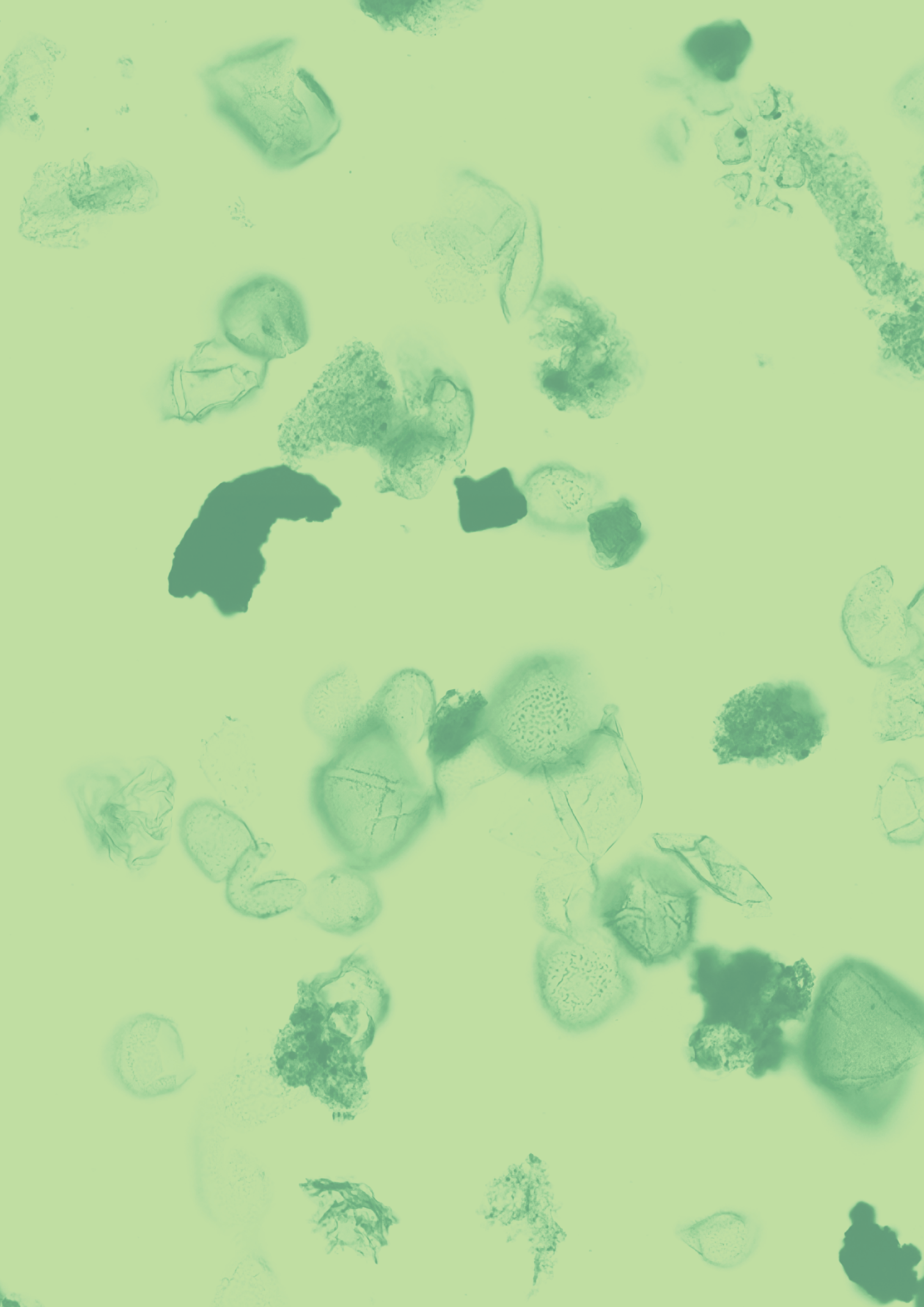
Resource report
2022

NORWEGIAN PETROLEUM
DIRECTORATE
50 years



Foreword

Fifty years have passed since the Norwegian Petroleum Directorate (NPD) was established by the Storting (parliament) and located in Stavanger. Its creation occurred a decade after Phillips Petroleum wrote to the Norwegian government to request exclusive rights to explore for oil and gas in those parts of the North Sea which lay within Norway's territory. The government rejected this request and the following year proclaimed Norway's sovereignty over the Norwegian continental shelf (NCS). A new Act was passed which specified that the right to submarine natural resources was vested in the state and that only the King (government) may give permission to explore for and produce natural resources.

The first offshore licensing round was conducted in 1965, with the first wildcat spudded the following year. A total of 27 wildcats were drilled before a commercial discovery was made – Ekofisk in 1969. This was the world's largest offshore oil field, and trial production began just two years after its discovery. Ekofisk has now produced for more than half a century, and its production licence was extended in 2022 from 2028 to 2048.

