGURE 5.4



Melkøya LNG Facility, Hammerfest

6 NORWEGIAN TRANSITION IN AN EU CONTEXT

Norway faces a difficult conundrum in balancing its role as a secure supplier of oil and gas to Europe, building a strategic position in energy transition opportunities – while managing inherent transition risks for its oil and gas resources – and meeting its own decarbonization ambitions under joint European commitments. Where the EU has stepped up its transition efforts, emissions cuts, and race for leadership in cleantech, Norway's progress is far behind its announced ambitions.

The energy transition in Norway is closely linked to EU climate goals, energy transition policies, and energy-related dilemmas, and heavily impacted by international factors including the war in Ukraine and global supply-chain problems. EU demand, regulation, and policies are driving energy discussion and policy in Norway. With much of the key legislation of the *Fit for 55* package adopted in 2023, the EU deems itself on track towards its goals to reduce EU emissions by at least 55% by 2030 and reach climate neutrality by 2050. Norway has reconfirmed its aim to cut emissions at least 55% by 2030 (compared to 1990 levels) and 90–95% by 2050, but our forecast shows these goals are unachievable with current trends and policies. The *Climate Progress Report 2023* (ESA, 2023) concludes that Norway expects "a significant gap towards its current targets" and should add measures to contribute to the Europe-wide effort.

EU transition legislation forging ahead

Norway shares the EU ambition for Europe to be the world's first climate-neutral region. With the *Fit for 55* legislative proposals from 2021, the EU hopes to put itself on a path for 55% less emission by 2030. Most pillars of the *Fit for 55* package are in place, with several adopted into law in 2023. Their urgency was heightened by the war in Ukraine leading to energy supply and price crises. The crises prompted temporary measures and accelerated the package's legislative changes and energy policy reforms. One example is the *REPowerEU* plan (May 2022) boosting efforts to save, diversify, and increase European renewable energy production and consumption, thereby increasing energy security. Renewable power and grids are the backbone of efforts to achieve European energy and climate objectives such as implementing *REPowerEU* and aiming for a renewable share in electricity generation to grow to 69% (592 GW solar PV and 510 GW wind) in 2030 (DG-Energy, 2023).

Many proposed measures and changes to EU directives are relevant to the European Economic Area (EEA), of which Norway is a member. These include measures to green industrial and energy sectors, an example being the *Renewable Energy Directive* raising from 32% to 42.5% (while striving for 45%) the EU target for renewable energy's share of the energy consumption in 2030; the updated *Energy Efficiency Directive*; a reform and extension of the *EU Emissions Trading System* (EU ETS); and the introduction of a *Carbon Border Adjustment Mechanism* (CBAM) on certain industry and energy imports into the EU. Clean transport investments are incentivized by the *ReFuelEU Aviation* initiative and *FuelEU Maritime* regulation aiming to reduce these transport subsectors' environmental footprint by promoting the uptake of sustainable fuels. Updated CO_2 standards for cars and vans introduce progressive EU-wide emissions reduction targets in road transport. *The Alternative Fuels Infrastructure Regulation* should ensure access to sufficient infrastructure for recharging or refuelling road vehicles and ships with alternative fuels.

Uncertain future demand for Norwegian oil and gas

Norway stepped up its role as a secure supplier to alleviate the EU's gas and oil shortage following Russia's invasion of Ukraine in 2022 and Russia cutting

24 April 2023, Norwegian Prime Minister Jonas Gahr Støre meets Ursula von der Leyen, President of the European Commission, to sign the EU/Norway Green Alliance. Copyright: European Union, 2023.

gas exports to EU countries. Gas production was boosted 8% in 2022 and Norway became the biggest supplier to the EU. The Norwegian share of EU pipeline natural gas imports increased from 38% in Q1 2022 to 46% in Q1 2023, and its share of EU oil imports increased from 10% in Q1 2022 to 13% in Q1 2023 (Eurostat, 2023).

However, long-term developments in the EU, aided by the aforementioned deepening of existing and new EU legislation, point toward oil and gas becoming less attractive to EU markets sooner than previously anticipated. Legislative efforts to meet clean energy goals, wean itself off Russian supplies, and reduce import dependencies, are likely to speed up the EU's phase-down and eventual phase-out of oil and gas, in turn creating uncertainty around future demand and therefore Norwegian exports. DNV's main ETO forecasts international and European oil demand to be, respectively, 38% and 62% lower than 2022 levels in 2050. EU demand for natural gas is projected to fall 66% by 2050. This demand decrease is similarly reflected in our ETO for Norway, which sees oil production fall 12% by 2030 and 88% by 2050, and gas production decline 6% by 2030 and 42% by 2050.

