WHEN TRUST MATTERS

ENERGY TRANSITION OUTLOOK NORWAY 2024

A national forecast to 2050

FOREWORD

Welcome to the 2024 edition of DNV's Energy Transition Outlook for Norway to 2050.

In 1900, when the Hammeren hydroelectric power station in Maridalen outside Oslo was inaugurated, it was said at the time that Oslo had "secured power forever". Today, according to official sources, the annual production from Hammeren would cover half a day of Oslo's electricity demand.

Just as Oslo's electricity consumption has expanded unimaginably from the perspective of 1900, the whole of Norway's power consumption has grown enormously, and now extends to the electrification of parts of our offshore oil and gas production on the Norwegian continental shelf. Ninety percent of this electricity is still supplied by Norway's hydropower systems, which has become the envy of nations. However, as we show in this forecast, Norway's electricity consumption is going to grow in the next 25 years by almost as much as it has over the past 100.

The reason for accelerated electrification in Norway – beyond what can be expected by population and economic growth – is that we are in a race against time to decarbonize our energy use. Norway, in lock step with the EU, has ambitious decarbonization goals and yet, as we detail, Norway is not on track to achieve either of its 2030 or 2050 emissions targets.

Part of the challenge facing Norway is that it cannot further electrify its major demand segments – transport, manufacturing and the oil and gas production, and support growth from new industries and data centres – without access to substantially more power and Norway's hydro power potential is close to its limits. Where is the additional power going to come from? The answer, unequivocally, is wind.

We show in this forecast that wind is the only decarbonization option available to Norway at the scale required. Not solar – although it will make a meaningful contribution to the power mix towards the end of our forecast period. Not nuclear, which we show is not suited to the characteristics of Norway's power system, and with which the country has almost no experience.

Our forecast reveals that Norway faces a looming power deficit such that in the early 2030s it will be importing some 10 TWh of electricity annually. The deficit is the result of hesitation with the buildout of wind power for reasons of cost and public pushback. The assessment made in this forecast is that Norway will overcome this hesitation and go on to build substantial onshore and offshore (both fixed and floating) wind power resources. In doing so, Norway will not only secure sufficient power for domestic needs and industrial growth, but will also be able to resume and indeed grow its power exports – both directly, in the form of electricity, and indirectly in the form of hydrogen. Notably, our forecast shows that Norway will be closer to fulfilling its 2050 emissions target than its 2030 target.

Norway provides 30% of Europe's natural gas and will continue to be a key partner in providing reliable and secure energy to Europe. Power and hydrogen export revenue will help to compensate for some of the export revenue that Norway will lose through the decline in oil and gas exports. But renewable power exports will not come close to matching the sort of energy export revenue that Norway has become used to. The broader energy transition therefore implies a shift towards a more technology-led and service-based Norwegian economy.

I hope you find this report useful and inspiring and, as ever, we welcome your feedback.

Remi Eriksen

Group president and CEO

DNV

HIGHLIGHTS

1 Demand for electricity grows by 60% from today to 2040.

- Norway is already the second-most electrified country in the world, but electricity use will double by 2050 to cover 65% of total energy demand
- Fossil fuel use in Norway more than halves to 2050, reducing its share from 46% today to 21% by 2050. Oil use in transport reduces 80%
- Energy efficiency effects are moderate, and current electricity support scheme remove much of the incentives to reduce consumption

2 Wind is the only scalable option for new power generation – delays result in a power deficit.

- Wind power is the only available scalable option, and between 2030 and 2050, Norway will see 13 GW of new onshore wind and 21 GW of offshore wind installed
- Prior to 2030, wind installations are minor, and rising demand will likely create an electricity deficit within five years, with average net import being 10 TWh in the early 2030s
- Grid expansion must accelerate to enhance flexibility, reduce bottlenecks, and optimize wind power, while hydropower adds valuable capacity

3 Norwegian energy exports remain central to Europe's energy security and green transition.

- Norway provides 30% of Europe's natural gas and will continue to be the preferred supplier. As European demand falls 60% to 2050, Norway will cover a growing share
- Norwegian hydropower has increasing value as a green flexibility provider balancing variable solar and wind. Cables to Europe will dramatically increase export value of the hydropower
- Norway will likely develop infrastructure for hydrogen exports, exporting 2 Mt/yr hydrogen to Europe, initially blue and later also green

4 Norway is not on track to reach its national emissions targets.

- Norway aims for a 55% emissions reduction by 2030 and 90-95% by 2050, but our forecast shows emissions only falling 27% by 2030 and 75% by 2050 relative to 1990 levels
- Existing and planned policies are too weak to ensure the necessary step-change in sectors like manufacturing, shipping, aviation, and agriculture
- Increasing global pressure on high-income nations calls for net-zero targets well before 2050. To comply, accelerated actions are needed on all areas and levels

1 Demand for electricity is growing by 60% from today to 2040.

Norway is already the second-most electrified country in the world, yet electricity demand will double by 2050. A small share of the long-term growth is for direct export of power. A far larger share of power will be indirectly exported in the form of hydrogen.

Demand for electricity is growing in all sectors, with road transport showing the strongest increase. New demand categories, such as oil and gas installations and data centres, are less price sensitive and can accept higher electricity costs than traditional industry. This will challenge the Norwegian manufacturing industry's access to cheap electricity.

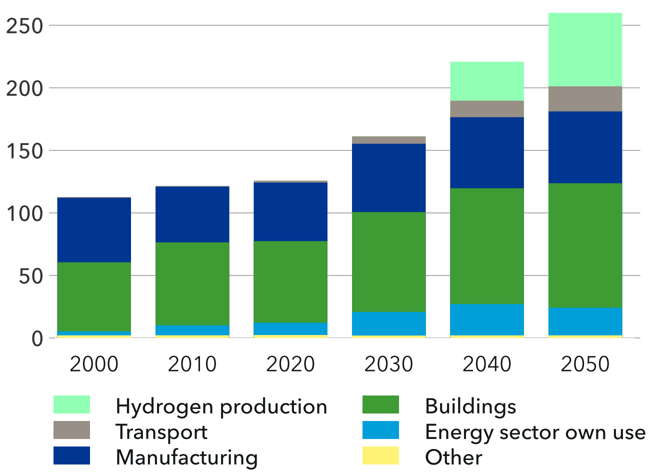
A lasting Norwegian power surplus is an important mechanism for securing low and competitive prices. Energy efficiency measures are important to implement, but their potential is relatively moderate, and much of the incentives have been removed by the electricity support scheme to households.

Norway's final energy demand of fossil fuels reduces 53% to 2050, and while efficient electricity is added, the decline of less-efficient oil and gas is significant. There will be an 80% decline in oil use in transport, mainly road (88%) and maritime (85%), but also halving in aviation. Natural gas used to power oil and gas productions falls by two thirds to 2050, due to reduced production and electrification of the installations.

FIGURE 1

Norway electricity demand by sector

Units: TWh/yr



Historical data source: IEA WEB (2024)

2 Wind is the only scalable option for new power generation – delays result in a power deficit.

Onshore and offshore wind are the only available and scalable options for adding significant production. Yet local opposition to onshore wind projects and complex regulatory hurdles are slowing progress, even as offshore wind presents a promising alternative but with high upfront costs. However, from the 2030s, offshore wind, with policies favouring both floating and fixed, will grow rapidly, driven by falling costs linked to 'learning-by-doing', sustained government support, and increasing opportunities for the trade of electricity. By 2050, we expect 18 GW of onshore wind and 21 GW of offshore wind in Norway, with fixed offshore marginally larger than floating.

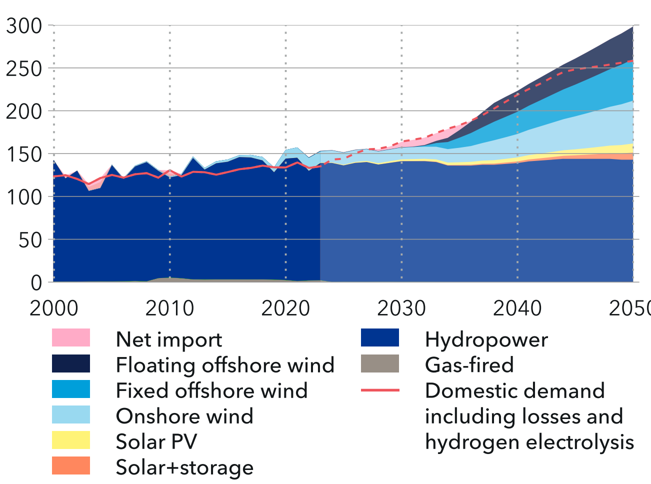
With its continuously declining cost we expect 10 TWh of solar production in about 20 years' time, partly combined with batteries. Hydropower has limited potential for new large-scale projects and current efforts to upgrade and modernize will increase power capacity more than total generation. Nuclear is often suggested as an alternative, but we do not find nuclear to be part of the energy mix within the forecast period to 2050. Grid expansion is essential to enhance flexibility, reduce bottlenecks, and optimize the use of wind power, but the current pace of grid development is too slow.

With demand growth outpacing supply, Norway faces a power deficit from the late 2020s, with net import averaging 10 TWh in the early 2030s. By mid 2030s, new offshore wind production will again turn Norway to a net electricity exporter.

FIGURE 2

Norway electricity supply by power station and net imports

Units: TWh/yr



Historical data source: IEA WEB (2024), SSB (2024)

3 Norwegian energy exports remain central to Europe's energy security and green transition.

As Europe's largest energy exporter, Norway is vital to the EU's strategy for energy security and decarbonization. Europe's demand for Norwegian gas surged after Russia invaded Ukraine. Norway has since maximized exports and opened new fields, but long-term forecasts suggest Norway's oil exports will fall to 15% of current levels by 2050, with gas exports likely remaining high until 2040 before halving by 2050.

As Europe pursues its emissions reduction targets, it must balance its reliance on Norway's fossil fuels, while transitioning to greener energy. Europe's policies, such as *Fit for 55* and *REPowerEU*, aim to enhance energy security but fall short of establishing an independent energy surplus, making Norway a future key partner.

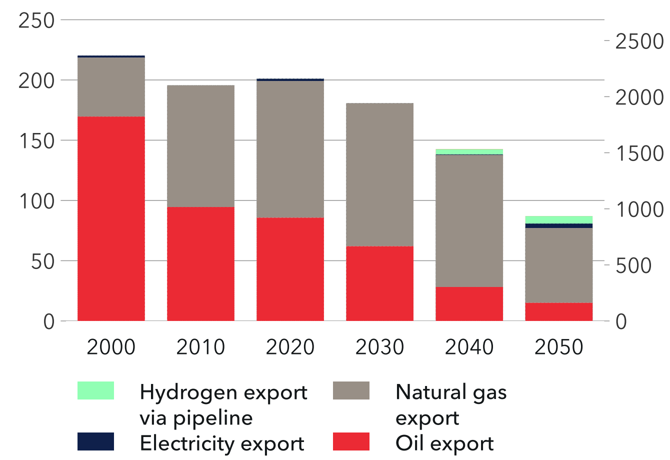
As Europe transitions, Norway will export more and more electricity and hydrogen, leveraging its renewable resources. However, these exports will only marginally offset revenue losses from declining oil and gas exports.

By 2050, Norway's net electricity exports are expected to reach 40 TWh annually. Hydropower will be a critical green, dispatchable energy source for Europe, providing valuable income for Norway. Blue hydrogen projects may currently be on hold, but we find no other 'affordable' hydrogen supply to Europe to decarbonize its hard-to-abate sectors, and thus anticipate exports reaching 2 Mt/yr early in the 2040s, initially blue hydrogen and shifting to green.

FIGURE 3

Norway energy export

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



Oil includes condensates, natural gas includes NGLs.
Historical data source: NPD (2024), IEA WEB (2024)

4 Norway is not on track to reach its national emissions targets.

We forecast that emissions in Norway will not fall fast enough for the country to reach its national emissions reduction targets. Emissions drop by 27% by 2030 (compared with 1990) versus the targeted 55% reduction. By 2050, emissions fall by 75% whereas the goal is to reduce 90%-95% compared with 1990 levels.

In the Norwegian government's 2024 budget, as detailed in the climate status and -plan (known as the "Green Book"), existing and planned policies address emissions reductions. We find the initiatives too weak to ensure the necessary step-change in sectors like manufacturing, shipping, aviation and agriculture.

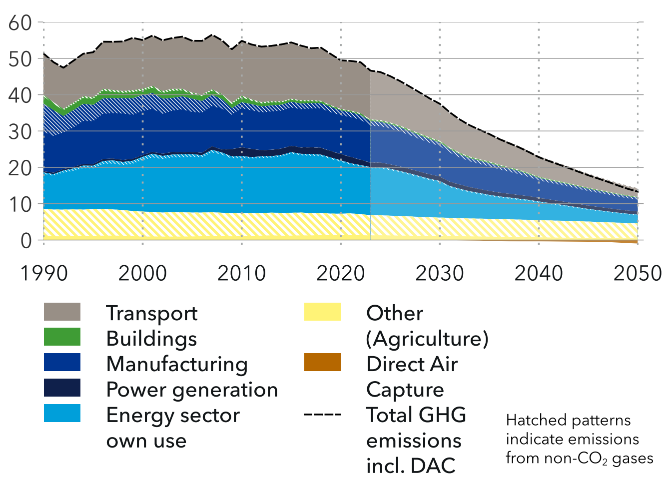
The largest decline in emissions comes from the electrification of road transport. Other noteworthy contributions include: a general decline in oil and gas production; using electricity instead of natural-gas turbines to power oil and gas production; and changes in heat-intensive manufacturing processes.

There is an increasing global pressure on high-income nations that calls for net-zero targets well before 2050. All regions must accelerate their net-zero ambitions, but OECD Countries, like Norway, must achieve net-zero targets earlier than stated ambitions. This buys time for low/middle income regions to attempt to reach net zero as soon as possible after 2050.

FIGURE 4

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Historical data source: SSB (2024)

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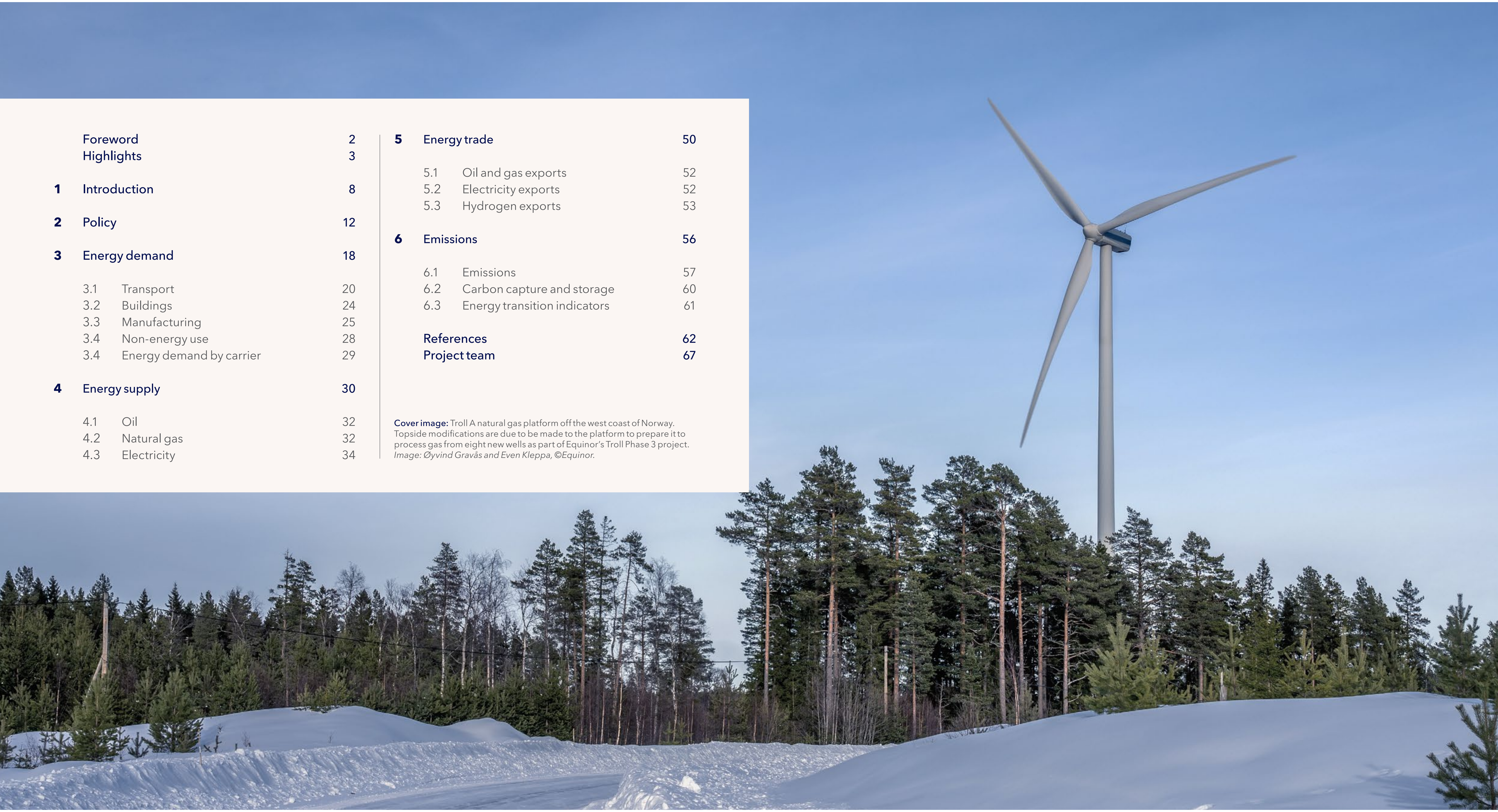


Cover image: Troll A natural gas platform off the west coast of Norway. Topside modifications are due to be made to the platform to prepare it to process gas from eight new wells as part of Equinor's Troll Phase 3 project. *Image: Øyvind Gravås and Even Kleppa, ©Equinor.*

INTRODUCTION

The energy transition in Norway is at a crossroads, where difficult decisions must be made. For example, should Norway's focus be on industrial growth, energy exports or climate? Succeeding with all three is a tall order and this report tries to highlight some of the upcoming challenges involved. There is a growing need for electricity in Norway to support industrial growth combined with initiatives in decarbonizing transport, industry, and oil and gas production. Building new capacity takes time, and wind (onshore and offshore) is the option that can scale in the short- to medium term. But wind power, especially onshore, faces public opposition and offshore wind faces uncertainties in how quickly costs can decline. However, currently there are no other alternatives available to significantly increase power generation for the next 15 years. The country's role as a significant energy exporter and its ambitious decarbonization targets demand a swift and robust energy transition. However, domestic hurdles in renewable energy expansion and high reliance on fossil fuel production limit its capacity to meet national climate objectives.

Model assumptions

The ETO model is driven by the dynamic changes in the Norwegian energy system, which in turn is connected to Europe and the rest of the world. We make use of external data-sources for some key input parameters that help determine the energy forecast. These are linked to areas such as population, economic development, technology development and policy, with the latter covered separately in Chapter 2.

Population

We use the most recent research and results from the Austria-based IIASA Wittgenstein Centre for Demography and Global Human Capital. These results have been updated in 2023 and track closely to the most recent UN population estimates for 2050. The Norwegian population is expected to keep growing from 5.4 million (mn) today and reach 6.1 mn in 2050. Decreasing fertility rates and limited immigration give Norway this relatively slow population increase, which is comparable with other neighbouring countries such as Sweden and Denmark.

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 uses the long-term economic development data from OECD (2021) to determine long-term GDP growth. 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. These short-term perturbations are covered with greater accuracy by the International Monetary Fund (IMF) than the more long-term oriented OECD model. For the near-term, we therefore use the IMF data, which points to a GDP change for Norway that is growing from the low levels in 2020 by an average 1.6% per year until 2028, thereafter returning to the growth rates given by the OECD GDP model.

For Norway, 2023 GDP was USD 439.2 billion (bn), or NOK 3,700bn, while it is likely to rise to USD 667bn (NOK 5,600trn) in 2050. 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 not directly translatable to 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 technologies we currently consider 'most promising' could change due to shifts in levels of financial support or altered 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.

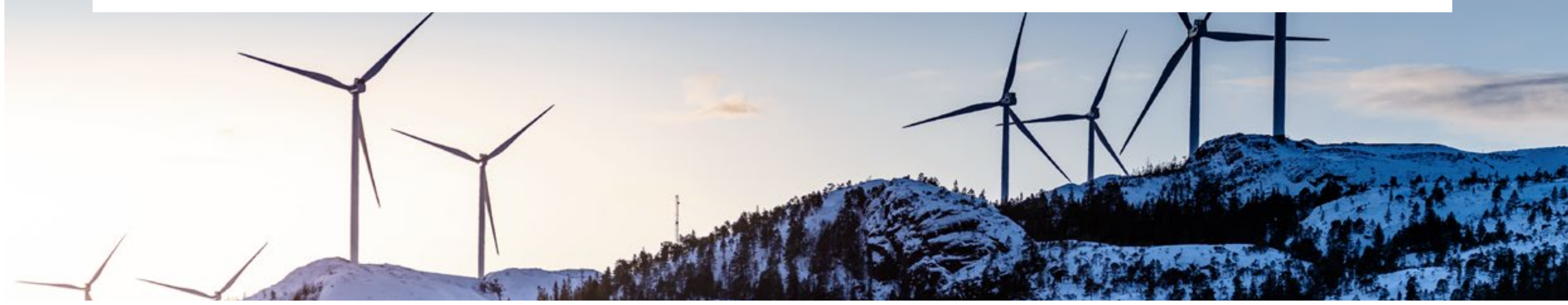
CLRs cannot easily be established for technologies with low uptake and which are still in their early stages of development. In such cases, calculations rely instead on insights from similar but more mature technologies. Carbon capture and storage (CCS) – other than that used in enhanced oil recovery – and next-generation electrolysis for hydrogen production are examples of this. New nuclear technologies based on Small Modular Reactors (SMR) face a similar challenge and here we use literature and empirical data to evaluate the potential cost reductions. 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.

Core technology CLRs that we have used through to 2050 in our forecast include 16% for batteries, 16% for wind turbines. The system cost for offshore wind have seen an increase as a consequence of differentiating learning rates between regions and delays in early project and increasing supply-chain costs. Solar PV have a CLR of 26% but falling to 17% later in the forecast period. For new nuclear, such as SMR, we use a CLR of 10% and 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. This last point is academic only, because global fossil fuel production declines in our forecast period.

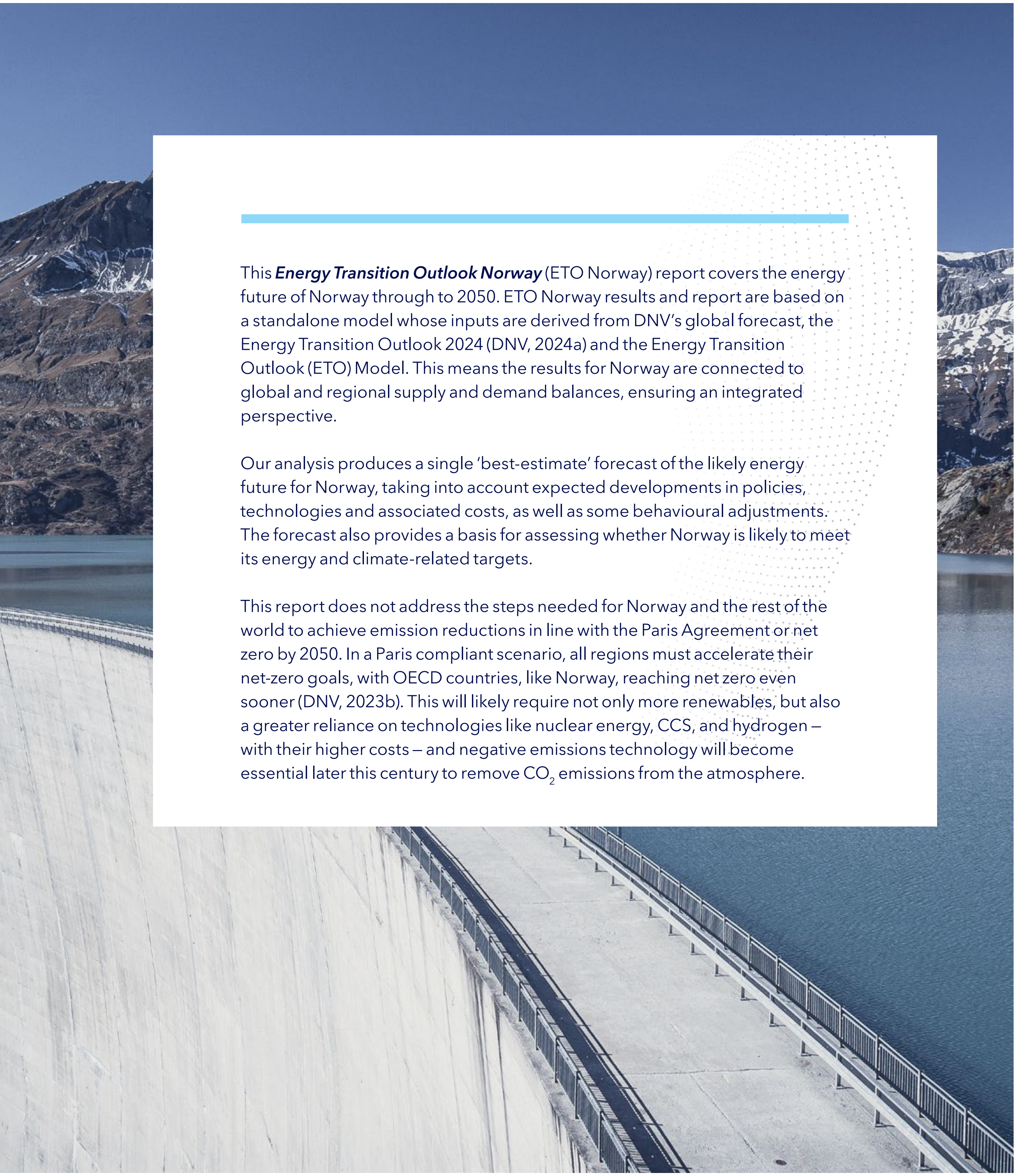
KEY FIGURES

	Population (Million)	GDP* (USD billion) GDP/person (USD)	Energy Use (PJ) Energy Use/person (GJ)	Energy-related CO_2 emissions (Mt) Energy-related CO_2 emissions/person (tonnes)
2023	5.5	439.2 80.3	1297 238	38.8 7.1
2050	6.1	666.6 109.1	1247 204	10.8 1.5

*All GDP figures in the report are based on 2017 purchasing power parity and in 2023 international USD



ABOUT THIS REPORT



This ***Energy Transition Outlook Norway*** (ETO Norway) report covers the energy future of Norway through to 2050. ETO Norway results and report are based on a standalone model whose inputs are derived from DNV's global forecast, the Energy Transition Outlook 2024 (DNV, 2024a) and the Energy Transition Outlook (ETO) Model. This means the results for Norway are connected to global and regional supply and demand balances, ensuring an integrated perspective.