With Ekofisk declared commercial, it was clear that the petroleum industry had arrived in Norway to stay. That made it necessary for the government to strengthen national management and control of the sector. In 1972, the state's involvement with petroleum activities was divided into three parts – a ministry (now the Ministry of Petroleum and Energy – MPE), a state oil company (Statoil, now Equinor) and a regulatory agency (the NPD).

Companies have subsequently explored, discovered and produced, developed and adopted new technology, and built up a unique Norwegian expertise. Throughout these 50 years, the NPD's main goal has remained in principle unchanged – to contribute to the greatest possible value for society from the oil and gas sector through efficient and prudent resource management which takes account of health, safety and the environment as well as other users of the sea.

A good and updated factual basis is a precondition for effective and prudent resource management. The NPD therefore regularly produces a resource report which provides an overview of petroleum resources, activity and value creation on the NCS. This report describes and analyses development trends and driving forces in order to help support a knowledge-based and predictable management of the petroleum resources.

This year's report presents the analyses which underlie the NPD's updated estimate of undiscovered resources on the NCS. Since output began in 1971, half the total expected resources have been produced. This means that the remaining half could provide the basis for many decades of continued production.

The past two years have been unsettled and affected by the pandemic, climate concerns and very high energy prices. The effects of these factors and the war in Ukraine following Russia's invasion in February 2022 make it more difficult than ever to predict developments. Owing to the loss of Russian gas deliveries and lack of alternative supplies, mothballed coal-fired power stations are again being taken into use in Europe.

With a European continent which needs increased deliveries of both oil and gas, and which has great ambitions for reducing greenhouse gas emissions, Norwegian deliveries with a low climate footprint and low costs could become even more important. Such supplies can contribute to both reduced emissions and increased energy security.

This requires that operations on the NCS are maintained through active players, a high level of exploration and purposeful technology development. In this transition, it is important to exploit synergies between value chains and the transfer value of expertise built up through 50 years of petroleum operations. At the same time, good coexistence on the NCS will always be a precondition for overall value creation – both for the industries concerned and for society as a whole.

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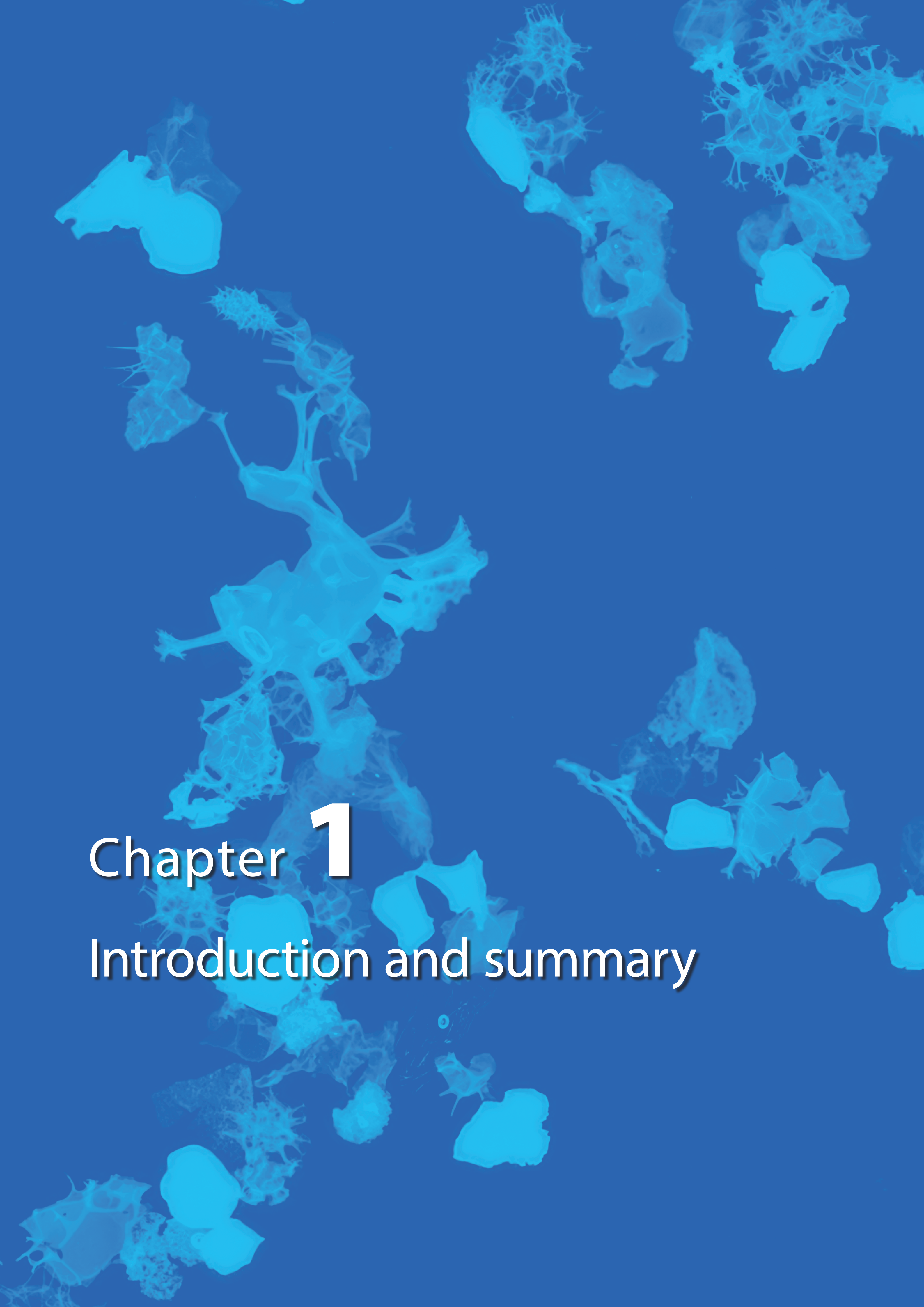
Resource report 2022