Lopsided investments tilt in favour of fossil fuels

Norwegian investment in oil and natural gas extraction is expected to increase 23% in 2022/23 following average growth rates fluctuating around 3% year-on-year over the last five years. In absolute terms, oil and gas extraction and pipeline investment constitutes 70% of total industry investment in Norway and is eight times higher than the investment in electricity production and transmission and distribution networks in 2023. Investment in energy generation, on the other hand, has been decreasing year-on-year since 2020 (see Statistics Norway, 2023 for all relevant investment data).

Though predominantly capital-intensive, the Norwegian oil and gas industry engages a crucial part of the labour force, which is consequently unavailable for electrifying industrial energy use and the build-out of the renewable power, transmission, and distribution sectors.

In addition, expected electricity demand from the oil and gas sector might also tie up grid capacity. Norway's 2021 *Climate Action Plan* foresees an increase in the Norwegian carbon tax for emissions from the energy sector's own use from around 760 NOK today to 2,000 NOK in 2030. With the oil and gas industry accounting for around a quarter of Norway's total GHG emissions, the carbon tax might provide higher incentives for electrification of petroleum activities. Statnett assumes a doubling of the power consumption, which is similar to our forecast, from the petroleum sector by 2030. This might divert grid companies' capacities from other much-needed network reinforcements.

In contrast to the perspective of dwindling demand for Norwegian oil and gas, there might be demand for decarbonized Norwegian gas in the form of blue hydrogen produced from natural gas using steam reforming and carbon capture and storage (CCS). Norway's Equinor and German power company RWE signed a memorandum of understanding (MOU) to jointly develop large-scale energy value chains. The aim is to replace coal-fired power plants in Germany with hydrogen-ready gas-fired power plants, and to build production capacities for low-carbon hydrogen in Norway. This MOU also includes export of low-carbon hydrogen via pipeline from Norway to Germany, and the joint development of offshore wind farms. This opportunity is reflected in our ETO numbers: more than three million tonnes of hydrogen is piped from Norway to the EU in 2050.

Discussing future Norwegian oil and gas production is challenging due to conflicting trends, such as the likely dwindling of long-term fossil-fuel demand, potential future opportunities related to CCS, and long-term effects and opportunity costs of today's investment decisions for adjacent energy and industry sectors. The Climate Committee was clear on the need for planning with an eye to resource scarcity and fossil-fuel risks, on the latter recommending the preparation of "a strategy for the final phase of Norwegian petroleum activities…" and "not granting any further licenses for development and operation (PDO) or installation and operation (PIO) until such a strategy has been completed" (Klimautvalget 2050, 2023).

Electricity sector – too little of everything, too slow

Norway's electricity is almost completely produced from renewable energy sources, especially hydropower. Yet on the back of decarbonization requirements and further electrification of energy demand through new electricity-intensive industries, there is a need for massive expansion. However, the development of renewable energy sources in Norway is stagnating due to several domestic issues, which are also likely to affect Norway's ability to export electricity into the EU in the medium term. At the same time, Norwegian power prices will continue to be affected by developments in the EU.

Increasing renewable electricity capacity is a key enabler in both the EU and Norway for combatting high electricity prices.

Up until recent years, Norway had an electricity surplus with abundant stored hydropower guaranteeing relatively low power prices and low power price volatility compared to other European countries. However, both price levels and volatility have increased over the last couple of years in line with European electricity prices. The build-out of interconnections with European countries and the increase in intermittent power generation in Norway and the Nordics both contribute to higher and more volatile prices in Norway. In addition, the war in Ukraine and the corresponding surge in commodity prices aggravated these trends over the past two years, driven mainly by costlier gas-fired generation. The EU's more ambitious decarbonization goal and the updated EU ETS will likely result in an upward price trend in the EU and in Norway compared with the pre-crisis price path. The EU ETS Carbon Permits price went from around 20 EUR/tCO_2 before 2021 to just above 100 EUR/tCO_2 in the spring of 2023. Current price levels are at 80 EUR/tCO_2 and are expected to increase to around 150 EUR/tCO_2 by 2030 (DNV, 2023a). Norwegian electricity prices are unlikely to return to pre-2022/23 levels in the medium term, due to (i) increasing CO_2 prices, (ii) increasing interconnectivity with continental Europe, and (iii) the growth in intermittent power generation, further boosted by more ambitious EU renewables targets combined with limited national capacity build-out. Only after 2035 could the wholesale electricity price reach pre-crisis levels, driven by lower renewables costs, new power generation, and further power sector decarbonization on the European continent.