Our analysis produces a single 'best-estimate' forecast of the likely energy future for Norway, taking into account expected developments in policies, technologies and associated costs, as well as some behavioural adjustments. The forecast also provides a basis for assessing whether Norway is likely to meet its energy and climate-related targets.

This report does not address the steps needed for Norway and the rest of the world to achieve emission reductions in line with the Paris Agreement or net zero by 2050. In a Paris compliant scenario, all regions must accelerate their net-zero goals, with OECD countries, like Norway, reaching net zero even sooner (DNV, 2023b). This will likely require not only more renewables, but also a greater reliance on technologies like nuclear energy, CCS, and hydrogen – with their higher costs – and negative emissions technology will become essential later this century to remove CO_2 emissions from the atmosphere.

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 developed a standalone model for Norway and connected this model to the regionally-based ETO model. In this way, we derive separate forecast results for Norway based on the global ETO results with 10 regions, where the European power system is connected to the Norwegian power system.

The analysis covers the period 1980–2050, 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 2024* (DNV, 2024a) but refer to that report for further details.

We are also mindful that this analysis has been prepared during the ongoing Russian war on Ukraine and in the context of an economic environment with high interest rates and historical data based on 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 historical data in 2022 and 2023 represent an anomaly in several sectors compared with historical trends, but also unprecedented energy prices, EU and Norwegian policy interventions, and behavioural changes.

In addition to incorporating the Norwegian energy trade of oil and gas to the rest of the world, we include import and export of electricity, hydrogen, and ammonia. The power sector is extended to include the power trade 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 exports grow.

External views and insights

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 closely align with our baseline expectation.

Such factors could be a changing geopolitical landscape, local opposition, energy security, job creation or global and local climate commitments. Therefore, 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. We are very grateful to everyone involved for taking the time to respond and give feedback on the different topics.

Chapter guide

Chapter 2 discusses the policy landscape shaping Norway's transition. Chapter 3 covers the energy needs of the main demand sectors: transport, manufacturing, buildings. Chapter 4 looks at energy supply from all primary sources (fossil, nuclear, and renewables) and through energy carriers like electricity and hydrogen. Chapter 5 describes Norway's role as an energy exporter and its importance for Europe. Finally, Chapter 6 quantifies and discusses the emissions in Norway and especially those associated with the energy system whose evolution we forecast.

2 POLICY

Norway's energy and climate policies are at a pivotal point, where time for alignment with climate goals and trends in key markets is running short. Amidst a shifting global energy landscape, the EU's energy, climate and industrial policy objectives are focusing on regional and national renewable energy, climate and economic security. Because it is deeply embedded and influenced by EU policies, Norway has a balancing act ahead in combining heavy reliance on fossil-fuel production/export revenue with domestic targets for emissions reduction and clean energy expansion. Progress on transition opportunities will falter unless greater clarity on Norway's implementation and alignment with the EUs policy framework is achieved, and predictability in governmental strategies and financial conditions, including public financing, is enhanced.

Political context framing Norway's transition
In the context of the EEA Agreement, Norway and the EU agreed to cooperate on climate change in 2019. Norway takes part in EU climate legislation (2021–2030) on the emission trading system (EU ETS), Effort Sharing Regulation (ESR applying to sectors not part of the EU ETS) and the LULUCF Regulation, with shared commitments applying to all Norwegian emissions (Meld. St. 13 (2020–2021)). The 2030 aim is to cut greenhouse gas (GHG) emissions by 55% or more, compared with 1990 levels. Norway's Climate Change Act has a 90–95 % reduction target for 2050. The energy sector is by far the most important source of GHG emissions, contributing to 68% of the national emissions in 2022 (NEA, 2024), and in 2023, the Government agreed to deepen collaboration in the Green Alliance with the EU with further partnering in areas such as CCS, offshore wind, hydrogen, and critical materials.

In 2023, EU total net GHGs had decreased 37% below 1990 (EEA, 2024); Norway had reduced its domestic GHGs by 5.2% from 1990 in 2022 (Government.no, 2023), 11% if including LULUCF. In monitoring Norway's delivery on climate targets in regulation currently in force under EEA law, the EFTA Surveillance Authority's ESA Climate Progress Report 2024 sees a gap to the ESR 40% reduction target (ESA, 2024) and urges additional measures. The '*Fit for 55*' legislative package, bringing EU legislation in line with the 2030 goal, and the *REPowerEU* plan strengthening the legislation further, is 'work in progress' in terms of incorporation into the EEA Agreement (NOU:7, 2024).

Five prominent developments and dilemmas affecting Norway's transition dynamics.

1. Fossil fuel revenue deflects non-fossil investment
As a primary supplier of oil and gas to Europe, Norway is playing a critical role in EU's energy security. Following the shock to the European energy market from Russia's invasion of Ukraine, Norway has boosted gas exports by around 10%. Total oil and gas export revenue in 2022 was estimated at NOK 1,900 billion, the highest ever recorded. The NOK 1,200 billion recorded in 2023 was still high by historic standards (Norsk Petroleum, 2024), and lower revenue in 2024 will reflect softer gas prices rather than lower volumes. The Sovereign wealth fund has grown to USD 1.7 trillion in 2024 and so has the amount available for the regular budget, given the 3% spending rule linked to the fund's value. This appears to instil much less urgency in the transition away from fossil fuels, compared with the observed policy signals and actions among fossil-fuel import reliant European neighbours that are progressing their transitions faster. Agreed EU policy is setting the European economy on course to become emission free; and since the EU is Norway's most important trade partner, uncertainty prevails over future demand for oil, gas as well as low-carbon ('blue') hydrogen production, and therefore also future export revenue. Despite uncertainty, the investment landscape remains skewed toward fossil fuels, while investment in non-fossil opportunities has largely stalled.

2. Rising demand from new power-intensive industries
While Norway's power production is dominated by hydropower (average yearly 137 TWh of total production around 156 TWh), and there is potential for upgrades and extensions (Vilberg et al., 2023), new hydropower development is constrained by nature concerns and by cost-competition from other renewables. However, demand for electricity is growing – driven by electrification of energy uses – while supply and transmission capacity are lagging. A power deficit is likely in the 2030s, underscoring the urgent need for renewable development and grid expansion. New types of power demand will originate from data centres, renewable hydrogen production, battery production, and the petroleum sector. Most recently, data centres by Google (Skien) and Green Mountain/TikTok (Hamar) are cases in point, which if fully built out would require almost 9 TWh/yr. The advent of these hyperscale data centres has stirred debate about use of renewable energy, and more specifically the use of hydropower given its value as a dispatchable source and the near-term prospect of a power deficit. Nevertheless, these developments underline the need for expedient investment in renewable power expansion.

A lasting Norwegian power surplus is the most important measure to ensure low and competitive prices long term (Strømprisutvalget, 2023). Similarly, the Energy Commission (2023) in the NOU 2023:3 assessment outlines the need for 40 TWh new renewable generation by 2030 and 20 TWh from energy efficiency improvements (savings) as part of sustaining competitive advantages for Norwegian industry.

3. Power to municipalities on new renewable generation
Norway signed the COP28 *Global Renewables and Energy Efficiency Pledge* to triple installed renewable energy generation capacity and double the annual rate of energy-efficiency improvements by 2030. Nationally, however, decision-making over renewables generation expansion increasingly resides with municipalities where projects face obstacles for reasons such as visual intrusion, conflicting land-use priorities, and questions concerning the equitable sharing of economic benefits. With onshore wind, environmental and public opposition has completely halted new installations. Amendments in 2023 to the Planning and Building Act and the Energy Act aim to improve coordination between the two acts. However, it still remains the responsibility of the municipalities to first adopt a zoning plan for wind power projects and other land uses (Government.no, 2024a) before licensing can take place under the Energy Act - which effectively allows municipalities to veto projects and requires their involvement throughout the planning process (i.e. the time from licensing applications for the construction of power plants to the licensing decision). To distribute economic benefits more equitably, tax rules have also been modified with a production tax at NOK 0.023 per produced kWh that is paid in full to the host municipality; but the effect on new project plans has yet to be seen. Offshore wind presents a slightly less contentious opportunity, though it requires significant investment and policy support to demonstrate 'first-of-a-kind' projects and create certainty for investors as part of triggering industry experience and technology cost-learning dynamics. Offshore wind will always remain more expensive than onshore wind but benefits from

higher revenue potential given the greater speed and reliability of wind offshore, and can also leverage strong Norwegian offshore competences and industrial co-benefits. However, the prevailing cost-efficiency logic that influences policy making (Andersen & Tvinnereim, 2023) and the related debate about commercial viability create uncertainty about commitments while neighbouring EU countries are advancing their plans.

4. Delay in implementation of EU policies creates business uncertainty

2024 marks 30 years of EU and Norway collaboration in the EEA agreement. EØS-Utvalget (2024) assessing the agreement in NOU 224:7 highlights the EU regulatory framework as increasingly comprehensive with policy-making on directives and regulations related to energy turbocharged lately – on the common market, renewable energy, energy efficiency, innovation, transport, climate and clean industry matters. The pressure on Norway's public authorities and administrators is growing to keep pace. While the EU announced the completion of key *'Fit for 55'* legislation in October 2023, Norway has yet to decide on implementation of the *Clean Energy Package* (CEP) on which the EU reached agreement in 2019. Several directives in the CEP have since been strengthened to deliver the EUs *Green Deal* objectives through the *'Fit for 55'* package (2021) and the *RePowerEU* plan (2022); and the EU is preoccupied with implementation of agreed policy. The backlog in EEA relevant legislation transposition is a hinderance for regulatory clarity for Norwegian business and market players wishing to shift the Norwegian energy profile and engage in the European market transition.

5. Predictable transition policies needed to unlock private investment

Positioning Norway for value creation in the low-carbon technology and energy space depends on long-term plans and predictable support to attract investments in nascent industry developments and infrastructures. Norway has taken steps to firm up efforts, such as incentives targeting the maritime sector, with ENOVA (2023) announcing up to 80% CAPEX investment support to hydrogen and ammonia from its NOK 2.2 billion programme, and the State Budget proposing a NOK 8,1 billion allocation to ENOVA in 2025 to contribute to new climate and energy solutions, including support to household energy efficiency improvements. Several Norwegian companies enjoy financing opportunities from EU funds, such as EUR 484 million (NOK 5,7 billion) from the Innovation Fund, October 2024 (ENOVA, 2024a), and the SKIGA project selected for a grant of € 81.3 million in the first hydrogen auction, April 2024. These allocations point to the relevance of resolving delays in policy implementation (previous point), and in so removing uncertainty around Norwegian participation in for example the *Renewable Energy Directive* (RED III) and the *Net Zero Industry Act*.

For Norway's domestic decarbonization efforts and for the transition to evolve, clarity on the 'next round' of projects and uptake obligations in domestic sectors is needed to derisk investments. For example, the future trajectory for biofuel blending and implementation of the *ReFuelEU* aviation initiative is unclear, which creates uncertainty for SAF production/investments. In the maritime sector, the government overturned the requirement for ships (above 10 000 GT) to sail emission free in UNESCO protected fjords by 2026, with a delay until 2032 (Goverment.no, 2024b), which puts early movers' investment at risk. In CCS, the follow up to the Longship project is missing as noted by NTNU/SINTEF (2024). In offshore wind, while the target is 30 GW of allocated areas by 2040, the number of consortium willing to bid has recently been shrinking; and in the context of agreed projects, safeguarding domestic value creation can be enhanced further, such as through economic resilience criteria like the EU adding non-price criteria to renewable energy auctions inclusive of economic resilience and biodiversity criteria. The ambition is for offshore wind to be a catalyst for industry development, but the Sørlige Nordsjø II project was awarded to the lowest bidder without requirements for domestic content or resilience considerations (Goverment.no, 2024c).

Overall what is needed is holistic planning for positioning clean energy-industrial value chains and infrastructure, and bolder and reliable policy frameworks and stable support to enhance investment attractiveness, also to sustain future energy exports ambitions.

FIGURE 2.1

Policy factors included in our Outlook

Policy factors in ETO Norway

Our analysis and input into the ETO Model is informed by the policies set out in Norway. Based on our global energy sector knowledge and our technical and commercial expertise, we include our own assessments of the state of play in key energy demand sectors of the economy. 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 1990 levels.

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. What matters to DNV's forecast is that the extent to which ambitious targets are followed by sectoral policies and supportive measures translating ambitions into reality influencing the energy mix and emissions trajectory. 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.

DNV's global Energy Transition Outlook 2024 (DNV, 2024a) includes a comprehensive discussion of the policy toolbox and policy factors influencing the forecast. We advise readers to visit that source for a detailed description of how we account for policy in our forecast. The same policy factors are incorporated in this Norway forecast.

> Our forecast does not assume that Norway will achieve its national target of reducing GHG emissions.

Using the policy factors in our main model, we have incorporated specific adjustments to accommodate the Norwegian policy landscape that has an impact on the results.

Renewable power support

- Fixed and floating offshore wind projects will initially obtain financial support to supply domestic energy demand and establish a domestic market of projects. As cost for offshore wind declines and there is surplus electricity generation in Norway, more electricity can be exported to Europe offering higher profitability, with financial support reducing towards 2050. We assume that floating offshore wind will require more prolonged support than fixed-bottom offshore wind. In addition, we expect there to be mechanisms to redistribute profits from high-margin energy exports, such as hydropower and green hydrogen exports, to further improve the financial viability of offshore wind development.

Zero-emission transport

- The support schemes for passenger EVs incorporate the most recent schemes with no or reduced VAT and registration fees.
- For EVs in the commercial vehicles segment, support schemes will continue as today, until EVs account for 90% of new vehicle sales in 2038.
- We have partially incorporated the government's ambition on increased use of biofuel in transport. The fraction of biofuel use for internal combustion engine vehicles (ICEV) increases from 14% today to 20% in 2030 and remains at that level until 2050.
- In aviation, electrification policy on short-haul flights is considered. In international aviation, future alignment with ReFuelEU policy to increase SAF use is expected.
- In maritime, the fuel mix will largely follow that of the rest of the world, however, nuclear propulsion in Norway is not expected. In short-distance sea travel, electric and hybrid solutions are supported.

Hydrogen

- Natural gas cost used to produce blue hydrogen for export will have a lower cost for steam methane reformers than the industrial gas price, due to the expectation that many reformers will be supplied directly from 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.
- Taxes and grid tariffs for grid-connected electrolysers are assumed to be a 25% surcharge over the wholesale electricity price. This is the combined result of two factors. One is active government support. The other is that some grid-connected electrolysers will be owned by renewable electricity producers who will decide, based on price, whether to sell electricity to the grid or for hydrogen production; if they withhold selling, they do not need to buy electricity.
- We expect production of hydrogen to be subsidized to compensate for initial high cost of low carbon hydrogen. The level of support is expected to be USD 0.25/kgH_2 for blue hydrogen and USD 0.4/kgH_2 for grid-connected hydrogen, until the 2030s when carbon pricing in Europe increases demand for green/blue hydrogen.
- Hydrogen export capacity is gradually growing with increasing hydrogen demand from Europe. An initial new hydrogen pipeline is expected for export with a total capacity for hydrogen export of 2Mt/yr by early 2040s.

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 and blue hydrogen support 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 rest of Europe (reaching USD 250/tCO_2 in 2050) are used.
- A Norwegian carbon price trajectory price reaching 217 USD/tCO_2 (2,230 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 purposes – even if profitable. Thus, we have limited the model for such expansion.
- For offshore wind (bottom-fixed and floating), we do not expect any similar limitation on power capacity expansions, and capacity will be added when profitable, also for export.
- Norway is expected to add generating capacity to support increasing demand for domestic 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 15 GW to Europe.

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 10% from 2023 or a decline of 28% compared to 1990.

3 ENERGY DEMAND

Norway's energy demand is mostly split between transport, buildings, and manufacturing. Total demand has historically grown with population and economic growth, but has not changed much since 2008, due to efficiency gains. Electricity is already the largest source, supplying 44% of the annual demand of 967 PJ (268 TWh). It will reach 65% through the electrification and decarbonization transition towards 2050.

Energy demand typically follows the growth of a population and its wealth through its increased activity. The Norwegian population is expected to grow about 10% to 6.1 million in 2050. The GDP is expected to grow even more, 50% by 2050. Under business-as-usual conditions, one would be expecting a significant growth in energy demand. However, total final energy demand in end-use sectors will not change noticeably towards 2050 and has not since the beginning of the century (Figure 3.1). Not included in this figure is the use of energy to produce energy, which we call energy sector's own use. As the energy sector in Norway is producing more than it consumes, i.e. for export, the energy sector's own use is disproportionately large, adding about 25% to the 1000 PJ in final energy demand. However, this demand is declining with reduction in oil and gas production, which we discuss further in Chapter 4 Energy Supply.

Technological and behavioural advances have steadily improved the overall energy efficiency levels in Norway. For example, changing from incandescent bulbs to LEDs give about 8 times more light per unit of energy and less undesired heat. Heat pumps extract residual heat from the air outdoors and transfer this to homes and commercial buildings. Changing from fossil to electric motors also gives more desired propulsion and less undesired heat.

The improvements in efficiency go hand-in-hand with a change in the energy mix. Norway, which is already quite electrified, will demand 60 TWh (220 PJ) more electricity by 2050 in its end-use sectors, and reduce its fossil dependency from 46% to 22%. That leads directly to lower emissions. However, it also challenges the Norwegian grid and electricity generation, as this demand no longer can be met by dispatchable hydropower alone (discussed in more detail in Chapter 4). Consequently, Norway will be a net electricity importer by the end of the 2020s for a short period.

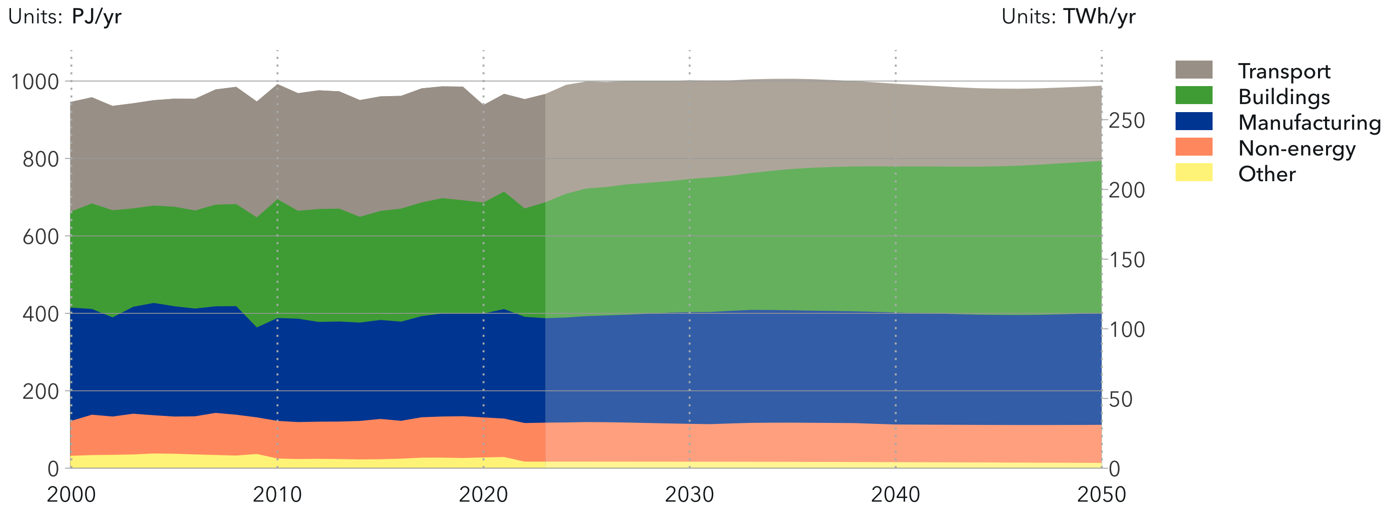
The largest reduction in energy demand will be seen in the transport sector, which will reduce its demand by 85 PJ by 2050. This is mainly due to electrification of road transport. Even though electric vehicles (EV) have the highest market share of sales, it will take time to replace the internal combustion engine (ICE) vehicles already on the road – particularly the heavier ones. Maritime and aviation, which are much harder to electrify, will see decarbonization efforts driven by policy. While not leading to significant reductions in energy demand, it will lead to reductions in emissions.

The reduced energy demand in transport is countered by increased demand from the buildings sector. Appliances and lighting are already pretty comprehensively electrified in Norway, unlike other countries where significant energy efficiency gains can be made by switching to electricity for cooking, etc. Additional, marginal efficiency gains can be made in Norway through continued installation of heat pumps and improving insulation. The biggest change comes from demand from AI and data centres, which will grow from 7 PJ this year to 47 PJ in 2050.

Manufacturing energy demand will only grow 4%. One reason is that Norwegian industry has traditionally developed in the context of cheap and plentiful electricity. The sector now faces the prospect of an electricity supply deficit in the early 2030 and limited options for new, cheap supply. Nevertheless, the relatively high share of electricity (64%) in Norway's manufacturing energy mix in 2023 will rise to 72% by 2050. This sector will also see decarbonization efforts, almost eliminating its use of oil and increasing its use of hydrogen. However, manufacturing will still cause 36% of Norway's energy and process-related CO_2 emissions in 2050.

FIGURE 3.1

Norway final energy demand by sector



Historical data source: IEA WEB (2024), SSB (2024)

3.1 Transport

Transport in Norway – road, aviation, maritime, and rail – accounted for 29% of the final energy demand in 2023, almost entirely in the form of fossil fuels. We forecast a significant decarbonization of the sector, aiding the overall energy demand for transport to decline 31% from 280 petajoules (PJ) in 2023 to 194 PJ in 2050.

Road transport takes the lion share of the energy demand today but will almost cut its demand in half by 2050 through substantial electrification (Figure 3.2). Aviation and maritime splits the rest, with rail demanding a negligible 1% of the transport energy. Aviation will increase its energy demand somewhat, through increased travelling, while maritime transport will reduce its demand, through improved efficiency. The sum of aviation and maritime energy use will stay approximately unaltered. These two subsectors are hard to electrify but will gradually transition to alternative low-carbon fuels. Overall, the fossil share of the transport sector's fuel mix will drop significantly from 89% in 2023 to 31% in 2050.

Road

Norway is world-leading in electrifying passenger-vehicle transport. Beneficial policies to EV owners since 1990, such as reduced taxes, tolls, access to bus lanes, improved charging infrastructure, and continuous international technological development, have substantially increased the market share of battery-electric vehicles in Norway (Figure 3.3). This long-term stimulation of the EV sales serves as an example to the EU, which has banned sales of new fossil passenger vehicles from 2035 (European Parliament and EU Council, 2023a). Despite Norway's growing population and economy, we forecast that the total number of cars will decline towards 2050.

In 2017, the Norwegian Parliament approved a National Transport Plan for 2018-2029, which quantified goals for the EV friendly policies (Samferdselsdepartementet, 2017). The plan stated that all new passenger vehicles and light vans sold from 2025 should be zero-emission. Similarly, 100% of heavier vans, 75% of buses, and 50% of long-haul trucks sold should be emission-free by 2030. The EV market share for new passenger vehicles nationally is now close to 90% and will be the most common type of passenger vehicle on the road by early 2032 (Figure 3.4). The transition is lagging for commercial vehicles, which includes everything from smaller vans and utility vehicles to municipal buses and long-haul heavy road transport. We forecast that EVs will take the dominant market share for commercial vehicles first in 2031.