Chapter 1

Introduction and summary

The NPD's *Resource report 2022* provides a status overview and analyses of the long-term opportunities and challenges for petroleum operations on the NCS.

It shows

1. the remaining resource potential, and the opportunities and value this could represent for Norwegian society

2. that the NCS is competitive in terms of both costs and greenhouse gas (GHG) emissions

3. what is required for Norway to maintain its role as a stable, long-term and secure oil and gas supplier to Europe

4. challenges, dilemmas and opportunities for developing the industry within more stringent climate policy parameters.

Roughly half the estimated petroleum resources have been produced from 1971 to the present. During this period, oil and gas production has contributed about NOK 18 000 billion to Norway's gross domestic product, measured in today's value [1]. The sector represents a large and important part of the Norwegian economy and accounts for a substantial share of government revenues.

Estimates suggest that oil and gas remaining on the NCS equal the amounts produced over 50 years. History shows that the remaining resources could yield substantial revenues for society and the industry for a long time to come.

A competitive NCS is a precondition for maintaining value creation. Remaining resources, low unit costs, low CO_2 intensity and a flexible gas infrastructure make Norway a competitive and long-term supplier of both oil and gas to Europe.

Limiting the expected fall in production is important if the NCS is to maintain output at a high level, contribute big value to society and provide stable long-term and secure oil and gas deliveries to Europe (Figure 1.1).

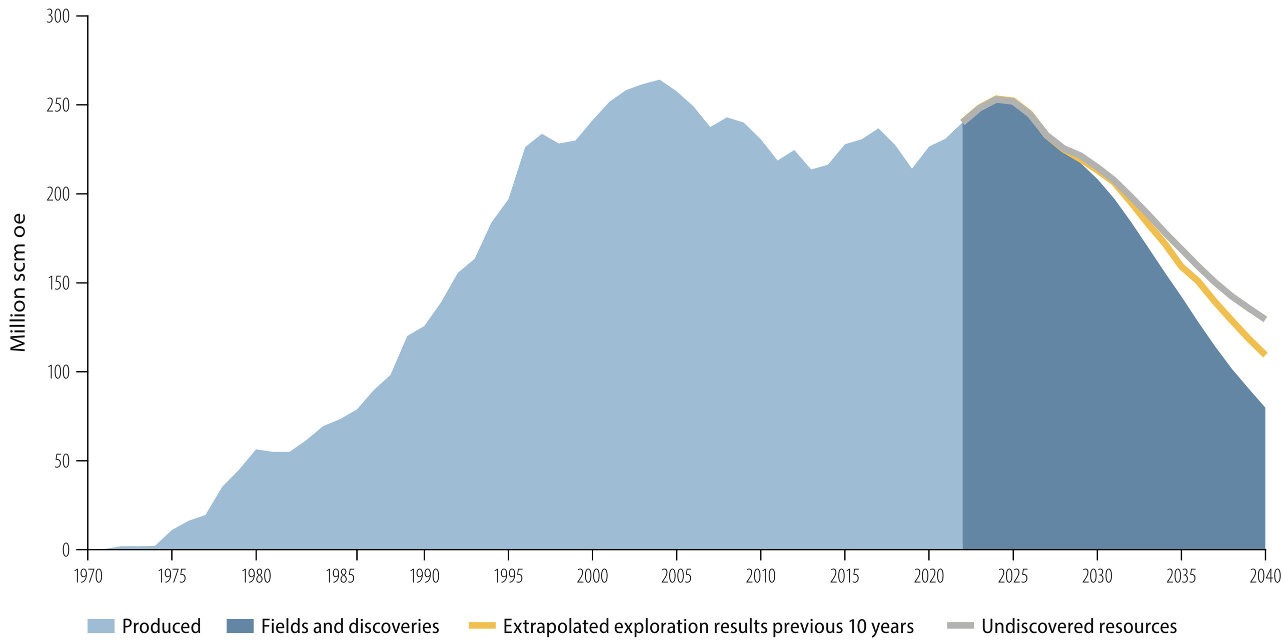


Figure 1.1 Production outlook for oil and gas from the NCS to 2040

Fields on stream contain large remaining resources, with a substantial potential for improved recovery which can help to counter the decline. This requires that more investment is made in improved recovery than at present, that existing discoveries are matured for development, and that unit costs are kept down.