In February 2023, the Energy Commission presented its report (NOU 2023:3) *More of everything – faster* on the long-term development of the Norwegian power system. Similar to Statnett (Statnett, 2022) and to conclusions in this ET Norway report, the Energy Commission warns that Norway could face a power deficit as early as 2028 as a net export of ~15 TWh in 2020 becomes a net import of 5 TWh by 2030, according to the ETO.[1] This shift is driven by growing power demand, mainly from energy-intensive industries, the oil and gas sector, and from road transport electrification. Statnett (Statnett, 2023) has revised its deficit projections from 2022 and expects the power surplus to continue until 2028, pushed back from 2027 due to slower growth in power demand. However, the consensus still seems to be that the power balance will deteriorate significantly in the coming years. A weaker power balance means that Norway has fewer hours of power export during the year and more hours of importing power, resulting in further convergence of Norwegian power prices towards higher continental prices.

Increasing renewable electricity capacity is a key enabler in both the EU and Norway for combatting high electricity prices, matching increasing power demand, and achieving climate goals. The Norwegian expert committee on electricity prices recently concluded that a lasting Norwegian power surplus is the most important measure to ensure low and competitive prices long term (Strømprisutvalget, 2023). However, almost no new power generation is being developed in Norway. A key question is therefore whether development of new power generation is sufficiently fast to achieve politically agreed targets and the necessary transition speed.

1. While Statnett estimates a 2 TWh deficit in 2027, NVE believes that the balance will barely be positive with 2 TWh. NVE and Statnett agree that the power balance will deteriorate significantly in the coming years.

NVE numbers show that, since 2020, almost no new licences for renewable energy capacities, including hydropower and wind power, have been granted; hence almost no new power generation is under development (Fornybar Norge, 2023). Several challenges for renewable electricity in Norway need resolving to ensure sufficient development of future energy capacity.

Conflict resolution is a major challenge for further onshore wind development. After the share of onshore wind in Norway's electricity system grew tenfold in the last decade, local opposition increased based on the perceived impact on landscapes and ecology. Popular support for onshore wind farms has halved between 2018 and 2021, according to CICERO's Population Surveys on Climate (CICERO, 2022).[2] Conflicts of interest between renewable energy developers, municipalities, reindeer husbandry, tourism, and nature preservation interests are difficult to align.

Offshore wind is expected to generate less conflict of interest, but it is not yet commercially viable in Norway. The expansion of offshore wind will be dependent on the available mechanisms supporting its expansion. In our forecast we have included initial support for the first build-outs. Support is declining towards 2040, with the lowering cost of wind technology. In addition to these sources of income, we expect there to be mechanisms to redistribute profits from high-margin energy exports, such as hydropower and green hydrogen exports, to further enhance the financial viability of offshore wind development.

As in most European countries, the necessary build-out of the transmission and distribution grids is challenging in Norway. Grid companies have a reactive strategy, making investments based on requests and thereby impacting concession lead times. Moreover, municipalities, interest groups, and the public have the right to raise concerns regarding any energy or grid development, with their views being accounted for in the licensing decision. With Norwegian grid operators already facing skills and equipment shortages, electrification of oil and gas activities could divert more scarce resources from grid reinforcements needed for more renewable energy and rising electricity demand.

A standstill in the power sector could dampen new energy-intensive demand and ultimately affect industrial development and jobs. The 2022 surge of electricity prices in Norway led to a more permanent dip in electricity demand than initially expected, and to the postponement of several electrification projects in the petroleum sector (Statnett, 2022; Statnett, 2023). Future industrial development in Norway can be negatively impacted by high electricity prices and a stagnating power sector. Recognizing that more renewable power is needed to match increasing demand, bring down electricity prices, and deliver on Norway's climate goals, the Energy Commission calls for "more of everything, faster". Given the challenges outlined, Norway's expansion of renewable electricity capacity over the past few years has, in our view, been too little, too slow.

Pick up the pace to leverage opportunities

Energy sector electrification has been progressing steadily, especially in road transport and manufacturing. Road transport emissions have decreased since 2022 and are expected to decline steadily until 2050. The ETO for Norway also expects the Norwegian power deficit to vanish after 2033 and power prices to decrease significantly thereafter, provided that investment in new renewables capacity picks up in the second half of the 2020s and the 2030s. In addition, Norwegian investments in CCS are pulling weight in an international setting. The Northern Lights project is seen as a CCS reference project open to CO_2 imports from EU countries. Large-scale renewable energy and CCS development are key prerequisites for Norway to seize the opportunity to export much-needed low-carbon hydrogen, ammonia, and e-fuels into the EU.

As the EU is accelerating towards its goal of climate neutrality in 2050, more needs to be done in Norway to keep up, realize its own ambitious climate goals, and to seize opportunities arising from the EU energy transition.

2. The proportion who answered "yes" to the statement that "Norway should increase wind power production on land" fell from 65% to 33% from 2018 to 2021. In 2022, the proportion rose slightly to 39% positive answers, against 35% negative answers.

Windmills at Fosen

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Historical data

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