With the market share of passenger EVs increasing in Norway, several beneficial policies are being rolled back, such as the heavily-debated access to bus lanes into Oslo. With the 2025 target for zero new ICEV passenger car sales around the corner, Norway's proposed National Budget for 2025 does not include the incentives needed to reach the almost decade-old goal. Indeed, some fees, such as the traffic insurance fee, seem to the benefit of ICEV sales (Loftås, 2024).

On the positive side, the slower than desired electrification of commercial vehicles has prompted new incentives in the new National Transport Plan for 2025-2036 (Samferdsels-departementet, 2024). The plan points to the lack of charging infrastructure for commercial vehicles as an inhibitor of the transition. To counter this, Enova started a funding programme for the building of charging stations for commercial vehicles (ENOVA, 2024b). 2024 also saw the opening of the first public charging station for heavy trucks in Norway. Additionally, the plan includes increasing the biofuel blending share from 14% in 2023 to 33% in 2030 to reduce fossil emissions from conventional ICEV fuels.

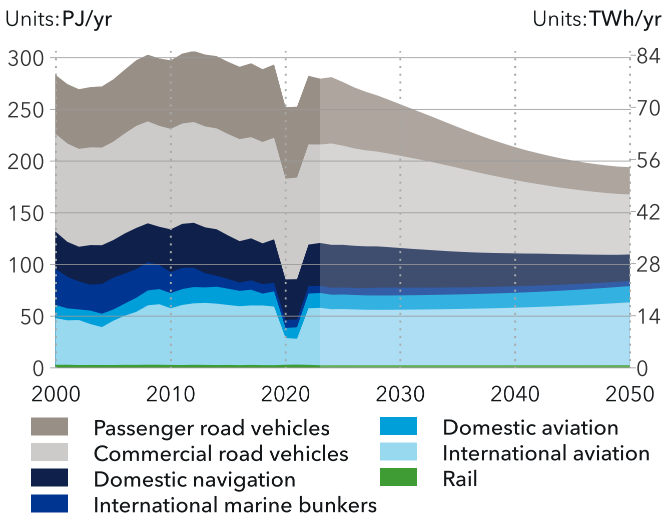
Even though EVs have a leading market share country-wide for passenger vehicles, there are clear regional differences in the number of registered EVs on the road. While Oslo has reached 40% EVs with Akershus close behind, Innlandet, Troms, and Nordland remain around 15%, with Finnmark bringing up the rear at 8% (Norsk Elbilforening, 2024a). The slower transition in the more rural areas, even though it has been cheaper to own EVs than ICEVs since 2016 (Figure 3.5), shows that cost is just one factor in the EV transition. Usability is also important – there is a reason why "range anxiety" and "charging anxiety" have entered the language. We forecast a doubling of the number of fast chargers over the next decade. Additionally, the average range per charge is expected to continue to grow (Figure 3.5).

If one considers driving from Oslo to Bergen, Stavanger, or Trondheim, the driving distances are all within 470-550 km. That could have required two recharges 10 years ago but is soon achievable without recharging. Such technological developments will make EVs a superior passenger-vehicle option countrywide. It will also aid the transition for many types of commercial vehicles, even though we expect a residual market share for long-haul commercial ICEVs in 2050.

The grand total number of vehicles on the road is expected to keep approximately constant until mid-2030s. From then, our analysis reveals a 12% reduction in the total number of vehicles by 2050, due to a reduction

FIGURE 3.2

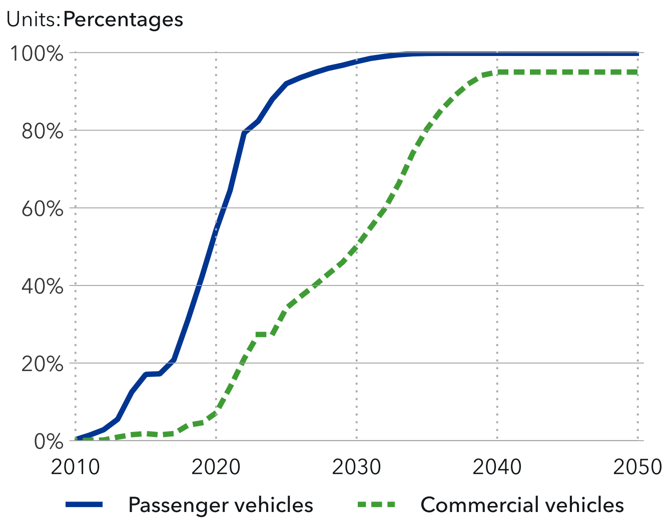
Norway transport sector energy demand by subsector



Historical data source: IEA WEB (2024), SSB (2024)

FIGURE 3.3

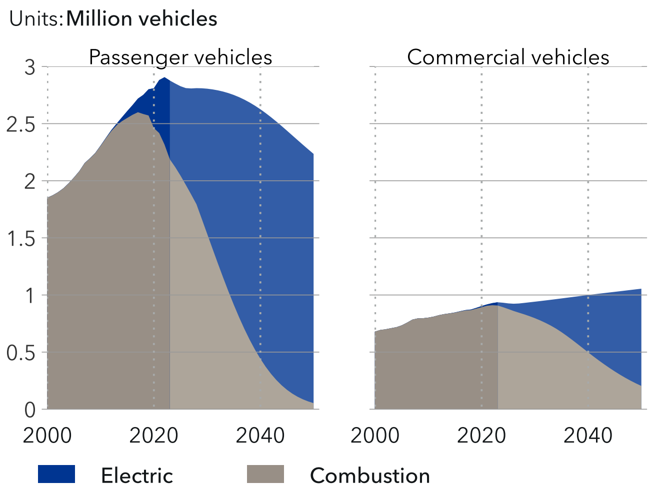
Norway market share of electric vehicles



Historical data source: IEA WEB (2024), SSB (2024)

FIGURE 3.4

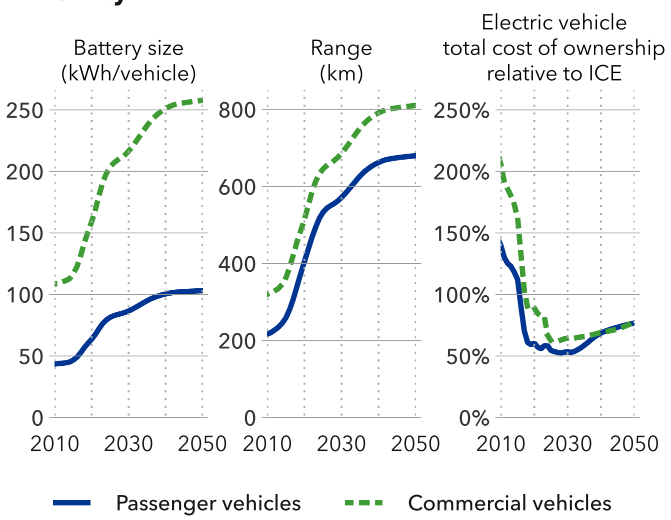
Norway number of road vehicles by type and drivetrain



Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs. Historical data source: SSB (2024)

FIGURE 3.5

Development of key parameters of electric vehicles in Norway



of passenger vehicles, while the number of commercial vehicles will increase. This is not due to a reduced need for travel. In fact, the total driving distance will rise 11% over the same period. Instead, each vehicle will be used more, through ridesharing and automation. This behavioural change will gradually reduce the total number of vehicles.

The electrification of vehicles will reduce the road subsector energy demand substantially (Figure 3.6), despite the increasing kilometrage. The main reason for this is that EVs are three to four times more efficient than ICEVs. This electrification will also reduce Norwegian CO_2 emissions.

Aviation

Aviation has been and will be important to ensure efficient travel domestically in Norway, particularly in the north, as well as internationally. Flying is currently price competitive between the biggest cities in the south compared with rail and private road transport. While we forecast a 69% increase in passenger flights per year from 2023 to 2050 due to a larger and more wealthy population, there will only be a 9% increase in energy demand in the same period, owing to efficiency gains. Significant changes will occur in the fuel mix due to regulations, causing CO_2 emissions to drop 51% in the same period (Figure 3.7).

Norway, with its sparse population separated by mountains and fjords, will most likely continue to rely on aviation for domestic transport, rather than building high speed trains in the south and new railways in the north. Many relatively short routes make Norway an ideal market for electric flights, supported by government and companies alike. The government aims at all domestic flights being electric by 2040 (Luftfartstilsynet, 2020). SAS is already selling tickets to their first electric flights in 2028 (SAS, 2023), while Widerøe aims at their first commercial electric flights in the early 2030s (Widerøe, 2024). We do not forecast the governmental goals to be fully met, but Norway will likely be a leading player in the electrification of short-haul aviation.

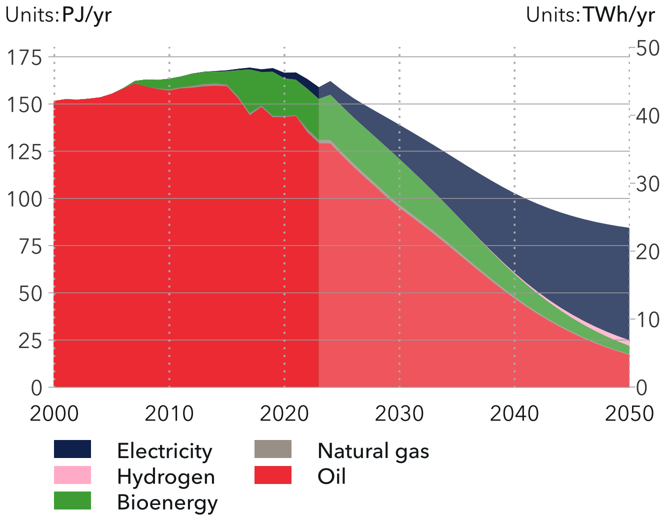
International aviation makes up 80% of the air travel and cannot be electrified due to the long distances. Nevertheless, a significant change to sustainable aviation fuels (SAF), including biofuels and synthetic fuels, is expected, and the ambitious *ReFuelEU* initiative (European Parliament and EU Council, 2023b) will be a main driver of SAF uptake. This regulation includes a gradually increasing SAF portion requirement from 6% in 2030 to 70 % in 2050. Norway is planning to follow these goals at some point in the future (Klima- og miljødepartementet, 2024). However, the infrastructure to produce and distribute the SAF is a key bottleneck for these goals, which are unlikely to be fully met, and will require additional policy and support.

Maritime

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

FIGURE 3.6

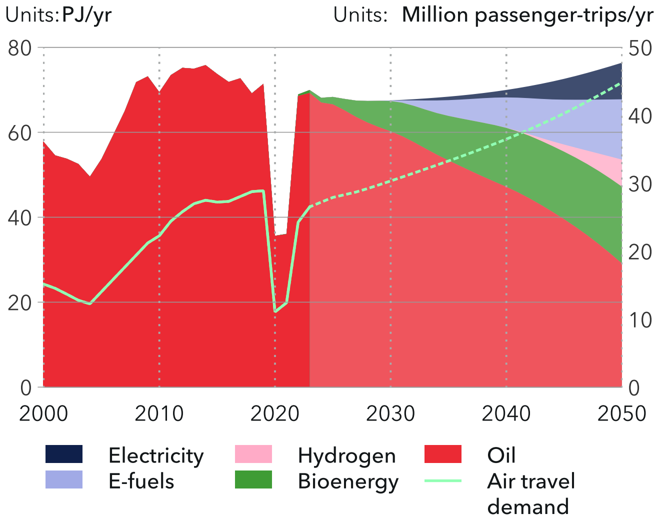
Norway road subsector energy demand by carrier



Natural gas includes LPG. Historical data source: IEA WEB (2024), SSB (2024)

FIGURE 3.7

Norway aviation subsector energy demand by carrier



Historical data source: IEA WEB (2024), SSB (2024)

metre. 5% of Norway's final energy demand is consumed by ships today, mainly from domestic use. This energy demand is largely fossil: 14% of Norway's oil demand goes to maritime transport. Hence, transitioning to alternative low-carbon fuels can significantly reduce Norwegian emissions. Additionally, maritime energy demand will decrease towards 2050 (Figure 3.8). The reductions stem from both efficiency improvements as well as a gradual reduction of offshore activities (Sokkeldirektoratet, 2024).

Significant changes in the maritime fuel mix are expected globally. The changes are driven by policies, such as the International Marine Organization's (IMO) strategy for cutting greenhouse gases (GHG). The goals include a gradual reduction to net-zero GHG emissions "by or around 2050" (IMO, 2023). Unlike in road transport, alternative fuels will be more expensive than conventional oil-based fuel in the foreseeable future. Hence, the strategy includes a GHG emission pricing mechanism. Due to the intentionally vague deadline, lack of enforcement mechanisms, and opportunity to rather pay for GHG emissions instead of transitioning, we do not foresee that IMO goals will be fully met. Nevertheless, the industry is moving towards a transition, figuring out which changes to implement first.
An in-depth analysis of the fuel options is given in DNV's *Maritime Forecast to 2050* (DNV, 2024b).

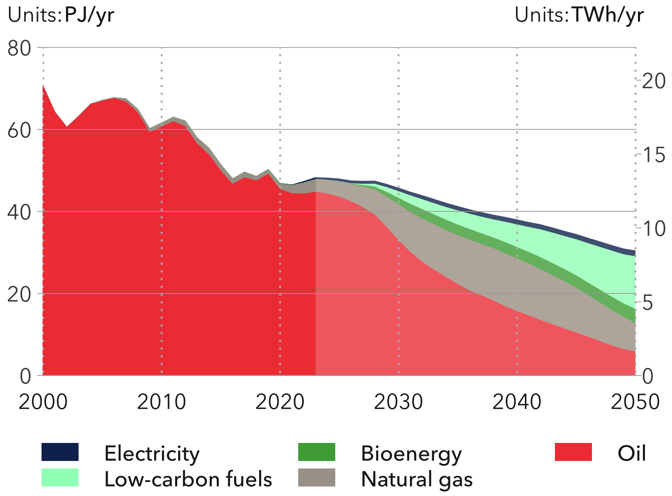
Norway's fuel mix will largely follow that of the rest of the world with two main differences: (1) We do not foresee nuclear propulsion in Norway, as we now have included in our global fuel mix in the late 2040s (DNV, 2024a). (2) Norway might lead the way in implementing electric and hybrid solutions. More than 1 in 4 Norwegian ferry connections include at least one ferry mainly running on electricity (Norsk klimastiftelse, 2024).

Rail

The Norwegian rail subsector consists of all tracked transportation, including urban rail transport such as subways and trams. It contributes about 1% of the national transport energy demand (Figure 3.2) and will continue to do so. While already quite electrified, diesel trains will increasingly be replaced, taking the share of electricity from 83% today to 97% by mid-century. Both the National Transport Plan for 2025-2036 and Bane Nor's list of projects (Bane Nor, 2024) include plans predominantly for increasing the capacity in and around the major cities. The plans do not include building high speed trains between these cities. Hence, rail will improve its ability to transport daily commuters but will most likely not challenge the position of aviation for domestic long-distance travel in Norway.

FIGURE 3.8

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 (2024), SSB (2024)

3.2 Buildings

Today, the buildings sector makes up 31% of Norway's energy demand, making it the largest demand sector. This share will increase further to 40% in 2050, as transport energy demand shrinks. Today, buildings' energy demand is at nearly 300 PJ; this will have risen to over 390 PJ in 2050 as growing GDP per capita and expanded floor area drive demand up. Energy efficiency gains from stricter regulations on improved building insulation, further electrification and efficiencies from learning will, however, temper demand. The Norwegian buildings sector is already highly electrified, with electricity making up 80% of buildings energy demand; this will continue to rise to over 90% as biomass and direct heat continue to fall away; oil and natural gas will be virtually non-existent in 2050.

We divide buildings energy demand into five end uses: appliances and lighting; space heating; water heating; space cooling; and cooking. Of our five end uses, space heating takes up the largest share of buildings' energy demand today, at 147 PJ, (49%), and will rise in absolute numbers to 164 PJ in 2050, though its share will decrease to 42% as appliances and lighting's share grows. Heat pumps will be key to this end use in 2050. Although sales have dropped this year in some European countries with the delay of the launch of the European Union's Heat Pump Action Plan, they have increased in Norway (Todorović, 2024). Space heating in 2050 will be over 80% electric, with 31% of households being heated by conventional electric solutions like underfloor heating, and 62% by heat pumps.

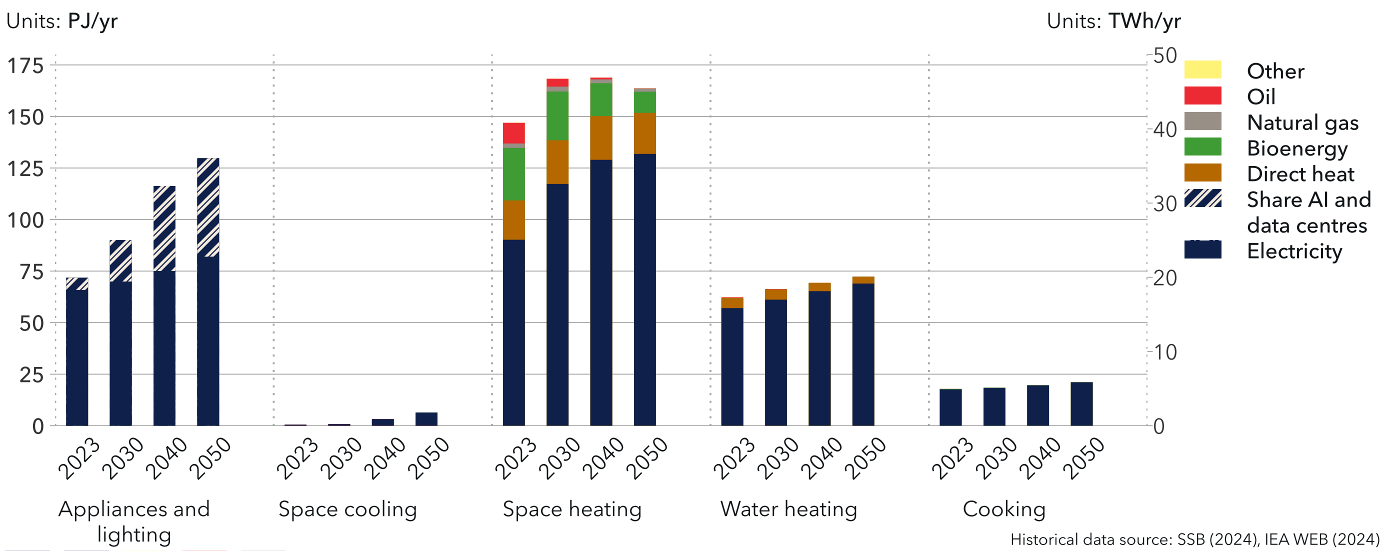
In our second-largest end use, appliances and lighting, we see a significant growth in demand, from 72 PJ today to 130 PJ in 2050. This is mainly due to demand for energy from AI and data centres. Big tech firms have already installed data centres in Norway, such as Green Mountain data centre in Hamar (working solely with TikTok), and Google's data centre in Skien, raising concerns about rising electricity prices and whether or not the grid will be able to handle the extra load. Today, data centres in Norway use about 2 TWh of energy; we forecast that this will rise to almost 6 TWh by 2030 and 13 TWh in 2050.

Water heating will rise about 15% to 72 PJ in 2050, and be 95% electric, with a small amount of direct heating. Cooking energy use will rise about 20% from 17 PJ today and will be exclusively electric. With climate change, increased cooling degree days and increased installation of air conditioning, space cooling energy demand will grow to 6 PJ in 2050, the smallest of our end uses.

> Electricity will continue to rise to over 90% of the buildings energy mix, as biomass and direct heat continue to fall away; oil and natural gas will be virtually non-existent in 2050.

FIGURE 3.9

Buildings energy demand by end use and carrier



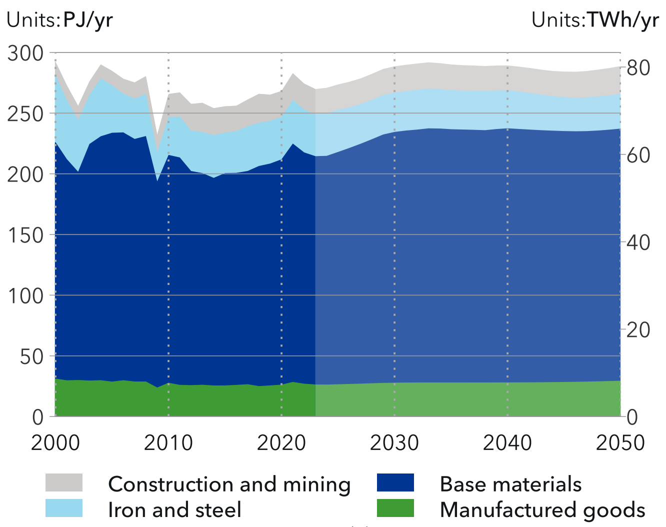
Historical data source: SSB (2024), IEA WEB (2024)

3.3 Manufacturing

Norwegian industry has developed in the context of, and partly because of, stable and sufficient access to cheap electricity. Hence, the electricity share (64% in 2023) has always been high, and is at present twice as high as for Europe as a whole. Further reduction of emissions through even more intensive electrification of manufacturing is demanding, and the electricity ratio will therefore increase only slightly to 72% by 2050. The sufficiency of access to electricity is also a challenge in the near term: today, parts of the Norwegian industry are impacted by limited growth in electricity generation and grid capacity.

FIGURE 3.10

Norway manufacturing energy demand by subsector



Historical data source: IEA WEB (2024), SSB (2024)

Energy demand from manufacturing will only increase 4% to 289 PJ in 2050, or 29% of total final energy demand in Norway, a modest increase compared with the present share of 28%. Volumes of natural gas consumption will stay at almost the same level throughout the forecasting period, starting at 11% and stabilizing at 9% from around 2030. Oil demand will be very small in 2050, approaching 1% of the final demand, following a reduction of more than three quarters of today's volumes. Hydrogen grows slowly through the period, from less than 1% in 2030 to 8% of the energy demand in 2050 as we expect decarbonized hydrogen to increasingly replace coal and natural gas as an energy carrier for manufacturing processes.

Energy demand across manufacturing

The manufacturing sector in our analysis consists of the extraction of raw materials and their conversion into finished goods. However, fuel extraction and conversion are accounted for under 'Energy sector own use' (Chapter 4). Manufacturing in our Outlook covers four subsectors:

- Construction and mining – includes mining and construction of roads, buildings, and infrastructure. It accounts for 8% of the energy demand in manufacturing, both now and in 2050 as seen in Figure 3.10. We predict a demand increase at around 10%, primarily linked to continued construction linked to an increase in the population.

- 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. Base materials will account for more than two-thirds (71%) of the total manufacturing energy demand (Figure 3.11). Energy consumption in the base material subsector is mainly from industrial high-heat processes and from operating machines, motors, and appliances. Norway is Europe's leading aluminium producer, and aluminium production demands more than 15% of the total electricity consumption in Norway and more than half of the electricity consumed in manufacturing. The segment plans for a higher ratio of recycled aluminium (Hydro, 2024) and that will reduce energy intensity per tonne produced but will not alter the prominent role of aluminium as energy user. On the other hand, some emissions will remain as coal used in anodes is hard to replace and will remain in the energy mix also in 2050. In our model, petrochemicals see a 30% increase in energy demand as production of blue hydrogen and ammonia for energy purposes are growing segments in this category. Energy demand for base materials in total grows by 8%.

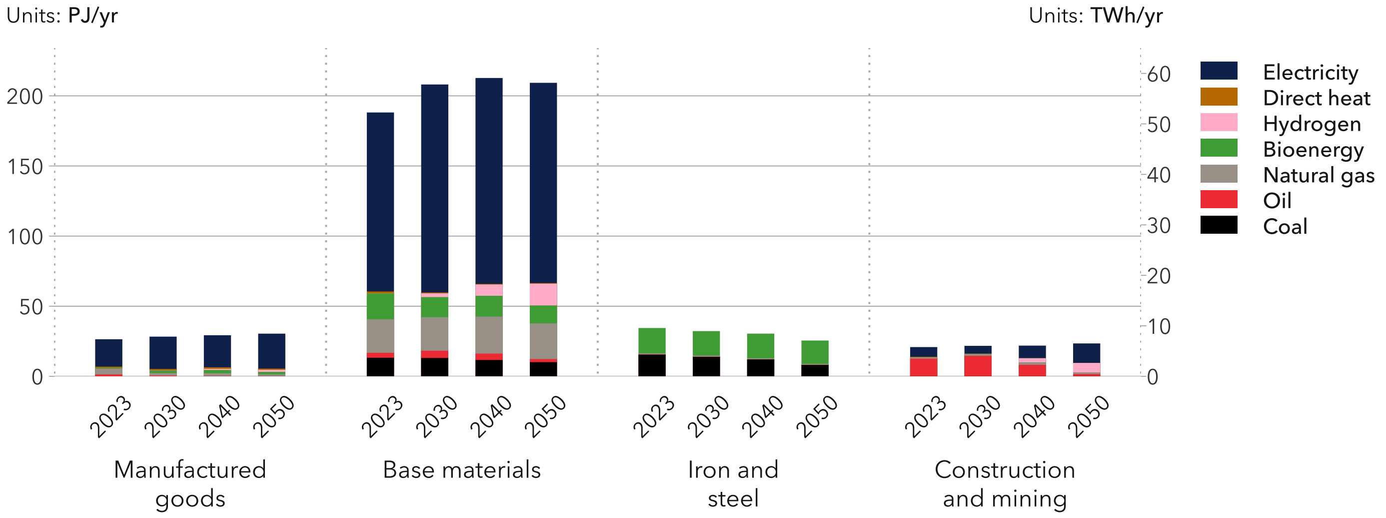
- Iron and steel production – We forecast a 10% reduction in the annual domestic steel production towards 2050. The share of the energy demand is reduced from 13% to 10% of the demand in the manufacturing sector. This corresponds to an 17% reduction in energy demand due to reduced production and efficiencies linked to introduction of hydrogen in the energy mix and a halving of coal consumption.