Based on current forecasts, a steadily rising proportion of production after 2030 must come from undiscovered resources. Small discoveries will account for much of this. When production from a field declines, spare capacity arises in the infrastructure. That will increase the incentive to explore for and produce small discoveries, which may make it possible to bring deposits on stream which are not large enough to be profitable as stand-alone developments.

To slow the decline in production, bigger discoveries than those being made today are needed. The potential for making large discoveries is greater in areas which are little explored or not yet opened for exploration. It is important for resource management that the companies not only reap from earlier investment but also explore for and invest in frontier areas on the NCS.

Exploration activity over the past 20 years has contributed huge value to society. The NPD's estimates show the overall net present value (NPV) of exploration for the past two decades to be about NOK 1 500 billion and NOK 2 100 billion at discount rates of seven and four per cent respectively. This activity has yielded an overall net income of more than NOK 3 000 billion. Exploration is profitable in all areas of the NCS.

A variety of companies have contributed to value creation through a great diversity of ideas and interest in different plays, technologies and exploration concepts. At 31 December 2021, 36 companies were active on the NCS. That represented a reduction from the 2013 peak of 56. The fall in the number of players reflects majors and European gas/power companies selling out in recent years, which has coincided with a number of mergers and acquisitions. A number of companies have grown and strengthened their position through this process, and the medium-sized players have become an increasingly important force in the continued development of the NCS.

Gas accounts for more than half the estimated remaining resources in opened areas of the NCS. Most of the proven gas lies in the North and Norwegian Seas, while about two-thirds of undiscovered gas resources are expected to be in the Barents Sea (Figure 1.2).

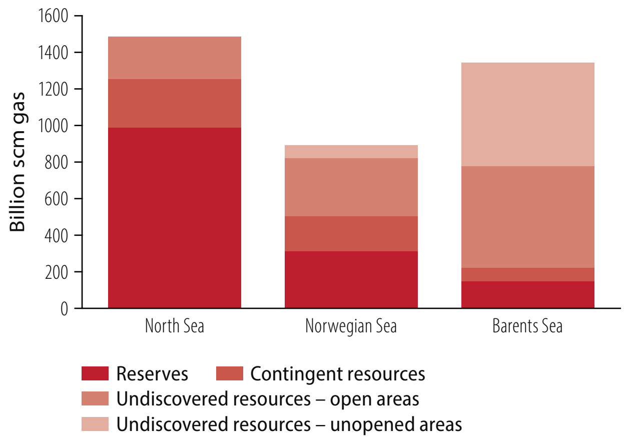


Figure 1.2 Remaining gas resources

Roughly half the undiscovered gas resources in the Barents Sea are expected to lie in unopened areas.

A well-developed infrastructure in the North and Norwegian Seas lowers the financial threshold for seeking and developing gas discoveries (Figure 1.3). Establishing the Polarled pipeline has helped to increase interest in exploring for gas in the Norwegian Sea. In the Barents Sea, such interest is restricted by the lack of sales opportunities. At present, the gas liquefaction plant at Melkøya outside Hammerfest provides the only opportunity to deliver gas from this part of the NCS. Gas from Snøhvit will fill all the capacity at that facility for a long time to come.

Without greater export capacity, both proven and undiscovered gas resources in the Barents Sea are of less interest. Developing oil fields with associated gas also becomes more demanding. The geology in the opened areas of the Barents Sea means that discoveries are unlikely to be large enough to support new export capacity on a stand-alone basis. Additional transport capability therefore depends to a great extent on coordinating resources. Studies carried out in 2020 by the NPD and Gassco showed that developing proven resources could make it socioeconomically profitable to increase gas export capacity from this area. That has been confirmed by subsequent studies [2]. The energy position in Europe suggests that the need for such a project has increased over the past year.

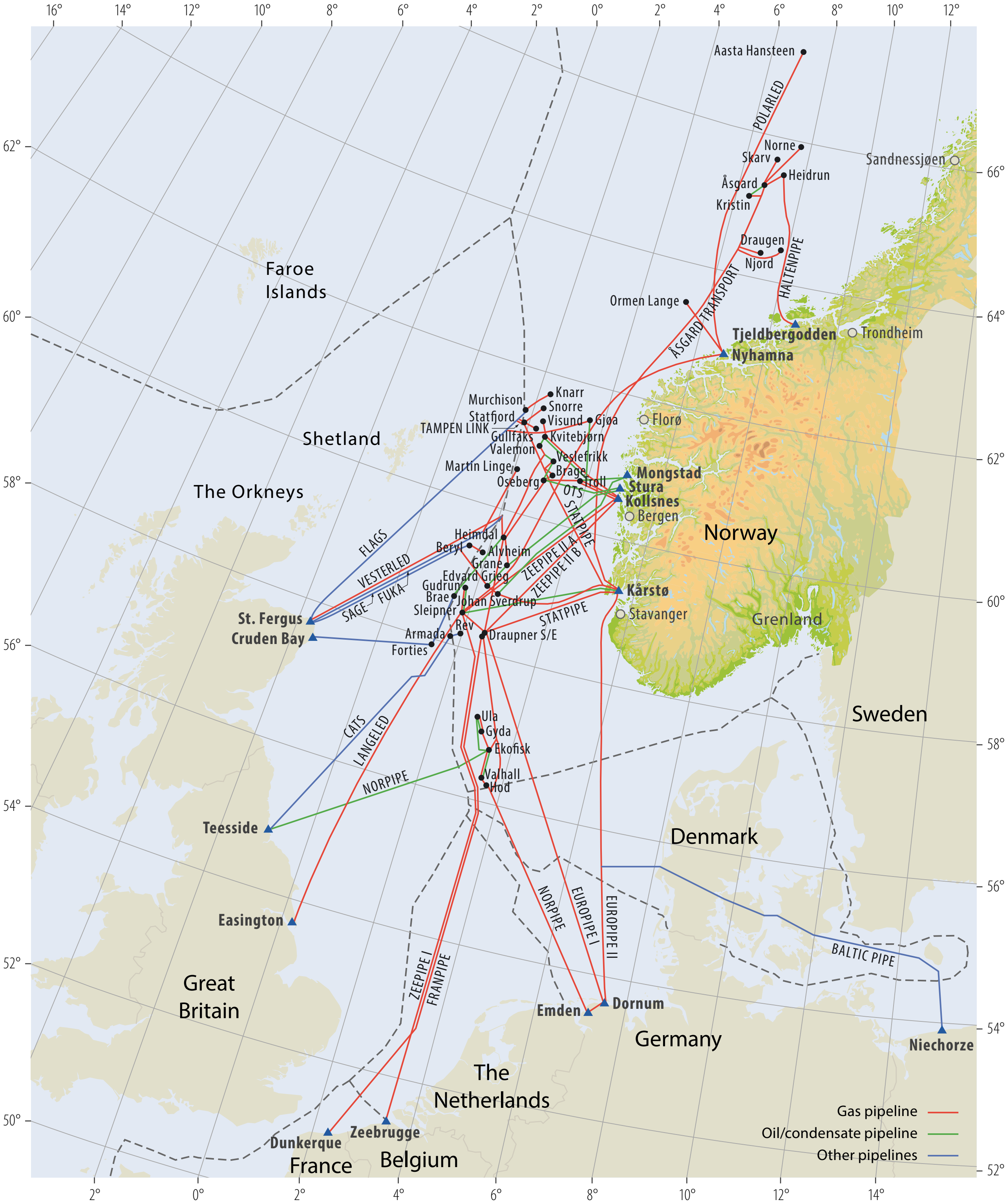


Figure 1.3 Infrastructure on the NCS

Norway is an important and long-term gas supplier to Europe, and Norwegian gas could occupy a key place in the EU's energy transition. In addition to providing energy with a relatively low climate footprint, gas can be used to balance variable renewable sources such as solar and wind power. If further resources are proven, it can also be utilised to produce virtually emission-free blue hydrogen. This might become an important energy bearer in Europe's energy transition. In the long term, hydrogen could thereby strengthen the competitiveness of Norwegian gas and help to create a market for carbon capture and storage (CCS). The NPD plays a key role in mapping opportunities and making provision for CO_2 storage on the NCS. The Norwegian government is studying whether the gas infrastructure, with some adaptations, can transport both hydrogen and CO_2.

The European energy transition could contribute to increased demand for seabed minerals required to manufacture electric vehicles, wind turbines, batteries, electrical components and so forth. Responsibility for mapping mineral resources on the NCS has been assigned to the NPD. Preliminary results show that interesting manganese crusts and sulphide deposits can be found on the seabed, and that these have a high content of such materials as copper, zinc and cobalt. That indicates exciting prospects for Norway.

At the same time, the energy transition creates great uncertainty about the world's energy systems and markets up to 2050 and how activity on the NCS will be affected. In addition to such general uncertainty, developments will depend on the resource position. That could lead to substantial changes in future production and revenues for society.

To maintain the competitiveness of the NCS, it is important that the industry has predictable access to prospective acreage. Increased technology development and measures which can keep down unit costs and further reduce the climate footprint will also be significant. At the same time, value chains in the oil and gas sector must be strengthened and expanded to include CCS, hydrogen and subsea minerals. A high level of exploration activity, purposeful technological development and active players can increase the opportunities for success.