- Manufactured goods – includes production of general consumer goods; food and drinks; electronics, appliances, and machinery; textiles and leather; and vehicles and other transport equipment. Manufactured goods will have a 12% increase in energy demand in the period. This includes moderate growth and some electrification. Battery production is an area that could increase demand in this part of manufacturing. Our forecast tentatively includes a modest growth; the current developments in Norway and Sweden suggest that getting battery production up and running in Norway is challenging.

Taken together, we find a 68% reduction in CO_2 emissions from manufacturing in 2050. This is one piece in the puzzle that adds up to the conclusion that Norway will not meet its emission reduction targets. The remaining CO_2 emissions in manufacturing 2050 will account for 36% of Norway's total emissions by then.

FIGURE 3.11

Norway manufacturing subsectors energy demand by end use



Historical data source: IEA WEB (2024), SSB (2024)

Electrification and access to electricity

Access to cheap electricity has been the manufacturing industry's main competitive advantage since the early 1900s. This is now at risk, both from a production and policy perspective.

From a production perspective, Norwegian hydropower is cheap, and large parts of it have been written down many decades ago. New hydropower is only minimally available, and not cheap. Norway has among the best wind conditions in Europe and cheap onshore wind, but public resistance has brought the buildout to a full stop. Solar PV is now the cheapest form of new electricity most places in the world, and also in Southern Europe, where electricity from solar PV, and from onshore wind, can be produced more cheaply than electricity in Norway.

From a policy perspective, Norway is evermore connected to Europe. In today's liberalized power market, with international connections, there are fewer opportunities for price arbitrage favouring Norwegian manufacturing. Hence, reducing reliance on imported electricity becomes even more important (as it indirectly influences prices).

According to our forecast, the share of Norway's total demand covered by electricity will continue to grow, reaching two thirds of Norway's energy demand in 2050. The country's manufacturing industry has expansion and decarbonization plans requiring additional electricity, but access to electricity is challenged by many potential offtakers within and beyond manufacturing, and we expect there will be a queue for grid capacity within the next 10 years.

New demand categories, such as oil and gas installations and data centres, are generally less price sensitive and can accept higher electricity costs than traditional industry. With constrained electricity supply, this competition will challenge the Norwegian manufacturing industry's access to cheap electricity. Politicians can in theory decide who will get the power, but direct involvement in prioritization is disputed.

Arguments for maintaining a strong Norwegian manufacturing industry are increasingly being linked to energy and economic security considerations. It is likely important for Europe to maintain aluminum production on the continent, hence, ways to maintain production, in spite of the historical benefit of cheap power fading away, are likely to be found.

Oil and gas installations and data centres are generally less price sensitive and can accept higher electricity costs.

Policy related to manufacturing

Changes in Norwegian manufacturing's energy mix depend on technological innovation and resource availability, but it also depends on policies and incentives. The most important of these is the CO_2 carbon price, which is planned to steadily increase up to 2030 for emissions not covered by the EU ETS-scheme. The carbon price imposed by the government will be 1400 NOK/tCO_2e in 2025 and increase to 2400 NOK/CO_2e (2025 value) in 2030 (Regjeringen.no, 2024). However, CO_2-compensation is paid to some of the companies, somewhat reducing the impact of high CO_2 prices. The industries receiving compensation are now required to allocate 40% of the funds towards emission reduction and energy efficiency measures, indicating a shift in the government's approach to CO_2 compensation, balancing industrial competitiveness with environmental objectives.

For the third year now, the government's Green Book (Regjeringen.no, 2024) linked to the proposed national budget for coming year. It details potential emission reductions and makes visible the need for further policy measures to achieve agreed/promised emission level by 2030. It describes that much of the potential for emission reductions with CCS (3 Mt CO_2) and transition to hydrogen (0.4 Mt CO_2) will need additional measures to be realized. The Green Book describes that Norway will not meet its targets with today's policy measures, potential additional measures are mentioned as key words but not proposed directly. We explore CCS and hydrogen in greater detail elsewhere in our report.

3.4 Non-energy use

Non-energy use refers to the use of coal, oil, and natural gas for non-energy purposes for example the production of plastics and fertilizers. Oil consumption for non-energy use is stable around 35 PJ/y all the way to 2050 (Figure 3.12), this is for all practical purposes use outside the petrochemical industries. Natural gas consumption is similarly steady with volumes just above 65 PJ/y used for production of ammonia and methanol as feedstock as well as products in the chemical industries including plastics. Altogether this represents 10% of the total energy demand in Norway.

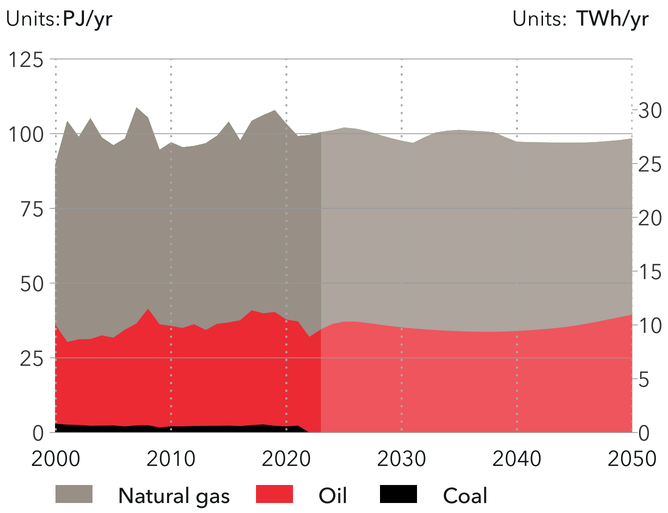
However, an important distinction is to highlight that natural gas demand for producing ammonia not for feedstock but for use as an energy carrier will grow in the future. Natural gas as raw material for producing blue ammonia will increase in the period 2030-2040, as there is an opportunity where Norway is price competitive in delivering blue ammonia to Europe.

Natural gas as raw material for methanol production intended to be used as energy carrier will grow about 25% from 2030 to 2050. We find that the increased volumes correspond with European market demand for blue methanol, and this can be produced due to an established CCS supply chain.

For other chemicals and plastics, the demand will be reduced by almost 30%. However, a higher ratio of recirculated plastics means that total plastics production is not decreasing as much. Annual domestic plastic production is around 410 000 tonnes primary plastic today, two thirds of this is exported and one third is used in Norway. The total domestic plastic consumption is higher (900 000 tonnes) but most of this is not visible in the energy/emissions accounting of Norway as it is imported.

FIGURE 3.12

Norway non-energy demand for energy carriers



Historical data source: IEA WEB (2024), SSB (2024)

3.4 Energy demand by carrier

By combining energy demand for the demand sectors covered, we forecast Norway's final energy demand by energy carrier (Figure 3.13). '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 2023, electricity represented 44% (424 PJ) of the country's final energy use. In 2050, it will account for 65% (645 PJ). Reasonably priced and efficient 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. We foresee electricity increasingly replacing coal, oil, and later gas in the final energy demand mix further amplified by new demand for electricity for electrolysis-based hydrogen production.

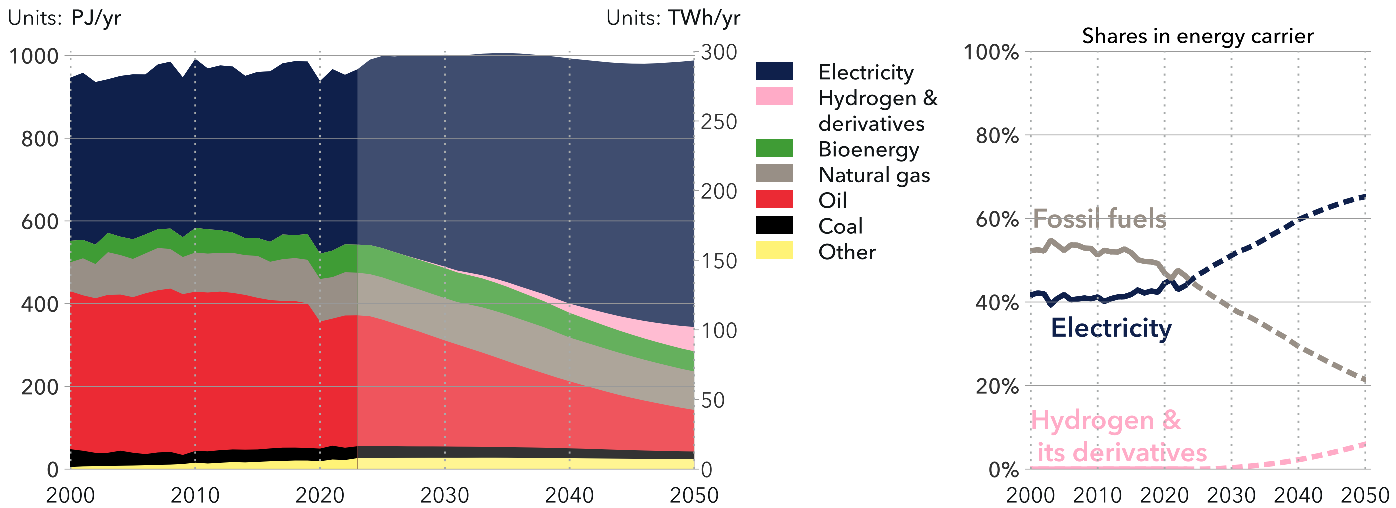
Hydrogen and hydrogen derivatives will enter the energy mix with a modest growth, represent 0.3% of energy use in 2030, 2% in 2040 and 6% in 2050.

Direct use of bioenergy will see increased uptake because of the incentives for increased biofuel use in the transport sector and will grow with almost 50% towards 2031. However, with declining shares of internal combustion engines from 2030 onwards, biofuels use will also fall such that its use will only be slightly higher (16%) compared with today. Other uses of biomass will decline towards 2050 with buildings leading the decline (60%) and manufacturing, that will see some uptake initially in the 2020s, but declining by 37% towards 2050 as electricity and hydrogen become preferred energy carriers.

Natural gas demand in end-use sectors will remain stable throughout the forecast period at ca 100 PJ/yr. 60% of the use is as feedstock and the rest is in the manufacturing sector, with a small but growing share for transport that ends up at 8% of natural gas demand in 2050. Oil demand will decline 80% in the transport sector, which almost exclusively comes from road transport changing to EVs. However, the decline in oil demand is somewhat mitigated by increased demand for oil as feedstock in the petrochemical sector.

FIGURE 3.13

Norway final energy demand by carrier



Historical data source: IEA WEB (2024)

4 ENERGY SUPPLY

Norwegian oil and gas production is set to decline sharply in our 25-year forecast period, with oil falling by 83% and natural gas by 44% (Figure 4.1). Our model results are roughly comparable with the Basis scenario recently published by Sokkeldirektoratet (2024), although our results indicate a faster decline in oil production and a somewhat slower reduction in natural gas production.

Despite the long-term decline, Norway's energy resources are still abundant and will be increasingly important in an European context as energy security rises on the agenda. Natural gas from Norway is important for the green transition in Europe in terms of keeping coal use at bay in the short term, and, from 2030s, as feedstock for blue hydrogen made from natural gas with CCS.

As seen in Figure 4.2, domestic use of oil will fall by more than 70% as Norway takes measures to reduce emissions. Natural gas consumption will *increase* by one third, primarily due to hydrogen production from gas. Electricity generation in Norway will almost double from today, climbing to 298 TWh in 2050. As the only scalable option, wind power will provide around 85% of the additional power generated. In 2050, wind (46%) will be close to delivering as much electricity as hydropower (48%) .

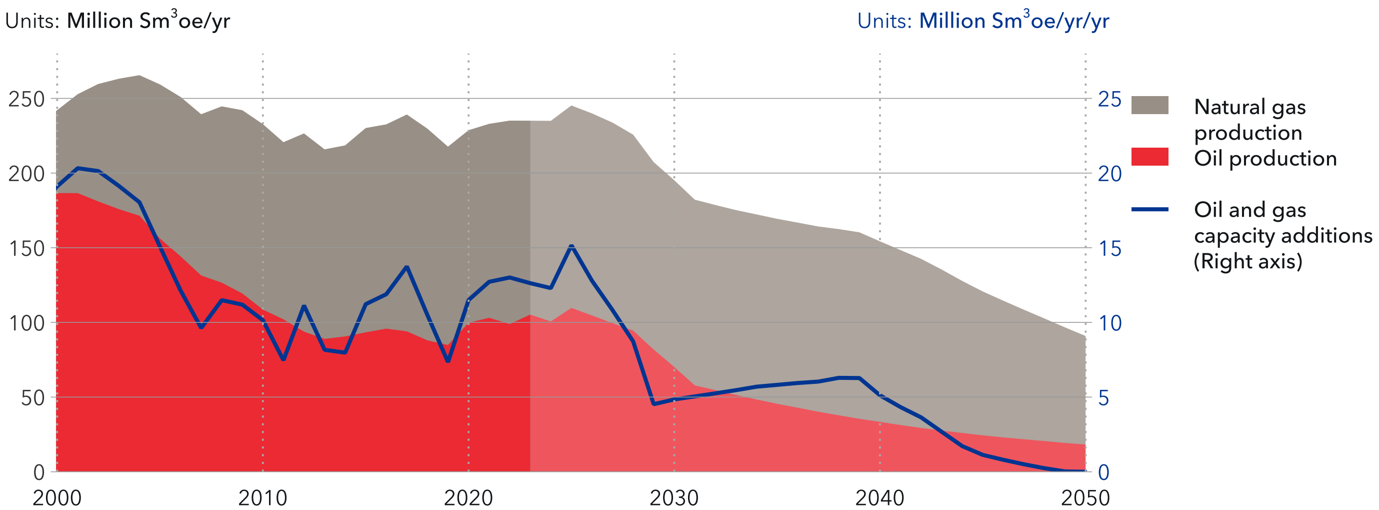
The contribution from wind at that time is relatively evenly distributed between onshore (17%), fixed offshore (16%) and floating offshore (13%). The increased power generation and consumption requires substantial investments in strengthening and modernizing the grid.

Domestic consumption of electricity increases in all sectors but around 40 TWh of the generation remains available for export. In addition, green hydrogen produced from (wind) power will be competitive for export from 2035 and will consume around 20% of the total electricity generation in 2050. From 2045, there will be just as much electricity as natural gas used in the production of hydrogen.

From the hydrogen produced, we foresee that the domestic hydrogen use will be 10% of production in 2040, growing to 15% in 2050.

FIGURE 4.1

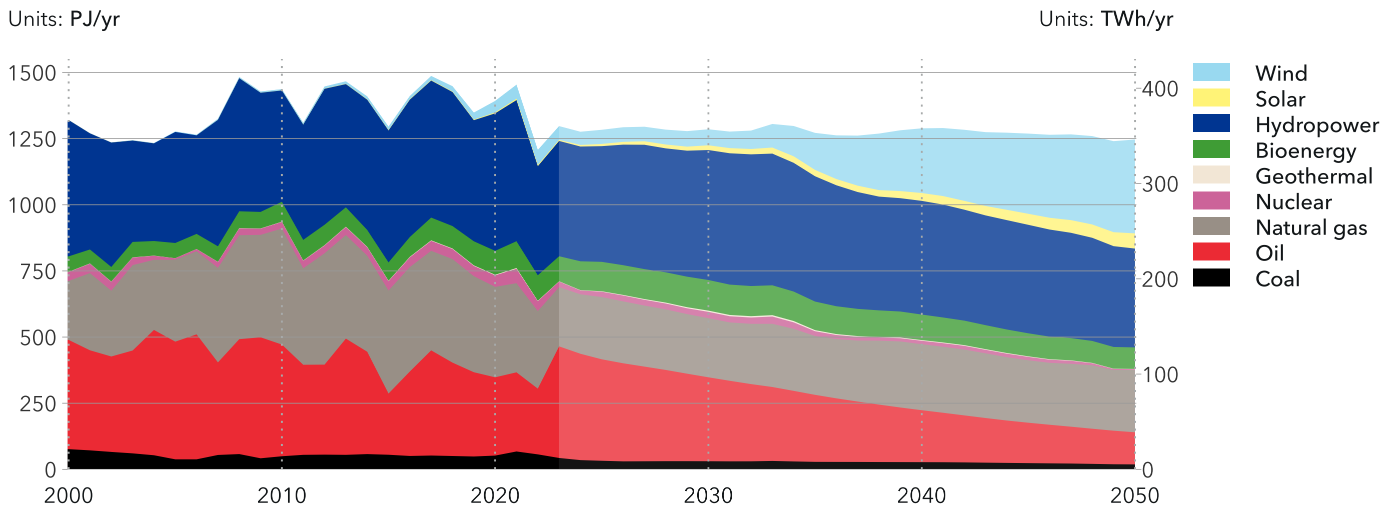
Norway oil and gas production and capacity additions



Oil includes crude oil and condensates, natural gas includes NGLs. Capacity additions are based on asset lifetime of 20 years.
Historical data source: NPD (2024), IEA WEB (2024)

FIGURE 4.2

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



Historical data source: IEA WEB (2024), SSB (2024)

4.1 Oil

There will be a strong decline in the Norwegian crude oil production (83%) by 2050, from the level of 1.8 Mbpd today to 0.3 Mbpd in 2050 as shown in Figure 4.1.

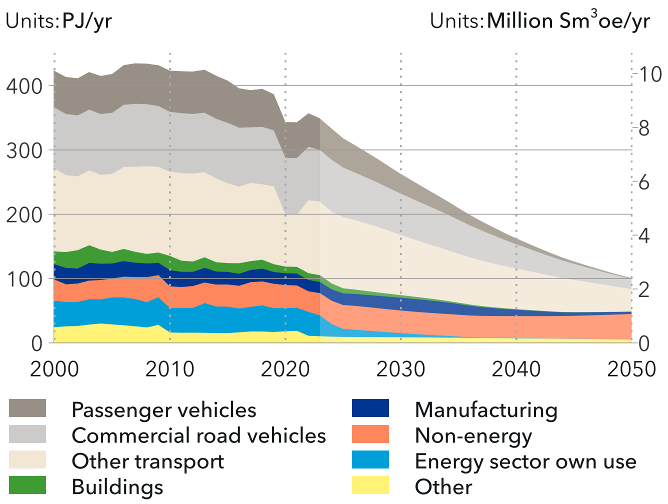
Norwegian production levels will be maintained for the first 5 years as the capacity increase from the Johan Sverdrup field and elsewhere will compensate for the shutdowns of old fields, but from 2030 no new oil fields will be added and only marginal additions will take place. Production levels will therefore decrease steadily as the fields age and export revenues will fall (as discussed further in Chapter 5). Despite the decline in oil production, produced volumes will easily exceed domestic demand throughout our forecast period. As shown in Figure 4.3, the domestic oil demand falls from 349 PJ at present to 100 PJ in 2050, which translates into 10% of national oil production in both cases.

The main contributor to the reduction in domestic oil demand is transport (Figure 4.3) where demand shrinks from 244 PJ in 2023 to 52 PJ in 2050, a decrease of almost 80%.

In 2023, about 53% of the transport sector's 244 PJ of oil demand came from road vehicles. For passenger cars, 95% of new sales are now EVs and the fleet is transforming rapidly. Commercial vehicles will also undergo this transformation, but at a slower rate of change.

FIGURE 4.3

Norway oil demand by sector



Historical data source: NPD (2024), IEA WEB (2024)

Altogether, oil supply for road transport will decrease by 87%, from 129 PJ to 17 PJ in our forecast period.

Total energy demand in maritime transport will fall by a third, from 48 PJ in 2023 to 30 PJ in 2050, mainly owing to the reduced transport need from declining oil and gas production. Oil currently covers nearly all (94%) of maritime energy demand. In addition to the demand reduction there is a diversification of energy carriers in maritime transport leading to a steep decline in oil demand from 45 PJ currently t to 6 PJ in 2050. Quite a bit of this oil reduction comes from switch to natural gas. Today, natural gas supply only 6% of the maritime transport demand but this will increase to delivering one third of energy demand in 2040. After then, the share of natural gas will reduce, ending at 23% in 2050. By then, ammonia will have grown to become the biggest energy carrier in maritime transport (28%).

Aviation's dependence on oil will be more protracted as 38% will still be covered by oil in 2050. That will be the situation after a steady reduction from 69 PJ to 29 EJ (58%) through the forecast period. In aviation, synthetic fuels and biofuels will drive the decarbonization up to 2040 and together they will be bigger than oil by 2050. After 2040, electricity and hydrogen will represent a visible share and together, they will supply 20% of the energy demand in 2050.

Oil is a minor energy carrier in manufacturing, it represents only 6% (17 PJ) of today's demand. This will be reduced to only 1% (3 PJ) by 2050. By then, hydrogen will cover 8% (23 PJ) of energy demand in manufacturing. Non-energy use has a stable demand through the forecast period, it is in the 35-40 PJ range and used as petrochemical feedstock. Due to regulations, oil use in buildings will fall to negligible levels after 2040.

4.2 Natural gas

Norway's natural gas production in 2023 was about 130 Bn m³. It is projected to remain at almost the same level until the late 2030s, and then declines from 125 Bn m³ in 2039 to 73 Bn m³ in 2050. We consider that the gas volumes available for export will be attractive in the international market considering the increased attention to energy security and the fact that infrastructure for gas export to the European continent is already in place.

In 2023, domestic consumption equals 6% of the natural gas production. By 2050 this will increase to 15%, mainly because the production is reduced, but also because domestic consumption rises from 8 to 11 Bn m³. Much of that increased demand relates to a substantial expansion of hydrogen production in Norway, which peaks in 2040, and gas consumption will then level off with continued electrification and the reduction of offshore production activity.

The production of hydrogen through steam methane reforming grows rapidly from the early 2030s towards a stable production level, drawing on 200-215 PJ/yr of natural gas through the 2040. Natural gas consumption peaks in 2042 in Norway (Figure 4.4) at 440 PJ, corresponding with the year of highest hydrogen production. The EU is increasing its targets for renewable energy and support measures generally favour renewable (green) hydrogen, from PV or wind, over low-carbon (blue) hydrogen from natural gas with CCS (EU, 2024). Nevertheless, our ETO analysis finds that there will be a fairly sizeable market for blue hydrogen in Europe, such that, by 2050, half of Norwegian domestic demand of natural gas will be for hydrogen production.

The energy sector's own-use of energy mainly involves the use of natural gas to produce electricity on platforms on the Norwegian continental shelf, and will shrink from 152 PJ to 45 PJ, a 70 % reduction. This strong decline is continuous and in the 15 coming years is linked to electrification of the continental shelf through shore power and wind turbines like Hywind Tampen, which replace gas turbines on offshore installations. From 2040, production of gas decreases and the energy demand for its own-use will also reduce as a consequence.

Natural gas as petrochemical feedstock represents a relatively stable volume through the forecast period. It stays around 66 PJ until 2040 and then reduces gently to around 60 PJ in 2050. As a share of overall gas consumption, this represents 23% in 2023, falling to 15% by 2050 following the strong growth of hydrogen production. The manufacturing sector consumed 29 PJ in 2023 reducing marginally to 24 PJ in 2050 due to process improvements.

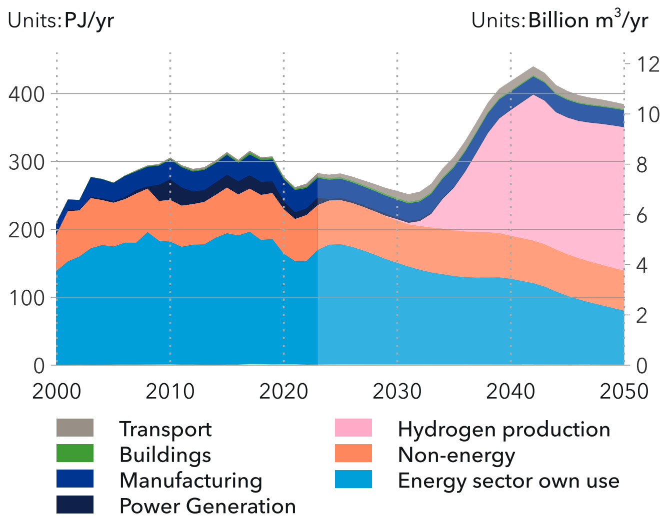
Transport has a limited use of natural gas, just 5 PJ today. We foresee that this will grow to a maximum of 14 PJ in 2040 and thereafter leveling off to 7 PJ at the end of the forecast period.

Natural gas for power generation has a marginal place in the Norwegian electricity generation mix with around 1% of the gas consumption up to 2035 and less than 0.5% from then and onward. This is due to Norway's unique hydropower-dominated power system. The use of natural gas in buildings is negligible.

Our ETO analysis finds that there will be a fairly sizeable market for blue hydrogen in Europe.

FIGURE 4.4

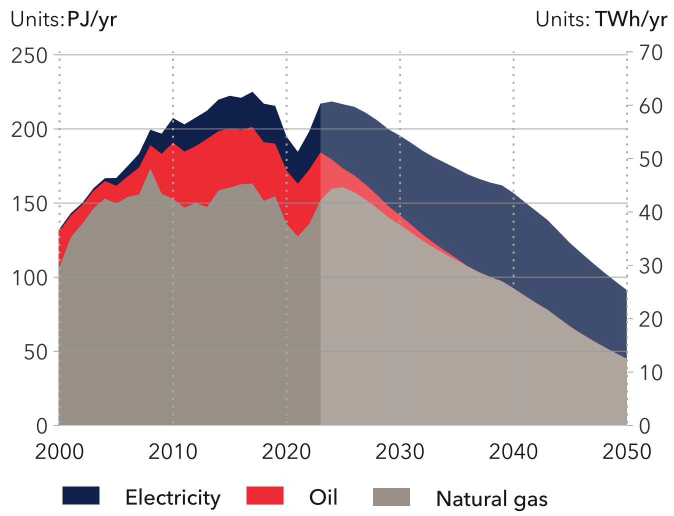
Norway natural gas demand by sector



Includes natural gas liquids. Historical data source: IEA WEB (2024), SSB (2024)

FIGURE 4.5

Norwegian continental shelf energy demand by carrier



Historical data source: IEA WEB (2024), SSB (2024)

4.3 Electricity

4.3.1 Electricity demand

Norway's electricity demand rose from approximately 110 TWh per year in 1990 to about 140 TWh per year by 2023, reflecting an average annual growth of 0.7%. This increase was partly driven by the abundance of hydropower resources and Norway's commitment to electrifying its offshore oil and natural gas sectors (Anchustegui and Tscherning, 2024). Over this period, electricity demand for appliances and lighting in buildings also doubled due to higher levels of prosperity and the broader adoption of information technology (IT) services. Consequently, Norway's annual per capita electricity consumption reached 25.5 MWh in 2023, among the highest globally. Additionally, electricity accounted for 44% of Norway's final energy demand in 2023, a higher share than that observed across Europe (DNV, 2024a).

Going forward, we forecast a faster pace for electricity demand growth, spurred on by four major demand segments:

- Transport and specifically EVs, and to lesser extent aviation and maritime
- Oil and gas production, through electrification of the Norwegian continental shelf
- Production of hydrogen for export through grid-connected electrolysers
- Buildings energy demand, specifically data centres and AI, and to a lesser extent, space cooling

Total electricity demand, including net electricity imports (gross imports minus gross exports in every year) is expected to increase from 140 TWh in 2023 to 290 TWh in 2050, a doubling of demand (Figure 4.6). Consequently, we forecast that the per capita consumption of electricity will increase to 47.5 MWh, and electrification of final demand at a little more than 65%, by mid-century.

However, the projected increase in electricity demand is not a uniform trend. Specifically, the forecast period can be segmented into two phases. Between 2023 and 2034, the annual growth rate is expected to rise modestly to 1%, a slight increase over the historical rate (1990–2023). In contrast, from 2035 to 2050, electricity demand growth is projected to accelerate significantly, averaging 3.5% per year. This dual-phase growth reflects two key factors:

- Firstly, Norway's offshore wind capacity in the North Sea is not expected to reach significant levels until after 2035, with a power capacity shortage anticipated by around 2030. During this period, Norway will likely have to rely on net electricity imports to meet demand.
- Secondly, the demand for hydrogen exports to Europe is not expected to scale substantially until the 2030s, since hydrogen optimism has been tempered significantly due to persistently high costs of production, and reluctance of potential hydrogen users to pivot to hydrogen due to high prices (DNV, 2024a; European Court of Auditors, 2024).

Electricity demand for operating grid-connected electrolysers will reach 49 TWh/yr by 2050, from practically nothing in 2023. This quantity of electricity will yield about 1 Mt of hydrogen, with the most of that exported to Europe via pipelines.

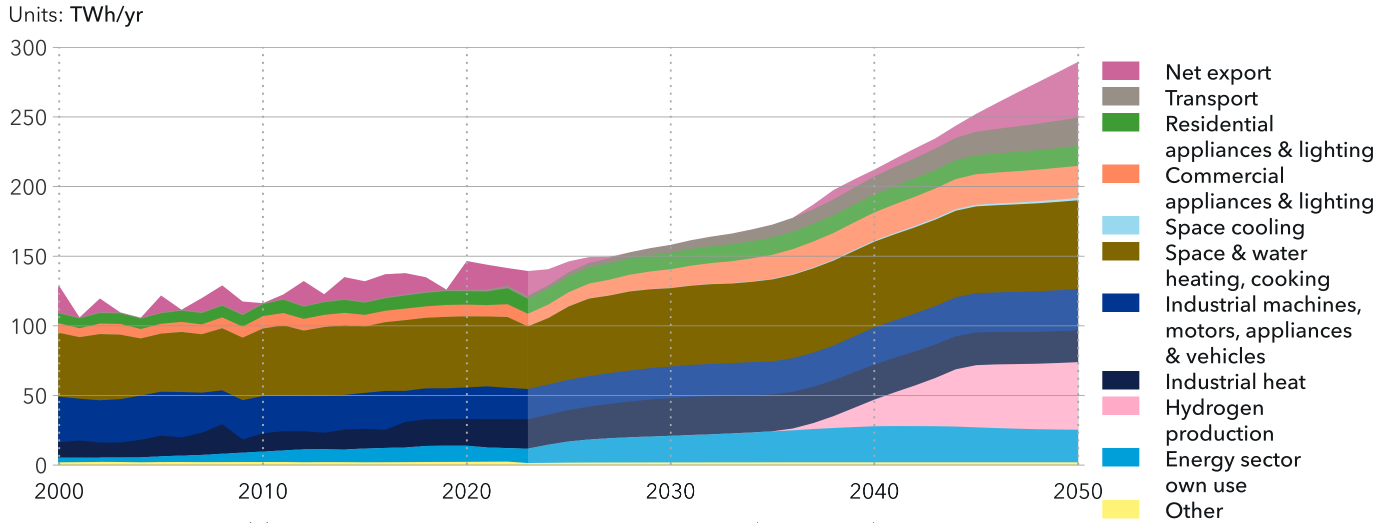
We will see the electrification of all transport segments, but first and foremost road vehicles, with 17 TWh consumed by 2.2 million passenger and 850,000 commercial EVs in 2050. Electric short-haul flights will consume 2.4 TWh in 2050. As hydrogen and e-fuels start to replace gas in manufacturing and marine gas oil in transport, from the late 2020s, electricity consumption from electrolysis plants will grow significantly, reaching 19 TWh/yr in 2040 and 49 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 (Offshore Technology, 2024). Electricity consumption within the sector is estimated to reach a plateau of 17 TWh in the mid-2030s and then increase slightly due to increasing electrification, towards 2050 while representing 51% of segment energy demand.

Total electricity use in buildings will increase about 59%, from 66 to 99 TWh from 2023 to 2050. Growth in provision of heat (space, water, and cooking) is expected to be only 42% due to more efficient heat pumps, better insulation, and a warming climate. Meanwhile, the appliances and lighting segment will grow by about 91%, in line with building expansion and increasingly tech-heavy lifestyles,

FIGURE 4.6

Norway electricity demand by sector



Historical data source: SSB (2024), IEA ETP (2016), Harvey (2014), Nakićenović et al (1996), IEA WEB (2024) along with estimated increase in electricity use for data centres in Norway.

Unsurprisingly, increasing global warming will bring higher summer temperatures, which results in higher electricity demand for space cooling in Norway. From 135 GWh consumed in 2023, space cooling electricity demand will grow to about 1.8 TWh in 2050.

4.3.2 Electricity supply

Historically, Norway's electricity supply has been dominated by hydropower (Figure 4.7), 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 2023 non-hydro electricity generation was 11%, split as 8.5% from wind, 1% from gas, 0.3% from biomass and 0.2% from solar PV. The rest comes from imported electricity.

In the future, we foresee an even more diverse production mix. Grid-connected electricity will almost double from 2023 to 2050 while hydropower generation grows by only 4%. 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. The land-use conflicts and equity aspects of the onshore wind adoption in Norway are detailed in a factbox on page 44 in this report.

From the 2030s, offshore wind, with policies favouring both floating and fixed, will grow rapidly, driven by reducing cost due to 'learning-by-doing', sustained government support, and increasing opportunities for the trade of electricity. 2050 electricity generation will include 6% solar PV, 17% onshore wind, and 29% offshore wind. Most of the remaining 49% 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.

4.3.3 Electricity generation

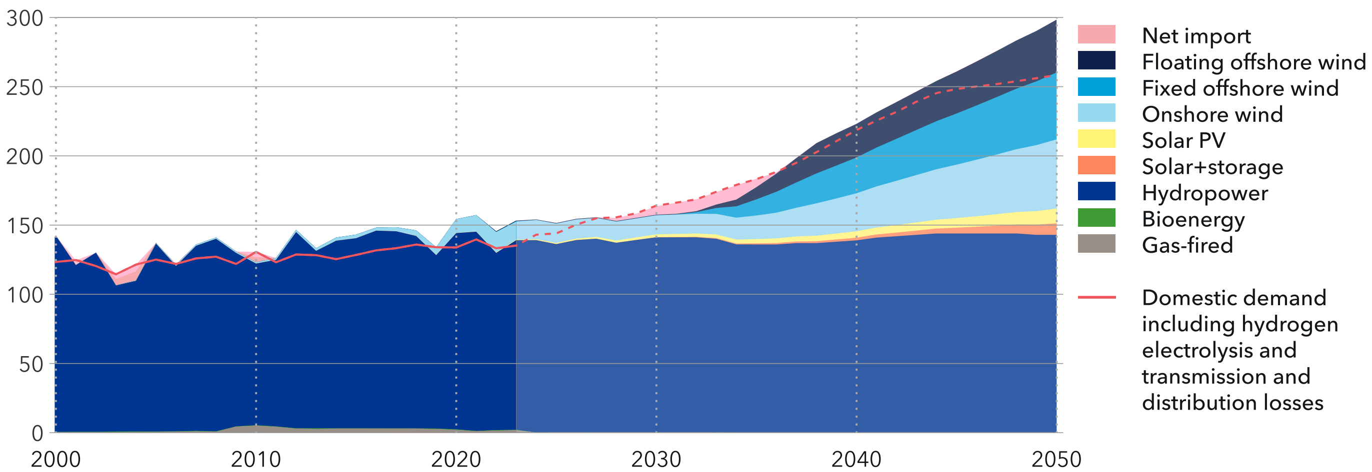
Our model categorizes different power generators and their generation patterns based on the technology underpinning the generation. For example, although it is possible to control how much power is generated from hydropower stations, their operations are impacted by water levels in the reservoirs. For that reason, we categorize hydropower as dispatchable generation with storage constraints. As Figure 4.7 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.

On the other hand, wind and solar PV are non-dispatchable because control over how much electricity these technologies provide is limited to how much the wind blows and sun shines. We have used normalized deterministic profiles for their generation patterns.

FIGURE 4.7

Norway grid-connected electricity generation by power station type

Units: TWh/yr



Historical data source: IEA WEB (2024), SSB (2024)

We account for the differences in onshore and offshore wind profiles, where offshore has higher capacity factors and a steadier profile, but we also penalize the offshore wind capacity factors for wake effects in offshore wind farms. The generation profiles vary over years, representing technological improvements and geographical distribution of the wind turbines and solar panels.

Our power market modelling 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 2031, 2040, and 2049. 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.

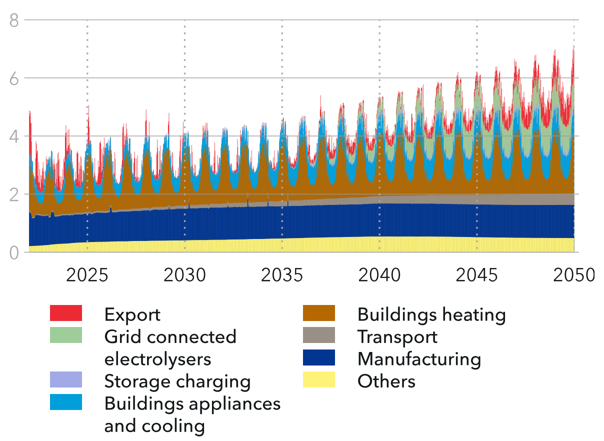
From the 2030s, both fixed and floating offshore wind will grow rapidly, driven by reducing costs, government support and increasing opportunities for electricity trade.

Norway's hourly supply and demand

The Norwegian power system is set to undergo dramatic change, both in terms of supply and demand. From a hydro-power dominated supply at present, the system will see wind become a nearly equivalent power source by 2050. But the delays in getting offshore wind up and running will lead to an electricity supply crunch in the interim. From a demand perspective, new demand categories, notably grid-connected electrolysers will scale up fast in the 2030s, and further supercharge the electricity demand growth. We illustrate this change by presenting the weekly power supply and demand for 2022-2050 and forecasting hourly demand and supply for the same winter week in three different years (2031, 2040, 2049).

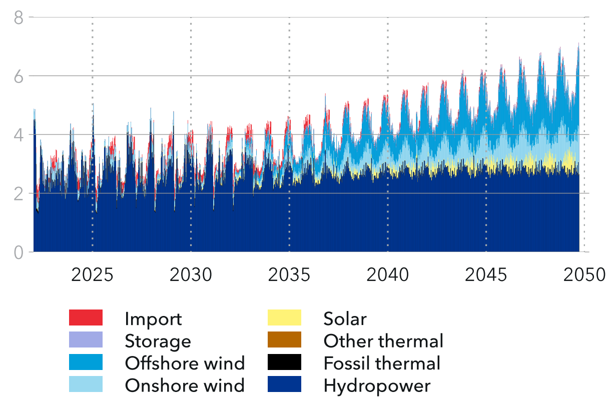
Norway electricity demand by segment; 2022-2050

Units: TWh/week (weekly readings)



Norway electricity supply by source; 2022-2050

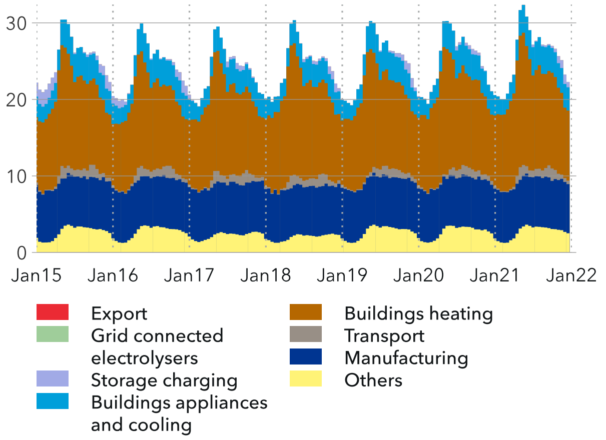
Units:TWh/week (weekly readings)



2022 – 2050: Figure above shows the evolution of demand and supply in the Norwegian power system, cumulated weekly and presented annually. Gross electricity exports, which are strong in 2022, start to decline around 2030 due to a domestic supply shortage, making Norway a net importer until 2035. However, with offshore wind expected to connect to the grid around 2035 to meet growing demand, both peak supply and peak demand are forecasted to increase significantly. By the 2040s, a substantial portion of grid-connected power is projected to be used for hydrogen production for export, alongside continued power exports to Europe.

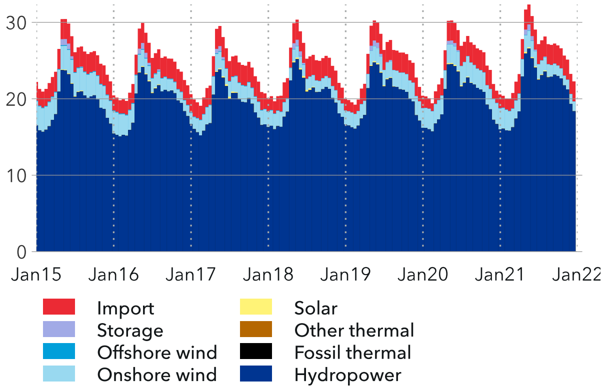
Norway electricity demand by segment; week 3; 2031

Units: GWh/hour



Norway electricity supply by source; week 3; 2031

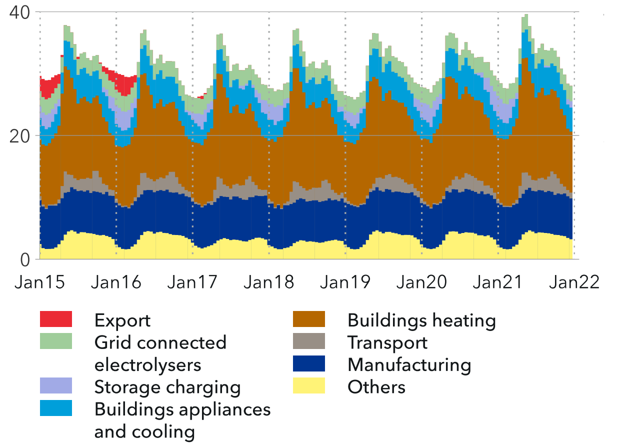
Units: GWh/hour



2031: In week 3 of 2031, Norway remains an electricity importer every hour due to limited offshore wind capacity development and high winter heating demand, which peaks around midday. During critical evening hours, significant power imports are required as the system encounters sustained, inflexible demand. Limited capacity and storage expansion restrict supply adequacy, and with lower prices across other European markets compared to the marginal cost of hydropower, Norway relies on electricity imports to meet its demand.

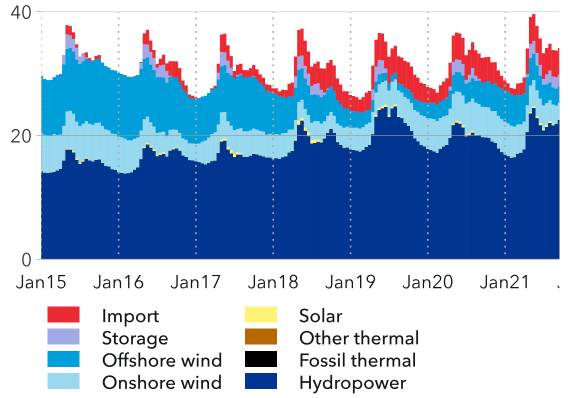
Norway electricity demand by segment; week 3; 2040

Units: GWh/hour



Norway electricity supply by source; week 3; 2040

Units: GWh/hour

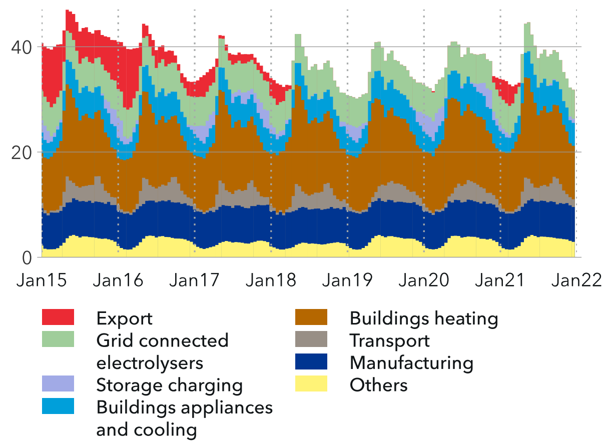


2040: In week 3 of 2040, Norway shows early signs of a shift in power supply and demand dynamics. During the first two days of the week, Norway exports electricity, driven by an abundant supply of low-cost offshore wind power. However, as offshore wind generation dips in the latter part of the week, Norway relies on its interconnections with Europe to import its surplus electricity, maintaining nearly constant operation of its grid-connected electrolysers. The import prices remain economically viable for hydrogen production, supported by strong European demand for hydrogen. By this time, Norway utilizes its European interconnections as a large-scale electricity storage solution.

Interestingly, Norway also charges its energy storage systems, especially electric vehicle (EV) batteries, even while importing electricity, then discharges this stored energy back into the grid during peak demand hours. Using vehicle-to-grid technology, this strategy supports the grid when heating demand for buildings is at its highest.

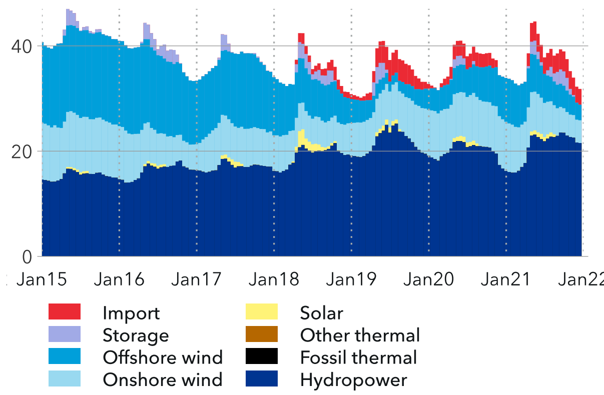
Norway electricity demand by segment; week 3; 2049

Units: GWh/hour



Norway electricity supply by source; week 3; 2049

Units: GWh/hour



2049: In week 3 of 2049, Norway transitions into a net electricity exporter during this winter week, supported by significant offshore wind capacity added to the grid alongside its hydropower resources. Similar to 2040, vehicle-to-grid storage systems contribute power during critical midday peaks, while excess electricity is exported. Although Norway exports substantial electricity at the start of the week, it imports power from Europe towards the end of the period to optimize the operation of its grid-connected electrolysers. Effectively, Norway leverages its power trade interconnectors with Europe as a short-term flexibility tool, reducing the need to both curtail intermittent wind power and scale down electrolyser operations.

Flexibility, storage and grids

As wind and solar power are projected to make up an increasing share of Norway's power system in the 2030s, the need for flexibility and storage will grow proportionally. Our focus here is on short-term flexibility, within a time-frame of one hour to approximately 24 hours, rather than weekly or seasonal flexibility (DNV, 2024c). We assess this short-term flexibility requirement and the supporting technologies by estimating the rise in daily, hour-to-hour load variability and aggregating it over the year. Figure 4.8 presents the annual flexibility requirements for the Norwegian power system, measured in GW.

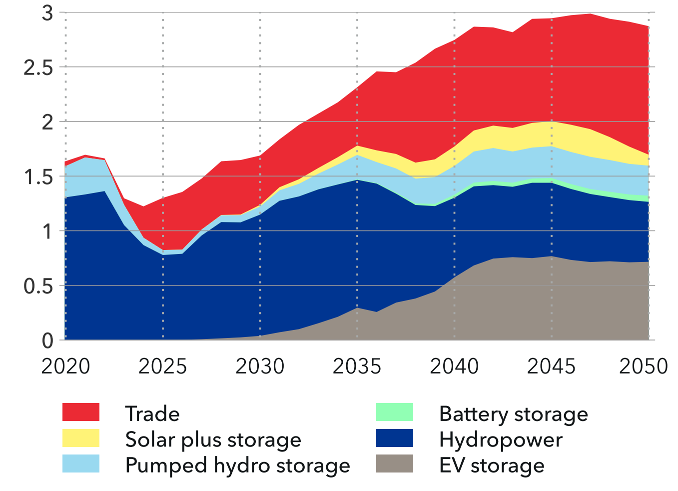
Norway's flexibility requirement has historically been between 1 and 1.5 GW, primarily met by hydropower, supported by pumped hydro and electricity trade. The ability to modulate hydropower output within reservoir limits, coupled with pumped hydro, has been the main source of flexibility. However, with increased variability from offshore wind generation and fluctuating demand from technologies such as EV charging, this requirement is projected to double to 3 GW by mid-century.

Additionally, "opportunity-demand" technologies like energy storage, solar-plus-storage, vehicle-to-grid (V2G), and, to a lesser extent, stand-alone Li-ion batteries, will play a growing role in absorbing excess electricity and releasing it back to the grid as needed. By 2050, V2G alone is expected to provide 25% of Norway's flexibility, supported by the extensive electrification of road transport.

FIGURE 4.8

Norway short-term flexibility need and provision by technology

Units: GW



Our model assumes that EV battery capacity available for grid support will gradually increase to represent 7% of the total EV battery capacity by 2035, maintaining this level thereafter. Electricity import and export, and the interconnector cables are also used as a flexibility tool. Electricity trade with Europe is driven by wholesale price differentials, while storage technology operations are managed using a heuristic algorithm designed to maximize value through price arbitrage.

To support a grid with significant renewable capacity, we forecast the need for 1 GW of pumped hydro storage, 6 GW of Li-ion battery storage, and 2.9 GW of V2G capacity in Norway's electricity grid by 2050.

Grids

Beyond the anticipated need for flexibility, significant grid expansion in Norway is also forecast to meet rising electricity demand and supply over the next three decades. Norway's total grid length is expected to increase from 370 thousand circuit-kilometers (c-km) to 605 thousand c-km, representing a 60% growth, even though Norway already has a well-developed grid (Energifaktanorge, 2024).