Summary

Chapter 2: Remaining petroleum resources

The NPD's estimate for total petroleum resources on the NCS is 15 864 million standard cubic metres of oil equivalent (scm oe). Roughly half of this quantity has been sold and delivered. Substantial undiscovered resources remain, and about 56 per cent of these are expected to lie in opened areas. The potential for discovering more gas is greatest in the Barents Sea. Fields on stream contain large remaining resources, with a substantial potential for improved recovery.

Chapter 3: Competition and value creation

Exploration for and production of oil and gas have provided huge value for Norwegian society. The petroleum sector is Norway's largest industry by value creation, government revenues, investment and export value. Timely exploration and development are important for ensuring good resource management.

Chapter 4: Changes to the players

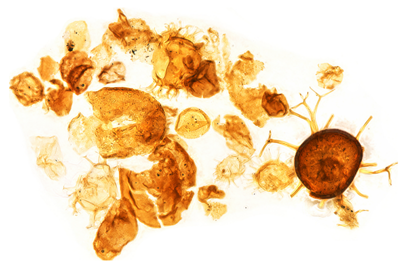
The number of players on the NCS has declined considerably in recent years. Nevertheless, the level of activity remains high. Many small and medium-sized companies have merged and strengthened their position. The medium-sized companies have become an increasingly important force in the continued development of the NCS.

Chapter 5: Energy transition opens new opportunities

The NCS is well positioned to meet the energy transition. At the same time, opportunities are being opened to strengthen the value chains in the oil and gas industry as well as in new business activities such as carbon storage, hydrogen production and recovery of seabed minerals.

Chapter 6: Future production and revenues

Uncertainty prevails over the future of both production on the NCS and revenues from the industry. Three scenarios show a substantial uncertainty range for both production and revenues. Purposeful technology development, players willing to invest and successful exploration can increase opportunities for maintaining both production volumes and revenues at high levels.



Resource classification

The NPD's resource classification system is used for petroleum reserves and resources on the NCS (Figure 1.4). This system is structured in such a way that the government receives the most uniform possible reporting from licensees in connection with the NPD's annual updating of the resource accounts.

"Resources" are a collective term for all the oil and gas which can be recovered. They are classified in the NPD's resource classification system by their level of maturity with regard to how far they have come in the planning process from discovery to production.

Developed in 1996, the classification system was revised in 2001 and 2016. Changes in 2016 primarily involved language improvements, including new designations for certain resource classes. The classification relates to the total recoverable quantities of petroleum.

The system is divided into three classes: reserves, contingent resources and undiscovered resources. All recoverable petroleum quantities are termed resources, and reserves are a special category of these. Reserves are the petroleum quantities covered by a production decision. Contingent resources embrace both recoverable quantities which have been discovered but are not yet subject to a production decision, and projects to improve recovery from the fields.

The classification utilises the letters "F" (first) and "A" (additional) respectively to distinguish between the development of discoveries and deposits and measures to improve recovery from a deposit. Undiscovered resources are those petroleum quantities which could be proven through exploration and recovered. The quantities produced, sold and delivered form aggregate historical production [3].

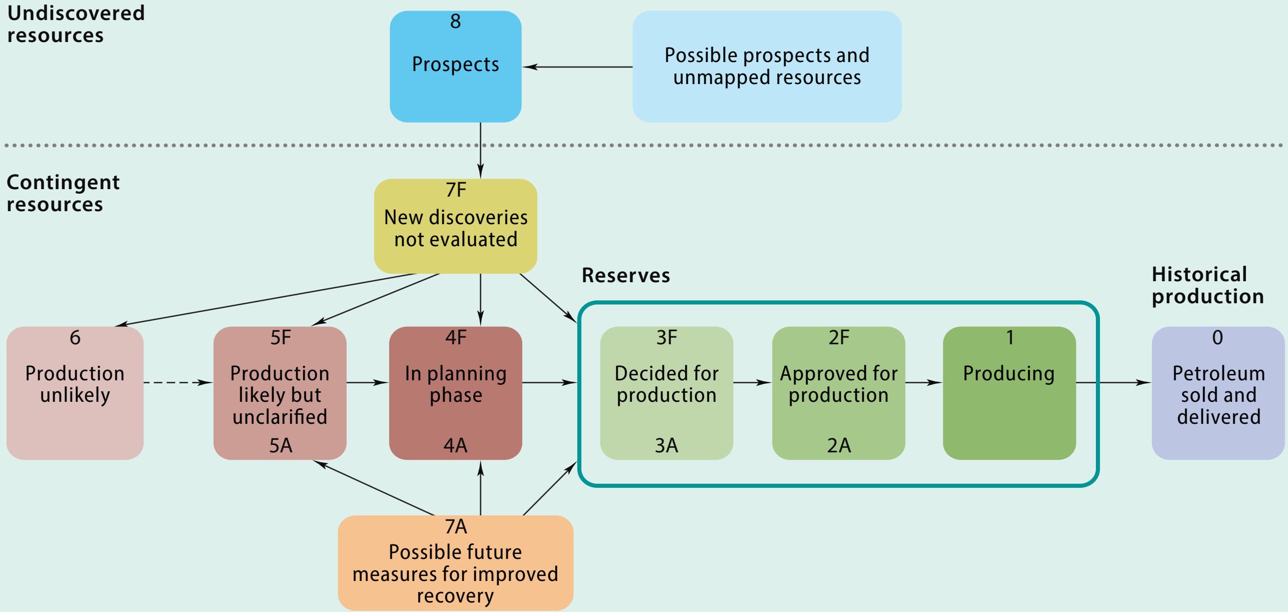


Figure 1.4 Resource classification in 2022

Chapter 2

Remaining petroleum resources

The NPD's estimate for total petroleum resources on the NCS is 15 864 million scm oe. Roughly half of this quantity has been sold and delivered. Substantial undiscovered resources remain, and about 56 per cent of these are expected to lie in opened areas. The potential for discovering more gas is greatest in the Barents Sea. Fields on stream contain large remaining resources, with a substantial potential for improved recovery.

One of the NPD's principal duties is to maintain an overview of the total petroleum resources so that the government has the best possible basis for planning measures to ensure good management.

Discovered oil and gas resources are developed as fields if they are technologically and economically commercial. The oil and gas are produced and sold. That creates dynamic resource accounts which change from year to year.

The resource accounts for 2021 estimate the total volume of resources (include the quantities sold and delivered) on the NCS at 15 864 million scm oe. This breaks down as 9 258 million scm of liquids and 6 605 billion scm of gas. Compared with 2020, that represents an increase of 97 million scm oe. The NPD's resource classification system is presented in chapter 1.

Remaining volumes broken down by resource class together with the volume sold and delivered at 31 December 2021 are presented in Figure 2.1.

The total is shown with the expected volume, and the uncertainty illustrated by low and high estimates. The distribution of both liquids and gas is presented in the figure. Uncertainty in the volume estimates decreases with increasing maturity. The pie chart on the right shows that 50 per cent of the expected resources on the NCS have been produced and that 24 per cent of the total resources remain to be discovered.

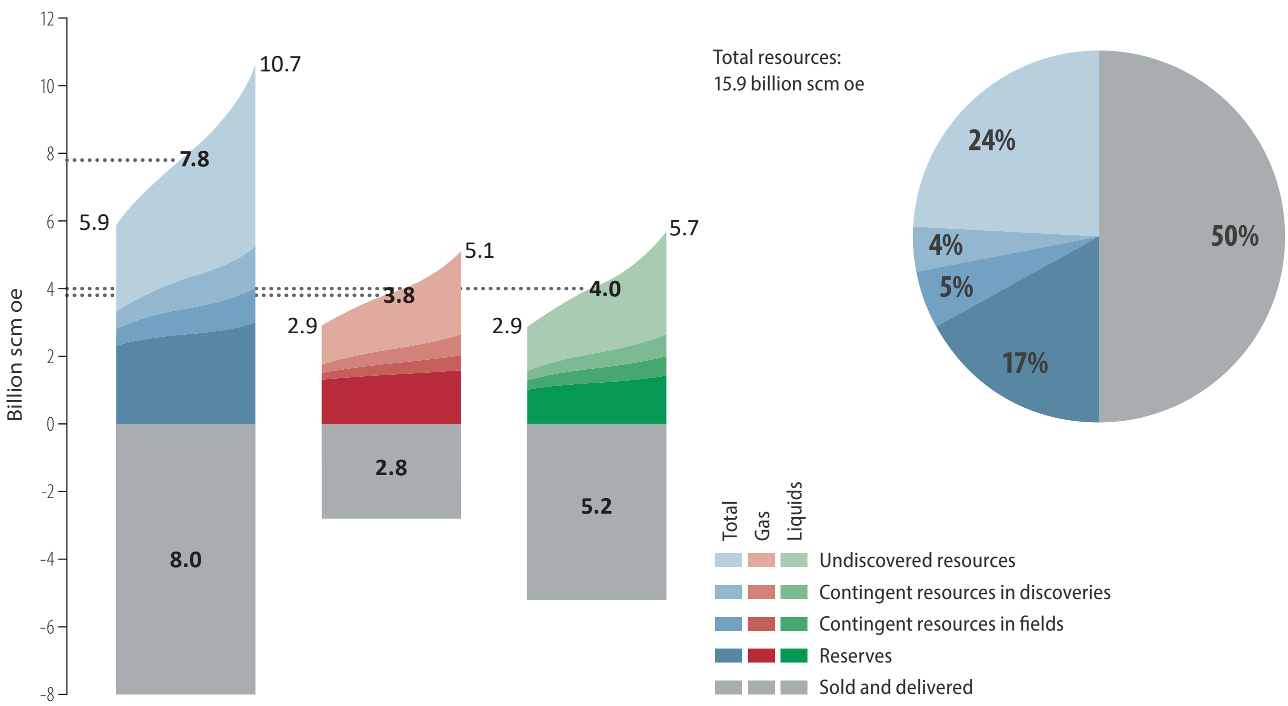


Figure 2.1 Total petroleum resources and uncertainty in the estimates at 31 December 2021

Figure 2.2 presents the development in estimated total liquid and gas resources in 2001, 2011 and 2021. The estimate for undiscovered resources in 2021 is about the same as it was in 2001. This is partly attributable to increased knowledge, technology advances and the expansion in the base acreage for calculating resources during the period as a result of opening new areas.