Both the transmission grid (high-voltage infrastructure for carrying electricity from generation sources) and the distribution grid (low-voltage network supplying smaller consumers) are projected to expand despite the grid's already advanced state and substantial capacity in 2023 (Figure 4.9).

Grid growth in Norway will involve not only physical expansion but also enhancements through smart technologies and digitalization, particularly in the distribution grid. Consumer-driven demand-response measures will support peak shaving, and technologies like V2G within local distribution grids are expected to reduce electricity price volatility while optimizing local supply and demand (Nagel et al., 2024). As the EV market expands, the distribution grid will need to manage increased demand fluctuations and peaks from EVs, alongside heating demand from buildings, despite the added costs this may impose on local grid operators and charging customers. Delays in distribution grid expansion noted in Regjeringen.no (2022) are expected to ease as the benefits of these investments accrue and supportive policies in the National Charging Strategy take effect.

Similarly, as new offshore and onshore power capacity is developed in greenfield sites, the transmission grid must expand and adapt. This includes significant growth in offshore cables to support the electrification of the Norwegian continental shelf and to transport offshore wind power onshore (Business Norway, 2024). We project that Norway's undersea transmission cables will expand five-fold, from 740 circuit-km to 3,650 circuit-km, between 2023 and 2050. Additionally, maximizing the existing transmission grid's capacity will require advanced solutions such as dynamic line rating and other turnkey methods (DNV, 2024d).

Capacity developments

The capacity developments in Norway are first and foremost driven by the need for capacity, and in the short-term, the planned projects expected to come online, especially where the financial investment decisions have been made. The composition of this new capacity is shaped by the profitability of various types of power plants, which is influenced by both the levelized cost of electricity (LCOE) and the average market price received (or "capture price") for each plant type.

FIGURE 4.9

Norway transmission and distribution grid length

Units: Thousand circuit-km

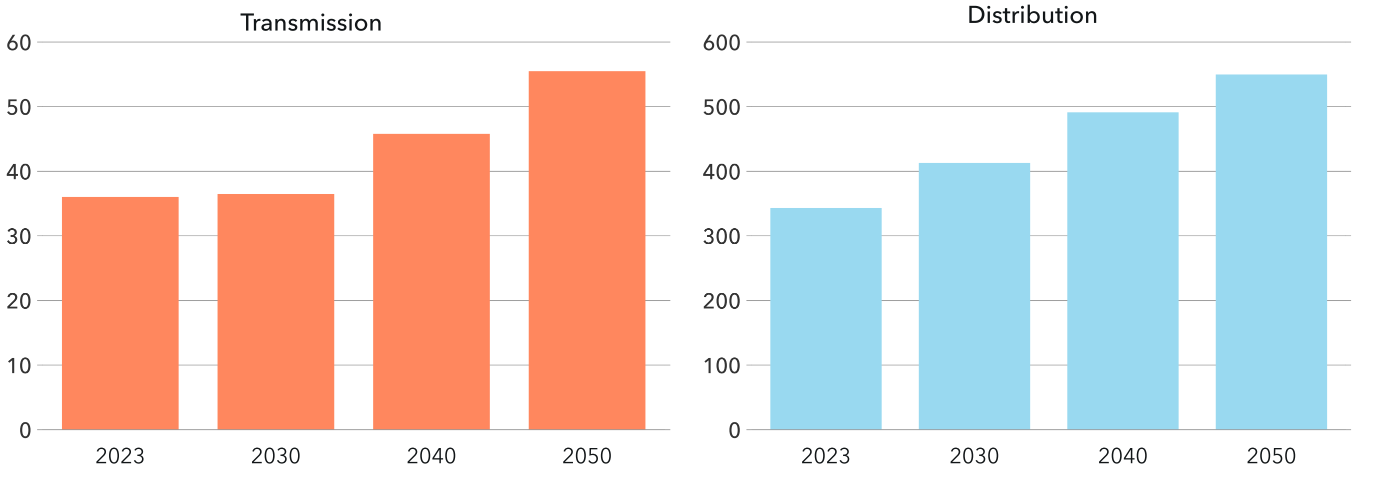


Figure 4.10 shows our forecast for renewable capacity, both grid-connected and off-grid for hydrogen production. From the 1990s through the early 2000s, Norway's power capacity relied almost exclusively on hydropower, which accounted for around 99% of installed capacity. However, from the late 2000s onward, onshore wind has begun to contribute significantly, supported by Norway's goal of diversifying its energy mix, its ambition to serve as Europe's renewable battery, and the financial viability of onshore wind enabled by favourable coastal wind conditions (NDTGroup, 2024). By 2023, onshore wind made up 13% of Norway's renewable capacity, while hydropower retained 85%. Solar PV, including both utility-scale and distributed installations, accounted for roughly 2% of total installed renewable capacity.

While the LCOE of onshore and offshore wind and solar PV is competitive relative to other power generation sources, these variable renewable energy sources (VRES) typically experience lower capture prices since they tend to generate electricity during periods of low prices. However, this is not expected to be a limiting factor for Norway. Hydropower and pumped hydro, which have higher and more stable operating costs, can help balance the variability of wind and solar by setting prices alongside the European electricity market. By 2050, hydropower is still anticipated to play a substantial role in both hourly and annual generation. Additionally, Norway's ability to export electricity and generate revenue from other regions further mitigates the impact of declining capture prices.

By 2050, hydropower capacity will still command a share of 43% of the installed capacity. Offshore wind power will be the second highest with a share of 21%, consisting of both bottom-fixed and floating bed wind turbines, off the coast of Norway.

Despite the costs of offshore wind being higher than the existing conventional power generator – hydropower – government support is assumed to close a fraction of the gap between the cost of these technologies. We forecast an almost even split between floating offshore wind and 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.

There are certain overlaps in the cost of new developments, and various geographical and political factors mean that the technology chosen for development is not always the lowest-cost option. This results in a distribution of technologies based on both cost and these additional considerations. Figure 4.11 illustrates historical and projected annual power capacity additions by type, estimated using this approach. Near-term capacity additions reflect projects currently under construction.

We anticipate that 2023–2031 will see a slowdown in power capacity growth due to inflated capital costs in recent years in Norway. Furthermore, unlike previous forecasts, we now expect substantial offshore wind capacity to be feasible only after 2032, as elevated costs from original equipment manufacturers (OEMs) and other global challenges continue to impact the sector (DNV, 2024a).

Starting in the mid-2020s, solar PV installations are expected to grow, driven by midday electricity demand peaks and a push for local energy security. By mid-century, solar PV projects are likely to be paired with battery storage, enhancing their capture prices. After 2040, the majority of new capacity is projected to come from wind power, with a large portion expected from fixed and floating offshore wind.

Table 4.1 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.

4.3.4 Hydropower

Hydropower generation provides 89% of electricity generation in Norway today and it will continue to be the backbone of the Norwegian electricity system even as this dominant share reduces substantially. By 2050, hydropower will have eased to 48% of the power mix as new added wind capacity will increase the wind share to 46% of the total grid generated electricity.

The Norwegian hydropower system has a very strong reservoir storage capacity, with a total of 87 TWh across the country. This is close to half of all hydropower reservoir capacity in Europe (Energifakta, 2024) and is part of the reason why it can act as a battery for electricity systems across Europe.

The existing 34 GW installed capacity will expand gradually, in small annual increments, reaching 43 GW in 2050. It is expected that hydropower generation will reach 143 TWh by then. Climate change is expected to lead to an increase in precipitation, but it is unclear how this may contribute to additional generation as there will be less snow and more rain, thereby reducing the natural seasonal storage provided by the snow pack (Kuya et al., 2024).

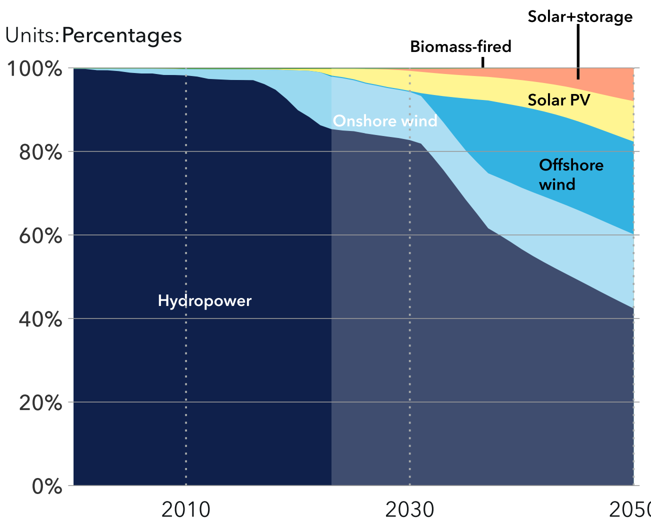
The need for dispatchable power will rise due to the growing share of wind and solar. As a consequence, hydropower will be incentivized to respond to fluctuations not only in demand, but also in generation with rapid response times rewarded by higher prices, strengthening the business cases for both hydropower reservoirs and batteries for medium- and short-term storage respectively.

There are a relatively few pumped hydro projects in Norway in the pipeline due to geographical and ecological limitations. These will typically be built as part of a capacity addition to or upgrade of an existing site. Pumped hydro will not necessarily increase generation but can improve system responsiveness and utilization of hourly price variations. This dynamic allows pumped hydropower to receive higher average prices and ensure sound profits despite having a higher LCOE than wind and solar PV.

FIGURE 4.10

Norway grid and off-grid installed renewable capacity

Units: Percentages

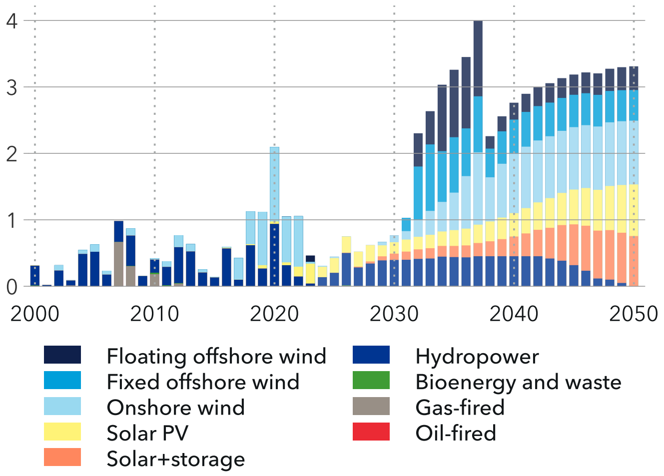


Historical data source: IEA (2024); GlobalData (2024)

FIGURE 4.11

Norway capacity additions becoming operational by power station type

Units: GW/yr



Historical data source: GlobalData (2024)

TABLE 4.1
Installed capacity and the annual average capacity factor of power stations

	Installed capacity (GW) by the end of year				Capacity factor			
	2023	2030	2040	2050	2023	2030	2040	2050
Hydropower	34.2	36.2	40.4	42.8	46%	45%	40%	38%
Onshore wind	5	5.1	10.5	17.7	30%	31%	31%	33%
Floating offshore wind	0.1	0.1	6	9.1	48%	48%	47%	49%
Fixed offshore wind	0.0	0.0	6.6	11.5		47%	47%	49%
Solar PV	0.6	2.1	4.6	10.1	10%	12%	12%	12%
Solar+storage	0.0	0.2	2.1	8.1		9%	12%	12%
Thermal	1.0	1.0	0.6	0.15	20%-49%	2% - 70%	1% - 67%	1% - 45%
Wind off-grid capacity for hydrogen production	0.002	0.004	0.264	0.5				

Land use conflicts and the complexities of onshore wind development

Hydropower cannot be expanded sufficiently to meet Norway's growing electricity demand. Hence, Norway must continue to expand its power production based on other sources such as wind, solar, or nuclear. Each of these options face various levels of legislative and public opposition, but onshore wind, being the lowest cost and most technologically mature, is currently effectively stymied by such opposition. The opposition has contributed significantly to the lack of new electricity capacity planned for the next five years.

Onshore wind is particularly contentious in the Norwegian context due to its preferred location in otherwise untouched nature. Non-profit organisations' and communities' arguments against onshore wind include preserving nature, both landscapes and wildlife, as well as various "not in my backyard" arguments, including noise, visual aesthetics, and impact on recreation. The construction of several approved projects has consequently been hindered by, e.g., locals blocking construction roads. The Norwegian public is also wary of arguments for building excess capacity for export to the European continent, fearing (incorrectly, as it happens) that it may cause domestic electricity prices to increase.

Wind projects in Norway have also faced legislative opposition from the Sámi, an ethnic minority indigenous to Norway. The best example is the proposed wind farm in Fosen, Trøndelag, an area that historically has been used by the Sámi people for reindeer husbandry.

Herders claimed that construction of the wind farm interfered with reindeer activities and therefore their right to enjoy their own culture under Article 27 of the International Covenant on Civil and Political Rights (ICCPR). In October 2021, Norway's supreme court ruled in the Sámis' favour. However, operation of the farm continued, prompting protests over the drawn-out process to implement the court's decision (Reuters, 2023). The dispute reached a resolution in March 2024: the wind farm may continue to operate for now, while the reindeer farmers get additional areas for winter grazing, and funding will be given to establish a South Sámi cultural fund (Energidepartementet, 2024a).

This case exemplifies the complexities of achieving an equitable energy transition and demonstrates that transitions are highly contextual. In Norway, the energy transition must consider many facets, including indigenous land rights, land use changes for local communities, energy security, the waning of oil and gas production in Norway and how this will affect the economy and welfare state, as well as labour force issues.

Opposition to onshore wind should also be seen in the context of Norway's climate commitments. It would be risky for Norway to stray too far from the expected transition trajectory of Europe as whole. Moreover, Norway has aspirations to support global forest protection, and is by far the largest donor to the Amazon Fund. Opposition to onshore wind on the grounds of nature preservation will need to be reconciled with the fact that global warming will overtake land use changes (like deforestation) as the number one driver of biodiversity loss well before 2050.

According to CICERO's Population Surveys on Climate, popular support for onshore wind farms halved between 2018 and 2021, and although support has slowly grown in 2022 and 2023, it is yet to recover to 2018 levels (CICERO, 2023). The survey found that support for offshore wind is consistently higher than for onshore wind, likely due to fewer perceived issues around siting and aesthetics, impact on environments and ecology, and land use conflicts. However, the high expected cost may increase the opposition in the future. Nevertheless, higher societal and policy support for offshore wind than onshore wind informs our analysis, where we forecast strong growth in offshore wind from the early 2030s (elaborated in Section 4.3.5 – Wind).

4.3.5 Wind

Wind power will be increasingly important in the Norwegian energy transition, seeing an 8-fold increase to 40 GW by mid-century. While most of the 5 GW installed capacity of today is onshore wind, we forecast 20 GW of installed offshore wind capacity by 2050, slightly more fixed than floating. That is a big growth since the first ever floating offshore wind turbine was installed in 2009 in Norway, with a capacity of just 2.3 MW.

Norway is a particularly good candidate for wind power generation. Firstly, because of the long inhabited and grid-connected coastline with areas of strong wind. Secondly, the renewable alternative of solar PV is limited by meagre and very seasonal irradiation patterns.

Norway needs more electricity. We forecast the domestic electricity demand to double by towards 2050 (Figure 4.6), due to, e.g., electrification of transport, oil rigs, and hydrogen production (see Section 4.3.1 for more details). With limited expansion opportunities for hydropower available, wind is in a prime position to meet the increasing demand. However, further expansions of onshore windfarms are hindered by a severe lack of public support, as detailed in the factbox to the left. Hence, future capacity additions will be more offshore than onshore.

Electrification of offshore oil and gas production is an important step in the domestic energy transition in Norway. For this use case, offshore wind is obviously well suited and is supported by politicians and companies alike. The current government's Hurdal Platform of 2021 set ambitions for using offshore wind to electrify the Norwegian continental shelf (Statsministerens kontor, 2021). The first floating windfarm of this kind, Equinor's Hywind Tampen, was then already in the pipeline and started producing electricity for offshore platforms in 2022.

Offshore wind is also a viable candidate to meet onshore energy demand. Unlike onshore windfarms that can be limited by space and must be adapted to topography, offshore windfarms can more easily be upscaled to GW capacities, such as the 3.6 GW Dogger Bank in the UK. Combined with its high energy output per square metre, that makes offshore wind able to provide electricity to densely populated coastal areas (IRENA, 2021).

However, offshore wind also faces challenges. Even though there are no human settlements offshore, there are other human activities, such as fishing, aquaculture, and boat traffic, as well as nature to preserve. This problem is described in more detail in the DNV *Ocean Spatial*

Competition Forecast (DNV, 2023a). While not receiving as much public resistance as onshore wind, competition for space must be considered when planning future projects. Floating offshore wind has an advantage over bottom fixed, especially in Norway, as it faces less spatial competition further from shore and is less invasive to life on the seabed.

A problem for offshore wind is cost. The levelized cost of energy (LCOE) is much higher for floating offshore wind than for fixed offshore, which again is slightly more costly than onshore (Figure 4.12). The costs of offshore wind have inflated in recent years due to interest rate increases and supply chain squeezes, but are widely expected to fall once again as the technology continues to mature, new markets open up, supply chains strengthen, and larger projects are commissioned (Global Wind Energy Council, 2024). However, governmental incentives and funding are needed to kickstart a substantial buildout in Norway with assurances for continued support. Equally important is the need to communicate effectively with the public on the necessity of the support given to wind power.

Norway plans to ramp up its efforts by assigning areas for 30 GW offshore wind by 2040 (Energidepartementet, 2024b). The ambition is backed by 35 billion NOK funding support for floating offshore wind in the State Budget for 2025. This is a good start, but not necessarily sufficient to properly propel offshore wind power in Norway, according to Equinor and its partners (Dalfest, 2024). Illustrating this, Equinor put its pipelined project, Trollwind, on hold indefinitely, in part due to rising costs (Equinor, 2023).

4.3.6 Solar PV

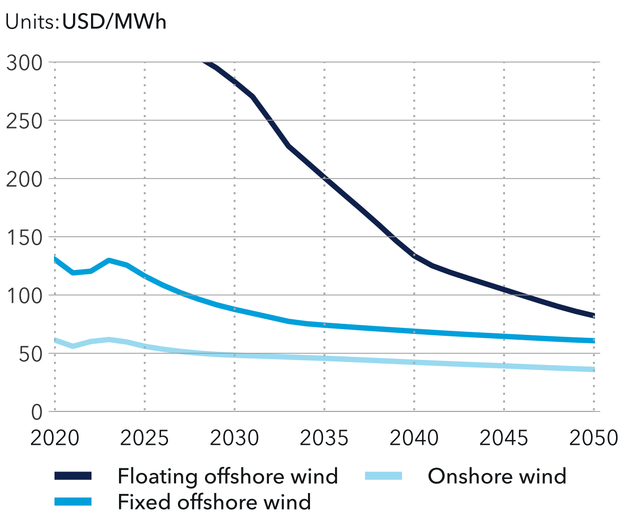
Norway doubled its installed capacity in 2023 to 0.6 GW and we foresee a further 30-fold growth to 18 GW in 2050. Initially, most of the added capacity will be solar PV, providing electricity at the time of production, i.e., when the sun shines. Eventually, more and more solar installations will also include storage as an integrated part of the installation, enabling the dispatch of power also when the sun does not shine.

The substantial price drop in solar panels globally, largely due to Chinese overproduction, have made it a key driver of the energy transition (DNV, 2024a). However, the same solar panels produce less electricity in Norway than in more southern countries, due to the lower solar irradiance. That makes utility-scale solar power plants less profitable in Norway. Nevertheless, this year the first utility-scale solar farm opened in Norway (Solgrid, 2024) and NVE gave the green light to the construction of four smaller solar farms of up to 11 MW (EnergiAktuelt, 2024).

Due to its downscalability, there is a substantial market for solar PV installations on, e.g., rooftops to mainly provide supplementary power for owners – saving them the cost of both the power and the grid. Such smaller installations will gradually become more ubiquitous in Norway. One example, albeit on the larger side, is a planned solar farm meant to power a ski resort and adjacent activities in Geilo (Grynning, 2024).

FIGURE 4.12

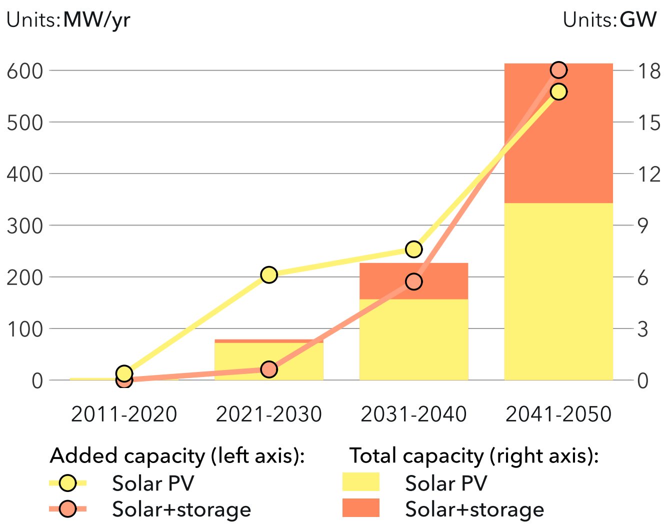
Norway levelized cost of wind electricity



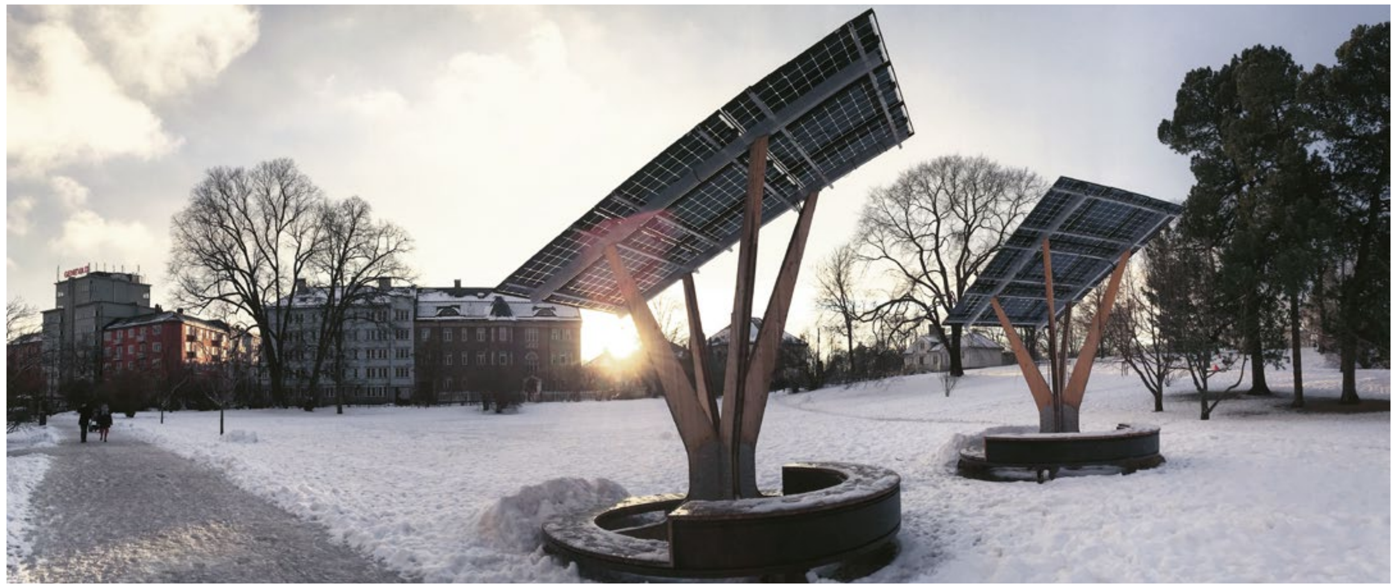
Historical data source: GlobalData (2024), DNV analysis

FIGURE 4.13

Norway solar capacity additions and installed capacity



Historical data: GlobalData (2024)



Even though solar+storage installations obviously require an additional storage investment, the combination has its uses. With the increased variability of the electricity mix in the 2030s, there will gradually be room for more such installations to smooth out the peaks and troughs of the power production. Selling at the price peaks may make this a more financially viable option compared with pure solar PV installations. In 2050, we foresee an almost even mix between standalone solar PV and solar+storage in Norway (Figure 4.13).

4.3.7 Nuclear

There is rising interest in nuclear for Norway, particularly around Small Modular Reactors (SMR). We include the expected nuclear technology developments, costs and support in our model, and the conclusion is that we do not see any nuclear additions happening in Norway by 2050.

Norway's willingness to subsidize nuclear the same way as offshore wind is likely low, as the argument for building an export industry is not present, and Norway has no competitive advantages on nuclear compared with other European countries.

From a cost perspective, we find that nuclear power in Norway cannot compete with other sources of electricity production and, therefore, will not play a significant role in the Norwegian energy mix. The SMRs currently under development are not yet available. However even if SMRs were to be successfully developed and available for implementation within 10 years, the conclusion from our analysis remains the same. The principal reason for this is the complementary nature of wind power (especially offshore) and hydropower. By the mid 2030s, there will likely be a surplus of electricity in Norway and only a moderate need for new capacity unless there is a desire to export electricity or convert it to hydrogen for export. Nuclear power produces electricity at moderate and stable marginal (operating) costs. Wind and solar, which have very low marginal costs, will always be preferred in the merit order as long as the wind is blowing and there is sufficient light, forcing nuclear to compete with low cost wind or low cost imported solar over long periods, thereby not necessarily covering its own marginal costs. During periods of low windspeeds and high demand, Norwegian hydropower is expected to fill the gap at a lower cost than nuclear can deliver. In short, variable renewables will be boundary setting for how nuclear must operate in the Norwegian grid (Reed, 2024).

The combination of wind and hydropower also enables the production of low-cost hydrogen at a price lower than Europe can achieve, making it attractive for export. Electricity from nuclear power has limited potential for export or for the production of exportable hydrogen, as neighbouring countries will likely be able to produce nuclear power at the same or even lower costs, given their existing experience with nuclear power.

SMRs intended for mass production with the aim of lowering cost are under development, however there is significant uncertainty as to how much and how fast modularity and cost compression will improve. In order to understand under what conditions nuclear power would be an attractive alternative to other sources of electricity in Norway, we have evaluated a number of sensitivity studies to test how much nuclear cost needs to decline in order to become a meaningful part of the Norwegian energy mix before 2050.

Sensitivity runs

To vary the costs, we use the original cost estimate based on our global analysis for European SMRs (DNV, 2024a). For Norway we increased the operational costs by 10% to account for an absence of experience in operating nuclear plants and the handling of waste. Build times are also accommodated to fit the Norwegian context of initially starting with 6 years in 2032 and improving down to 4 years by 2050. The rest of the cost parameters are kept the same as for European nuclear except for the discount rate, an important factor affecting cost, estimated to be 10% higher in Norway than in Europe, going from 6.5% in 2030s and declining to 4.4% by 2050.

Assuming that nuclear will be commercially available, and it is possible to make an investment decision in 2032, using 6 years of building time. Then, using the assessed cost for European SMRs as reference cost (7000 USD/kW), we find that the CAPEX costs for nuclear in Norway have to be 15% lower than in Europe by 2038, and this results in around 500 MW of SMR capacity being built by 2050. Lowering the cost by 65% compared to what we think European SMRs will cost in 2038 initiates uptake earlier with 300 MW capacity in operation by 2044, and a total of 1500 MW connected to the grid by 2050, which would be 5 units if the approximate size is 300 MW per SMR at a cost of 1,800 USD/kW. The results validate the conclusions from the discussion above. A power system with 50% variable renewables, with existing flexibility from dispatchable hydropower and limited need for new capacity to meet domestic demand results in very few new nuclear plants being added to the grid even in the context of such unlikely low costs. For more details, read our SMR analysis and factbox found in our *Energy Transition Outlook* report (DNV, 2024a).

Another reason for the limited uptake, is the low capacity factor achieved by nuclear in Norway, being between 0.5 and 0.7. With an abundance of wind and solar producing at near zero marginal cost, nuclear cannot operate as much as is needed – plants are usually designed to operate at least 90% of the time – to warrant the high CAPEX cost. A way to improve the financial situation is to include the value of heat produced by SMRs, which is not included in this study. This could be useful for industrial applications or high-temperature electrolysis. Thus, there could be a limited amount of industrial cluster sites where nuclear is commercially attractive before 2050. However, both the number of sites as well as the installed capacity would be limited in size and not installed primarily for electricity generation. Other unsolved issues regarding nuclear in Norway, such as waste management, national policy framework, relevant and up-to-date secondary legislation and not the least public acceptance have not been part of this study. Such issues are likely to be addressed in the Official Norwegian Report (NOU) on nuclear power scheduled for delivery in April 2026.

In our 2024 *Energy Transition Outlook* (DNV, 2024a) and our 2024 *Maritime Forecast* (2024b), we discuss the potential for nuclear shipping, where SMR technology does not have to compete with low cost renewables but more expensive bioenergy or hydrogen derivatives. We find that nuclear shipping might scale in the 2040s, but as most ships calling Norwegian ports have relatively moderate engine sizes, they are not the most likely deployers of nuclear propulsion, and we have not included nuclear in Norway's shipping fuel mix.

The results validate the conclusions – very few new nuclear plants being added to the grid even in the context of such unlikely low costs.

4.3.8 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 expect the SMR advantage to diminish as carbon prices rise and electrolysis-based hydrogen production improves, supported by decreasing electricity costs from expanded VRES capacity.

Hydrogen supplied via electrolysis is seen as one of many flexibility options to take advantage of low power prices when production from VRES is plentiful. However, Norway will not have abundant and cheap VRES/offshore wind until the mid-2030s.

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. With increasingly abundant VRES, renewable hydrogen will start gaining traction: already in 2040 this 'green' production route will supply 32% of hydrogen as an energy carrier and 30% of total hydrogen production (Figure 4.14). By mid-century, these shares will increase towards 46% and 42% respectively. Yet, by 2050, blue hydrogen will continue to make up slightly more than a half of hydrogen production for energy purposes. Growing acceptance of blue hydrogen in Europe, especially amid challenges in scaling electrolytic production, suggests it will remain a substantial component of the hydrogen mix for the coming decades.

This year, we revised our 2050 hydrogen production forecast for energy purposes down by 38%, from 3.8 Mt/yr to 2.3 Mt/yr. The adjustment reflects mixed progress in hydrogen scaling in Norway, Europe, and globally. On the positive side, the Norwegian SKIGA project secured support in the EU's first Hydrogen Bank auction on 30 April 2024, receiving funding from the EUR 800 million Innovation Fund for its 117 MW electrolysis capacity. However, project delays and cancellations, such as Statkraft's reduced hydrogen capacity target – now 1–2 GW by 2035, down from 2 GW by 2030 – highlight market challenges, high costs, and implementation delays, aligning with our forecast of a more cautious outlook for hydrogen adoption.

We see hydrogen as a likely zero-emission energy carrier for heat applications in manufacturing (Figure 4.15). By mid-century, 190 kt of hydrogen will be used for industrial heat provision in manufacturing, a 13% share. Most of the hydrogen will be used in the manufacturing sector, producing heat for base materials, followed by the construction industry and iron and steel production.

While hydrogen was once seen as key for decarbonizing heavy trucking, battery-electric solutions are now set to play a major role in this segment. This will likely limit hydrogen's role in road transport despite developments in hydrogen combustion engines for trucks. In our view, hydrogen use in Norway for road transport will pick up from 2040 onwards but only reach 25 kt by 2050, representing 4% of road transport energy demand.

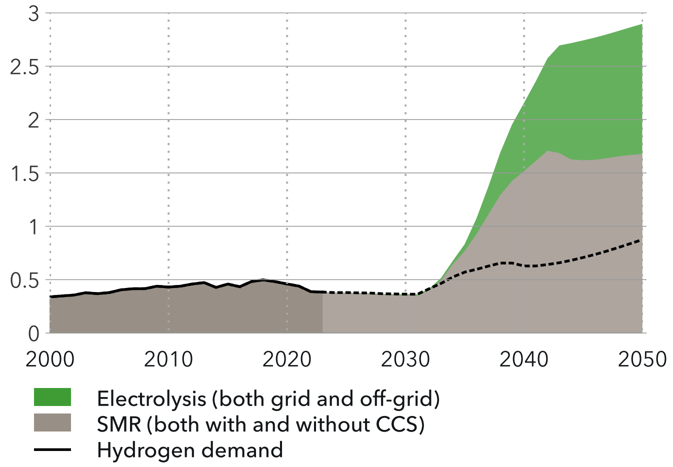
Within maritime transport, covered thoroughly in our *Energy Transition Outlook* (2024a) and in our *Maritime Forecast* (DNV, 2024b), we expect significant uptake by 2050 of low- and zero-carbon fuel alternatives derived from hydrogen (e.g. ammonia and synthetic fuels like e-methanol). They will be partly implemented in hybrid configurations combining diesel and gas-fuelled propulsion options, and will provide slightly more than 39% of the maritime fuel mix by mid-century. We forecast ammonia and synthetic fuels combined will provide 13 PJ/yr of Norway's maritime sector energy demand 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, 27% (21 PJ) of aviation energy demand will be covered by these energy carriers.

FIGURE 4.14

Norway hydrogen production by production route

Units: MtH_2/yr

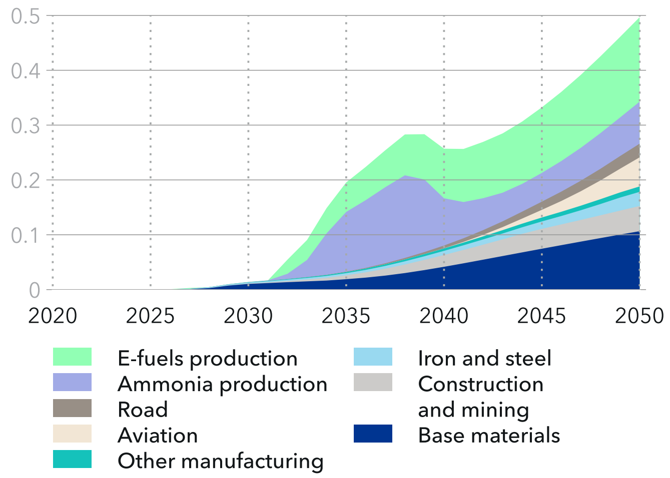


Does not include hydrogen use in residual form from industrial processes.
Historical data source: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021).

FIGURE 4.15

Norway hydrogen demand as energy carrier by sector

Units: MtH_2/yr



5 ENERGY TRADE

Norway is Europe's largest energy exporter and plays a crucial role in the EU's journey toward energy security and decarbonization. We forecast Norway's oil and gas exports to decline significantly by 2050. As Europe transitions, Norway's future lies in exporting renewable electricity and hydrogen, though the growth of these energy exports will only partially offset declining fossil fuel revenues.

Norway has been a significant net exporter of energy, and, while it will retain this profile, energy exports will decline over the next 30 years. The Ukraine war and the subsequent response from Europe to reduce its dependency on Russian fossil fuel has put pressure on Norway to increase energy exports, especially gas. Although Norway has responded to the challenge and 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 5.1). By 2050, oil exports will be 15% of today's level, and gas exports will halve compared with 2023 levels, partly driven by a decline in European, and later global, gas and oil demand, and partly by available resources on the Norwegian continental shelf.

As the EU aims for a 55% reduction in emissions by 2030 and climate neutrality by 2050, it faces a delicate balance between decarbonizing its energy systems and ensuring reliable supply. Even with strong policy packages such as *Fit for 55* and *REPowerEU* with its associated support schemes, Europe does not have sufficient surplus energy to enable it to independently solve both energy security and decarbonization goals (see our 2024 *Energy Transition Outlook*). Norway will be essential to achieving the EU's industrial and climate targets in the short term with a continuous supply oil and gas that minimizes dependency on more volatile global markets. In the medium term, the EU will increasingly depend on greener sources of energy, and, as both electricity and hydrogen are energy carriers that are not easily transported over long distances without significant energy losses, Norway will be needed to meet rising low-carbon energy demand in the EU.

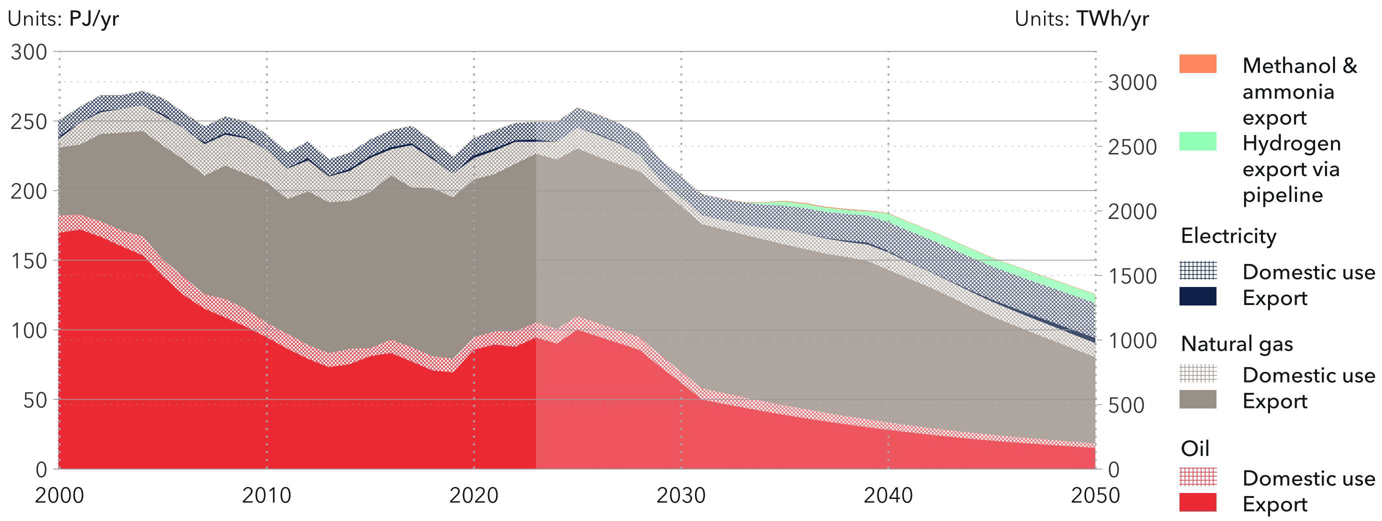
The value of Norwegian oil and gas exports was 490bn NOK/year on average over the last 10 years but grew to an astounding 1 900bn NOK in 2022, to then drop to 200bn NOK in export revenue in 2023 (Norsk Petroleum, 2024; SSB, 2024). With oil exports declining 85% and gas halving during our forecast period, export revenues will drop to levels much lower than we have seen historically (Figure 5.1).

Electricity and hydrogen exports from Norway to Europe will initially be marginal, but will grow as power capacity increases in Norway and in line with gradually increasing demand for hydrogen from Europe. However, volumes will remain comparatively minor in the sense that electricity and hydrogen revenues will compensate for only a very small share of the lost revenue from oil and gas exports in the long term. Net electricity exports will be around 40 TWh/year in by 2050. While that is sizeable (equivalent to about a third of current domestic consumption) export revenues have to be weighed against the overall result of trading electricity where there is often a significant difference in the export and import price. Hydrogen exports of 2 MtH_2/yr in 2050 could yield additional income but the volumes are not large enough to make a big increase in revenue.

Electricity and hydrogen revenues will compensate for only a very small share of the lost revenue from oil and gas exports in the long term.

FIGURE 5.1

Norway's energy production allocated to domestic use and export



Oil includes condensates, natural gas includes NGLs. Historical data source: NPD (2024), IEA WEB (2024)

5.1 Oil and gas exports

Norway's oil 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, our analysis finds that Norway's share of the global oil market will gradually reduce to around 0.5% by 2050. As a result, total oil exports (including oil products) will fall to 1 Mbpd (62 million Sm³oe/yr) in 2030, 0.5 Mbpd (28 million Sm³oe/yr) in 2040 and 0.3 Mbpd (15 million Sm³oe/yr) in 2050.

The outlook for gas is less bleak, since natural gas will retain a strong market position in the European energy system. Norwegian natural gas is preferred from a security perspective; moreover gas through pipelines can compete economically with LNG from the Middle East or US. In addition, Norwegian natural gas has a low carbon footprint from its production and especially stringent and low emissions from leakage and flaring (Flareintel, 2020). However, EU is set to reduce its dependence on natural gas as a direct consequence of Russia's war on Ukraine. The continent's demand for gas likely peaked in 2021 and will not return to historical levels. Norway supplies close to 30% of Europe's gas demand (Norsk Petroleum, 2024). In line with the declining gas demand in Europe towards mid-century, Norway's gas exports (including natural gas liquids) will start to decline within this decade. In 2050, Norwegian gas exports will be 62 billion m³/yr, 49% lower than in 2023.

We forecast LNG export to stay at existing levels as gas demand outside Europe will be increasingly uncertain, and likely met by low cost supply from the Middle East. Most LNG from Norway is exported to Europe and LNG export capacity will likely not grow in the future as gas export via pipelines will remain the main form of export to Europe. It could also be, as discussed below, that natural gas is converted, with carbon capture, to hydrogen or ammonia and that those decarbonized energy sources are then being exported using existing infrastructure with some retrofitting.

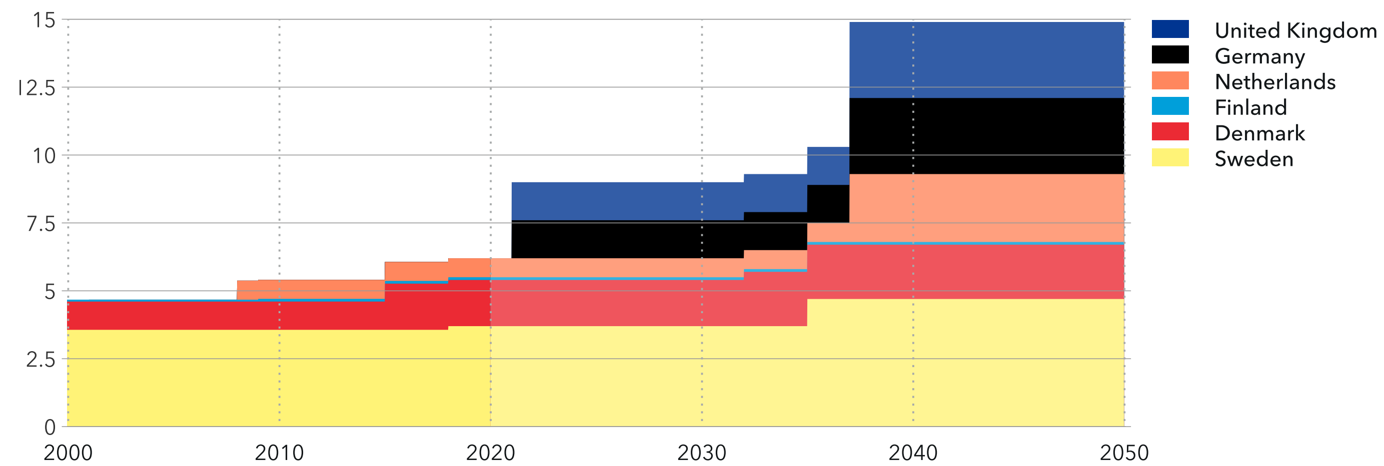
5.2 Electricity exports

Norway's total net transfer capacity to other countries is 8.9 GW. Of this, 3.7 GW goes to Sweden, 1.7 GW to Denmark, 0.7 GW to the Netherlands and 0.1 GW to Finland. There is now also additional export via the two recently installed HVDC cables: the NordLink subsea cable to Germany (1.4 GW) and the North Sea Link to the UK (1.4 GW). Both of which came online in 2021 (NVE, 2023), see Figure 5.2. To facilitate its neighbouring countries' ambitions to grow renewable generation, we foresee an increase in Norway's cross-border capacity to Sweden and Denmark by another 1 GW and 0.3 GW, respectively in the mid-2030s. An additional 1.4 GW interconnector between Norway and UK is expected along with a similar new interconnector with Germany. Finally, we assume another 2.8 GW to the rest of Europe, which could be either Netherlands, Finland or other countries to be built by 2040.

FIGURE 5.2

Norway net electricity transfer capacity

Units: GW



Historical data source: ENTSO-E (2023)

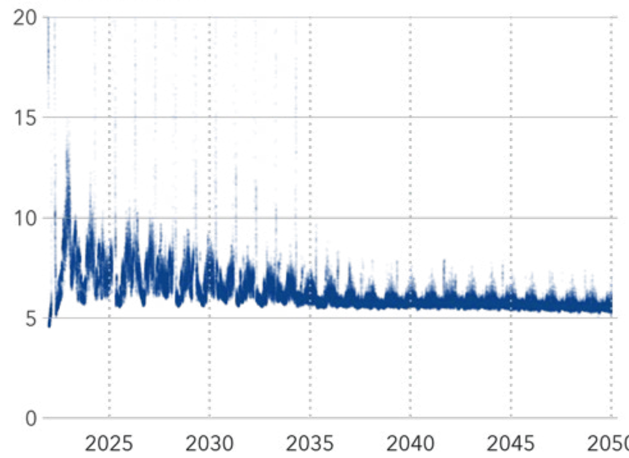
Today, Norway's electricity grid is divided into five bidding zones. The actual cross-border electricity trade is very dependent on the supply and demand conditions in these bidding zones and the markets they trade with. Our model simplifies this structure by representing Norway and the rest of Europe as two electricity markets without any grid constraints within each market. This simplified power market modelling 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. However, we cannot simulate the bidding zone differences within the five bidding zones in Norway and accordingly, the differences in price found between north and south as a consequence of transmission limitations. However, over time such imbalances will be reduced with increasing grid expansions.

Over the last 20 years, Norway's average annual net electricity export has been around 10 TWh. Annual total net exports will be lower than current levels between 2025 and 2035. An increase in domestic electricity demand combined with limited capacity additions shifts the dynamic towards imported electricity with a net imbalance of up to 10 TWh/yr by 2034. The actual situation is highly dependent on the weather such as wind and precipitation. Norway's hydropower generation can vary by up to 60 TWh (Tellefsen, 2020). In our assessment, we use the estimated average annual production of 137.3 TWh. From the early 2030s, new capacity additions from offshore wind are added to the grid and improve the balance such that Norway is again a net exporter from 2037, increasing the annual net export to 5 TWh/yr by 2040 and then growing in the 2040s when more offshore wind is being built and giving surplus electricity exports of 40 TWh/yr by 2050. Additional wind capacity in Europe will create situations when there is lots of wind and thus low electricity prices, which makes 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 again become a net electricity exporter, also during winter months.

FIGURE 5.3

Norway wholesale electricity price distribution

Units: US cents/kWh



Shows simulated wholesale electricity price at a particular week.

In the short term, with increasing imports due to electricity deficits, and less new capacity added combined with limited flexibility in the power system, our analysis shows that electricity prices initially will increase and face bigger fluctuations (Figure 5.3). As both capacity and export/import volumes increase, not only will average electricity prices decline, but price fluctuations within the year will also reduce. The price stability is linked to increased flexibility resources in the power system, brought by new interconnections, new utility-scale storage capacities, availability of EV batteries through vehicle-to-grid systems, and better demand response afforded by widespread adoption of smarter 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.

5.3 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, requirements 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.

The EU, with its strong hydrogen support policies, will lead global hydrogen uptake with 8% hydrogen and its derivatives in its 2050 final energy mix. Europe is one of three leading world regions that together will consume 65% of global hydrogen demand for energy purposes by 2050. The EU has set ambitious hydrogen targets for 2030 as part of its green transition goals, aiming for 20 million tonnes (Mt) of renewable hydrogen, with 10 Mt produced within Europe and another 10 Mt imported (EC, 2024). This target requires significant investment in hydrogen infrastructure, both with respect to electrolyser capacity as well as sufficient renewable energy capacity to produce cheap enough electricity for the electrolysers. The European Court of Auditors (ECA, 2024) criticized these targets, calling for a "reality check". Production goals do not align well with current demand estimates and market readiness, making it difficult to achieve the ambitious 2030 target. In our forecast, we too find that the European hydrogen ambitions will not be met. By 2030, hydrogen demand (including Norway and UK) is 13 Mt, with 70% of that still based on fossil sources without CO_2 removal. By 2040 the demand is at 18 Mt, and then growing to 35Mt by 2050 (DNV, 2024a). Hydrogen is difficult and expensive to transport long distances which means imports will have to come from regions close to the EU, and any country with surplus energy capacity will be incentivized to contribute.

Norway is in a very good position to support supply of hydrogen to Europe. Today, Norway uses predominantly natural gas as source for hydrogen production for use in its domestic feedstock market. By mid-century, Norway's domestic hydrogen demand more than doubles, but its hydrogen production can grow significantly beyond that, and this opens possibilities for hydrogen export to Europe. Thus far, hydrogen export discussions have involved blue hydrogen production and exports, but several projects have recently been shelved by Equinor and Shell (Reuters, 2024; SPGlobal, 2024).

Without a technical breakthrough in hydrogen production, surplus energy from either natural gas or electricity must be present to produce low-carbon or renewable hydrogen. Presently, the willingness to pay for either blue or green hydrogen is very weak but, if EU does not abandon its pursuit, we expect growing demand from EU will arise and by 2030 there are no better alternatives than blue hydrogen based on natural gas produced in Norway and transported by pipelines to the continent. In our analysis, we include additional cost for pipeline investments, but with relatively low volumes of hydrogen exports and with declining gas exports, we assume the already installed pipelines to Europe could be retrofitted to enable an increase in hydrogen transport from Norway to Europe. By 2040, we expect an export volume over 1 Mt and growing to 2 Mt hydrogen by 2050.

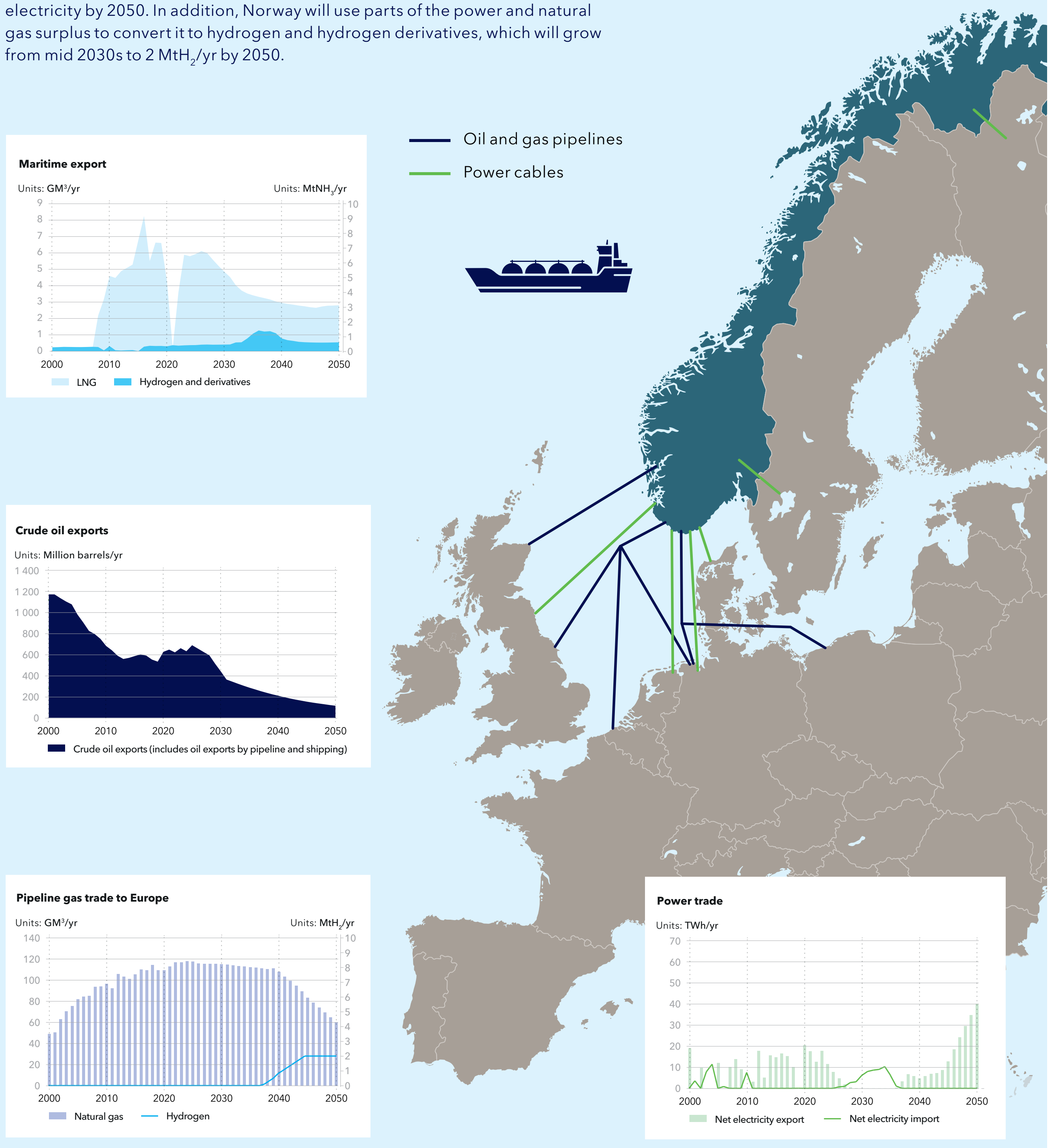
Blue hydrogen from natural gas coupled with CCS will initially provide a steady flow of hydrogen using Norway's natural gas resources and CCS knowledge effectively, supplemented by green hydrogen from renewable energy sources such as offshore wind. The export-based based short- to medium-term focus is on blue hydrogen accounting for 52% of Norway's hydrogen production by 2035. Another 36% will still come from unabated natural gas-based hydrogen production. However, by mid-century this ratio changes: 40% of Norway's hydrogen will be grid-based, 50% in total from natural gas with CCS, 2% from dedicated wind, and only 8% from unabated natural gas.

Big uptake markets in Europe, such as Germany, have historically indicated a marked preference for renewable, electrolysis-based hydrogen production over hydrogen from natural gas, even if coupled with CCS. However, the current turmoil in gas markets and the difficulty in securing a steady supply of hydrogen seem to be changing this view. The next step in public opinion could be to also accept CO_2 capture from natural gas use in Germany, and to pipe the gas to safe storage in the North Sea or elsewhere; however, this is presently not part of our most-likely developments.

While we forecast significant amounts of hydrogen to be exported to Europe via pipelines, some low-carbon ammonia is likely to be traded on keel from Norway. In the late 2030s, low-carbon ammonia exports from Norway will reach about 0.8 Mt/yr year, to be shipped mainly to European ports. However, this blue ammonia will quickly face competition from other regions, mainly the Middle East. Thus, much of Norway's capacity will be allocated to producing blue hydrogen for export to Europe, as EU's demand for hydrogen continues to grow. Transporting hydrogen over long distances is challenging and costly, whereas ammonia can be transported globally with relative ease.

Energy trade

By 2050, Norway's oil export will be 15% of today's level. Natural gas exports will be halved compared to today. A growing share of energy exports will be diverted to electricity and hydrogen. Electricity production will increasingly grow faster than domestic demand and Norway will export 40 TWh/yr of electricity by 2050. In addition, Norway will use parts of the power and natural gas surplus to convert it to hydrogen and hydrogen derivatives, which will grow from mid 2030s to 2 MtH_2/yr by 2050.



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

6 EMISSIONS

The energy sector is the dominant source of anthropogenic greenhouse gas (GHG) emissions globally as well as in Norway. CO_2 is the main contributor to these emissions and comes largely from the combustion of fossil fuels. We forecast that emissions in Norway will not drop fast enough for the country to reach its national emissions reduction targets. Emissions drop by 27% by 2030 (compared with 1990) versus the targeted 55% reduction. By 2050, emissions fall by 75% whereas the goal is to reduce 90% to 95% compared with 1990 levels.

In this chapter, we describe how we estimate developments of Norway's emissions by source and by sector. 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.

6.1 Emissions

Norway's energy-related CO_2 emissions have risen steadily for three decades, and a decline has only been observed since 2018. In addition to those from combusting fossil fuels, a large share of Norwegian CO_2 emissions is process-related industrial emissions without fossil-fuel combustion. A large quantity of these come from using fossil fuels as feedstock in the steel and petrochemical industries. Process-related emissions also come from the calcination process in cement production and from other process-based emissions using 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 – which comes from agriculture, landfills, waste management and industry – are small compared with CO_2, but converted to CO_2 equivalents, they contributed 17% of total GHG emissions in 2023 and will account for 37% in 2050.

We forecast continued GHG emissions through to 2050. In 2023, they were slightly lower than in 1990 and we forecast the decline to reach 27% by 2030 and 75% by 2050, when total GHG emissions will be 13.4 million tCO_2e (Figure 6.1). This falls well short of the ambitions for a decline of at least 55% by 2030 and 90–95% by 2050. Since early action on emissions is more meaningful than later action, it is unfortunate that Norway is on track to achieve only half its stated reduction ambition by 2030.

The largest decline in emissions will come from electrification of road transport and the associated reduction in oil consumption. Other factors are: a general decline in oil and gas production; using electricity instead of natural-gas turbines to power oil and gas production; and changes in heat-intensive manufacturing processes. As our energy transition 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.

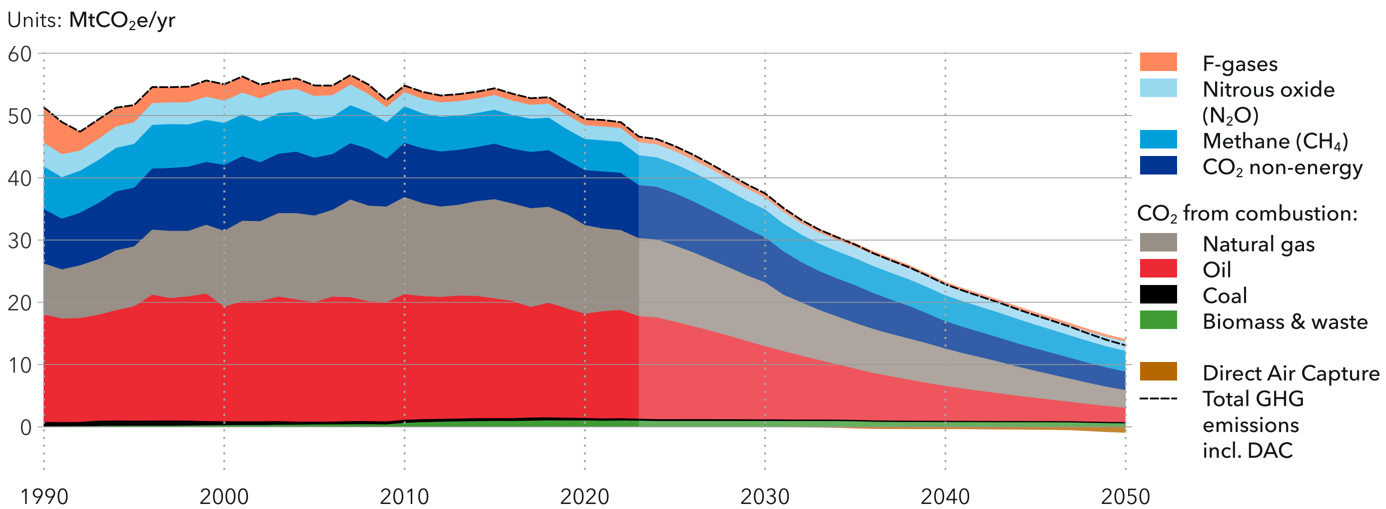
Emissions by sector

From a sectoral perspective, all emissions have been associated with the main sectors described in our energy systems model (Figure 6.2). CO_2 emissions dominate all sectors except the 'Other' category, which in this context is mainly agriculture.

In 2023, transport emitted 29% (13.4 $MtCO_2e$) 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 $MtCO_2e$ in 2023. By 2030, we find these likely to decline to 5.6 $MtCO_2e$, 25% less than in 1990, and 31% lower than in 2023. The main driver of this reduction is electrification, especially in passenger vehicles, where emissions decline 56% from 1990 levels

FIGURE 6.1

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



F-gases include: HFCs, PFCs and SF6. Historical data source: SSB (2024) by 2030. The government's ambition to increase biofuel use to help decarbonize road transport will also contribute. Between now and 2050, road transport emissions will decline 91% to represent 5% (0.7 $MtCO_2e$) of Norwegian emissions.

Aviation, rail, and maritime combustion emissions have been declining since 2000 and are currently 40% of Norwegian transport emissions. However, with limited electrification potential in shipping and aviation, 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 non-road transport segments are expected to fall 57% between 1990 to 2050, when they will be 1.7 $MtCO_2e$.

The second largest sectoral emission today is the 13.2 $MtCO_2e$ (28% of total emissions) from 'energy sector own use', mainly for energy extraction and production. Most (86%) of this is CO_2 from gas turbines generating electricity on the Norwegian continental shelf (NCS). As the NCS continues to electrify production, as efficiencies increase, and as installations without electrification reach end of life, emissions will decline by 24% between 2023 and 2030. By 2050, energy sector own use will have reduced 82% to 2.4 $MtCO_2e$ since 2023 due to declining activity levels on the NCS and an electrification rate of just over 51% of the energy used being from electricity.

Manufacturing today emits 11.4 $MtCO_2e$, a quarter of Norway's total GHG emissions. Just over two thirds of the sector's emissions are from process-related CO_2 emissions in heavy industry, and the rest comes from combustion of fossil fuels and fluorinated gases. By 2030, the sector's emissions will have declined by only a sixth (18%) due to some growth in industrial output. By 2050, however, emissions of 3.8 $MtCO_2e$ will be two-thirds (66%) less than today. 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.

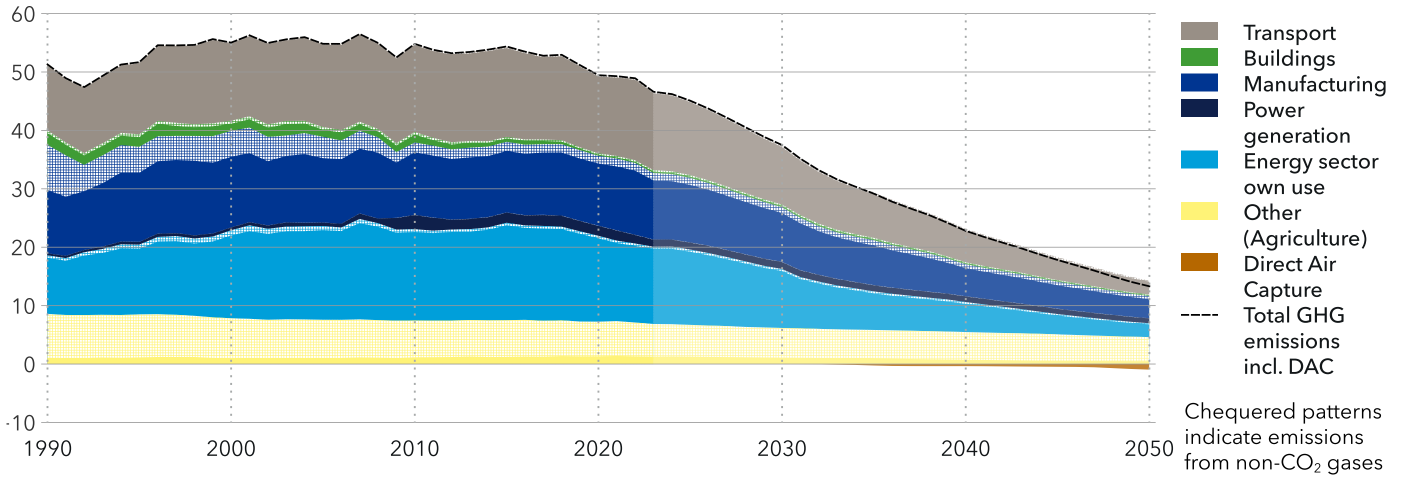
The buildings sector's energy use in Norway is largely linked to electric heating. Some fossil fuels are still used for space and water heating for commercial buildings. The remaining emissions are methane from burning biomass for heating. Today, the buildings sector represents only 1% (around 500 $ktCO_2e$) of Norwegian emissions. Even with an expected increase in building mass and floor space, these emissions will decline further due to building efficiency standards, fuel switching, and the further introduction of heat pump systems, making electric heating even more prevalent. By 2050, these emissions will have further declined by 52% to 240 $ktCO_2e$ per year.

Agricultural emissions are largely methane from enteric fermentation and manure. The other major source in the 'Other' category is methane from landfill. We expect some progress in reducing emissions from agriculture and animal management by 2030 and 2050, but these are tied to activity level and thus relatively challenging to

FIGURE 6.2

Norway greenhouse gas emissions by sector

Units: $MtCO_2e/yr$



Historical data source: SSB (2024)

reduce through technical means. We have included some progress as described in the Norwegian Government's 'Green Book' (2024). However, 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.

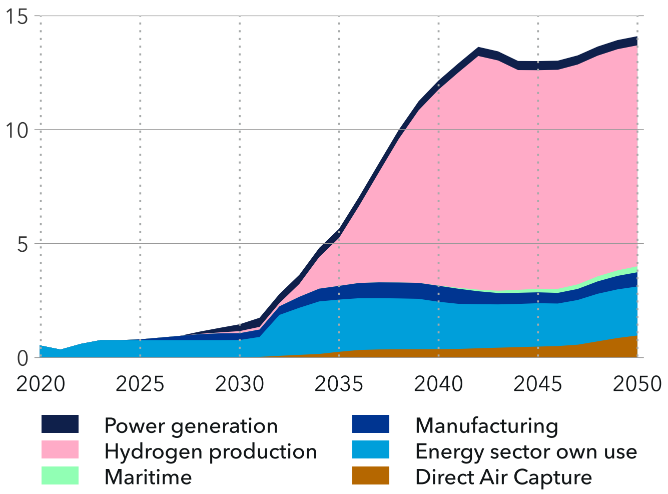
In the Norwegian government's 2024 budget, as detailed in the 'Green Book', land-use changes, including emissions from forestry activities and peatlands, are addressed. The government acknowledges that land-use changes, such as deforestation and afforestation, as well as the management of peatlands, significantly impact GHG emissions. However, these emissions are not included in our assessment of Norwegian emissions.

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 challenging to reduce through technical means.

FIGURE 6.3

Norway CO_2 emissions captured

Units: $MtCO_2$/yr



6.2 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 reductions 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 there is capacity to remove some 850ktCO_2/yr from gas with injection into an offshore sandstone reservoir (GCCSI, 2024). At the Melkøya LNG facility, up to 700ktCO_2/yr can be 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 400ktCO_2/yr carbon capture at Brevik cement plant and 400ktCO_2/yr from the Klemetsrud waste-to-energy plant, with both capture streams anticipated to come online gradually from 2025 and from 2028, and stored on the NCS as part of the Longship project.

In the Longship project, the Norwegian government has committed around NOK 16.8 billion (approximately USD 1.6 billion) to fund about 80% of the project's estimated costs (Government.no, 2020). This covers both initial construction and operating costs over a decade. The Northern Lights component, a partnership between Equinor, Shell, and TotalEnergies, handles CO_2 transport and storage and is designed to eventually accommodate emissions from other European countries, expanding its storage capacity from 1.5 million to potentially 5 million tonnes of CO_2 per year in the future.

Such significant investment into infrastructure development incentivizes increased CCS activity, which we include in our analysis, along with a significant increase in CO_2 pricing. However, the effect is a very modest increase of emissions captured, starting in the early 2030s and slowly adding CCS capacity in new sectors to be capturing a total of 11.5 MtCO_2/yr by 2050 (Figure 6.3). The biggest share by far is CO_2 captured during blue hydrogen production – around 9GtCO_2/yr from 2040.

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 stage and will need to prove it works in large-scale installations. In our forecast, DAC will grow slowly out of pilot stage and reach a few hundred thousand tons captured by late 2030s. 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 remaining emissions. We are only moderately optimistic also in the longer perspective, and expect that capture reaches 1 MtCO_2/yr by 2050.

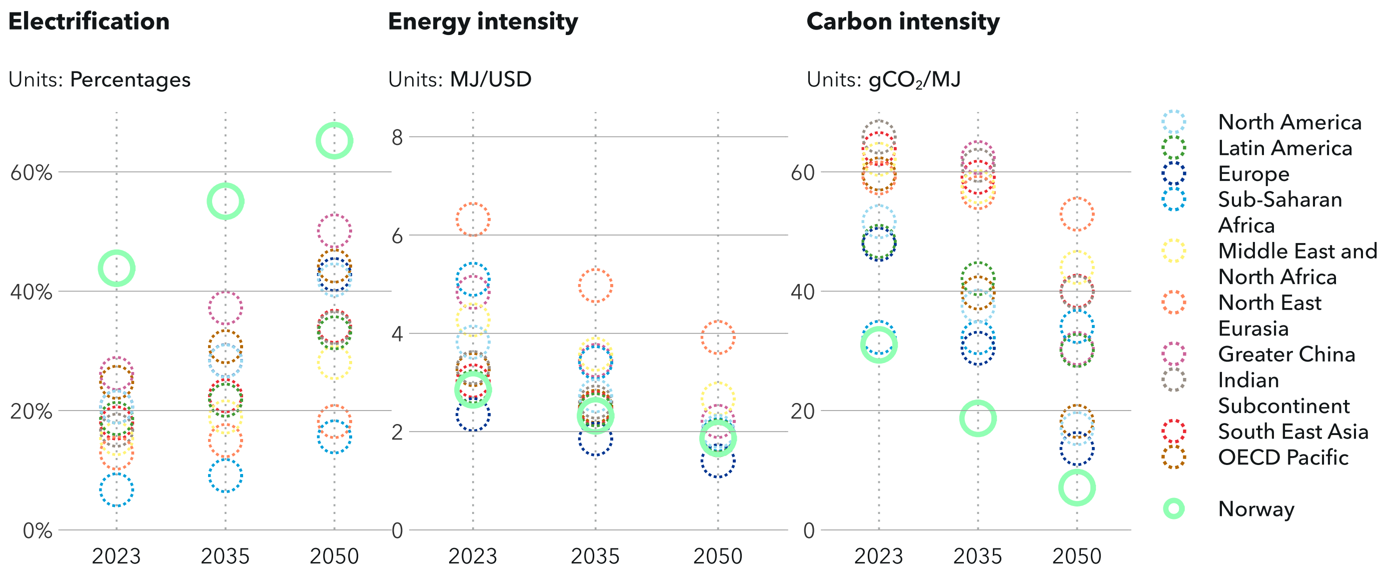
Combining CCS from point sources with DAC, we expect a total capture of 12.4 MtCO_2/yr in 2050, leaving 13.3 MtCO_2 uncaptured. Remaining CO_2 emissions stem from sectors such as transport, where emissions are difficult to capture, as well as from other point sources where capture remains expensive and complicated. Remaining non-CO_2 emissions in 2050 (4.1 MtCO_2e) are found mainly in the agricultural sector (80%) and will be increasingly difficult to avoid or remove without considerable disruption to food production.

6.3 Energy transition indicators

Norway's energy system is unique compared with those of other regions. It has abundant natural energy resources and a relatively small population; a large energy export; and a power sector already among the most decarbonized globally. Figure 6.4 presents Norway's development against three main energy-transition indicators: electrification, energy-intensity improvements, and decarbonization in comparison with other developed regions. Norway's share of electricity in final energy demand will reach 64% in 2050, far higher than in any of the regions in our global forecast.

Norway will reduce the energy intensity of GDP from 2.8 today to 1.9 MJ/USD in mid-century. That is quite an achievement, but because it will still be producing energy for export, Norway will have a considerably higher energy intensity than the European average in 2050, where it is expected to reach 1.4 MJ/USD. Carbon intensity significantly (75%) declines between 2023 and 2050, reaching a final value of 7.1 gCO_2/MJ. This level is much lower than in Europe, where we see an intensity of 13.6 gCO_2/MJ, 72% less than today. The main reason for this difference is that emissions in Europe stem largely from transport and buildings, which are sectors that Norway has already electrified considerably, and will continue to do so.

FIGURE 6.4



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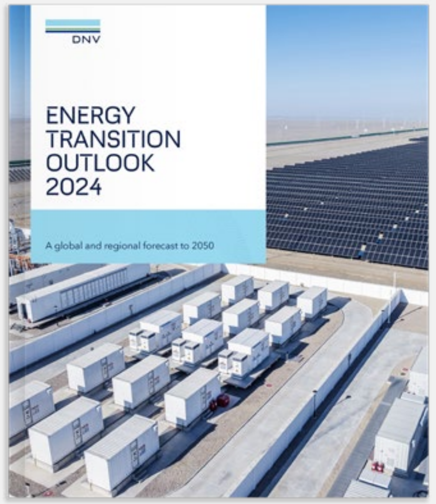

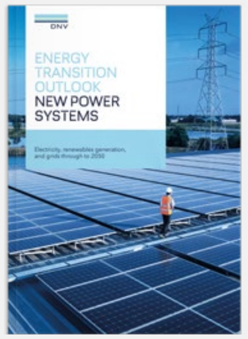

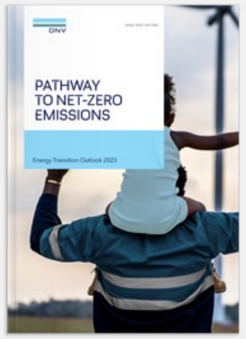

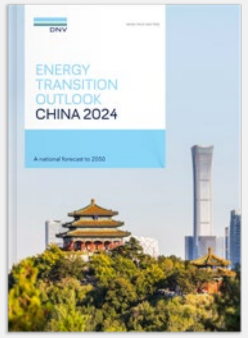

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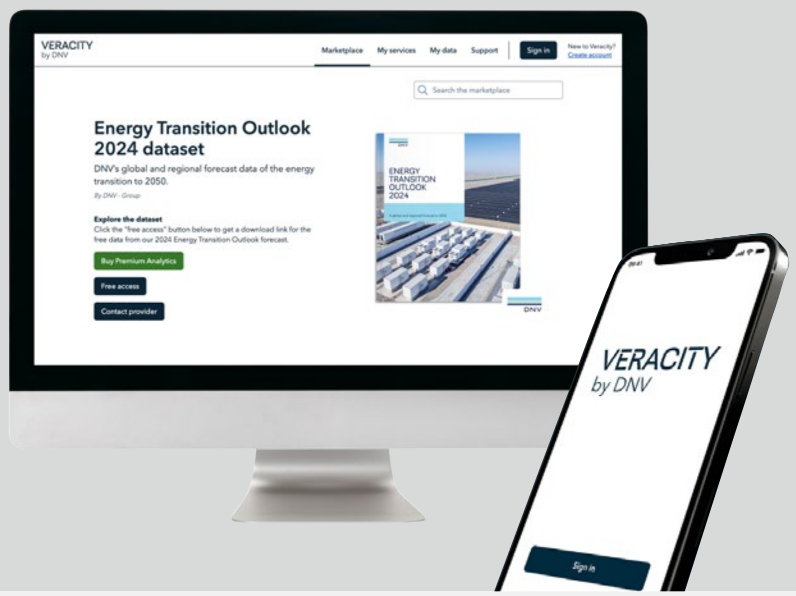

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