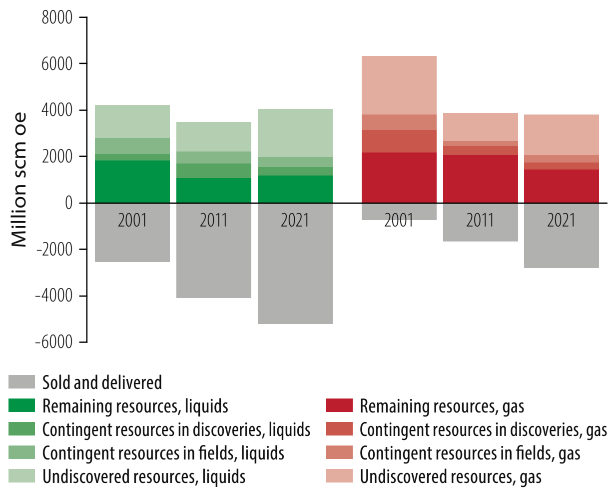


Figure 2.2 Development of the resource estimate

Area status on the NCS

The NCS covers a total of 2 279 965 square kilometres, six times greater than mainland Norway, Svalbard and Jan Mayen put together. Roughly half this area comprises sedimentary rocks which might contain petroleum. With some exceptions, the North and Norwegian Seas and Barents Sea South have been opened for petroleum activities (Figure 2.4).

The first production licences in the North Sea were awarded in 1965. Opening the Norwegian and Barents Seas (the areas above the 62nd parallel) for petroleum operations occurred in 1980.

Oil and gas in the North Sea are mostly classified as reserves – in other words, they are covered by a development decision. The bulk of the oil and gas resources in the Barents Sea is undiscovered. Large parts of the Barents Sea are not opened for petroleum activities, and this is where the expected value of undiscovered resources is highest (Figure 2.3).

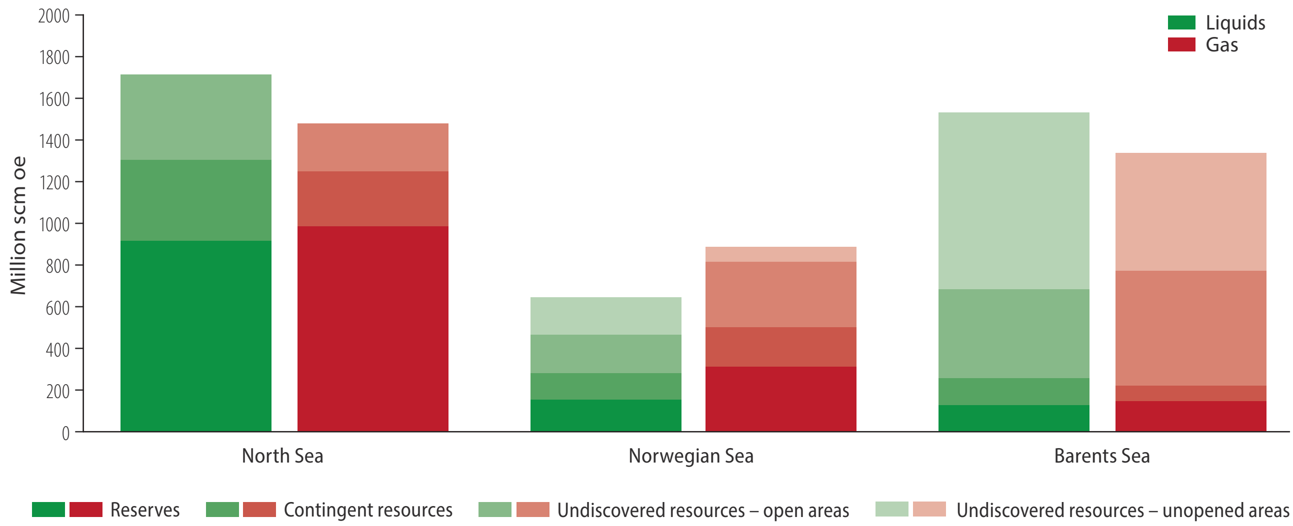


Figure 2.3 Distribution of remaining liquid and gas resources (expected value) by NCS area and class

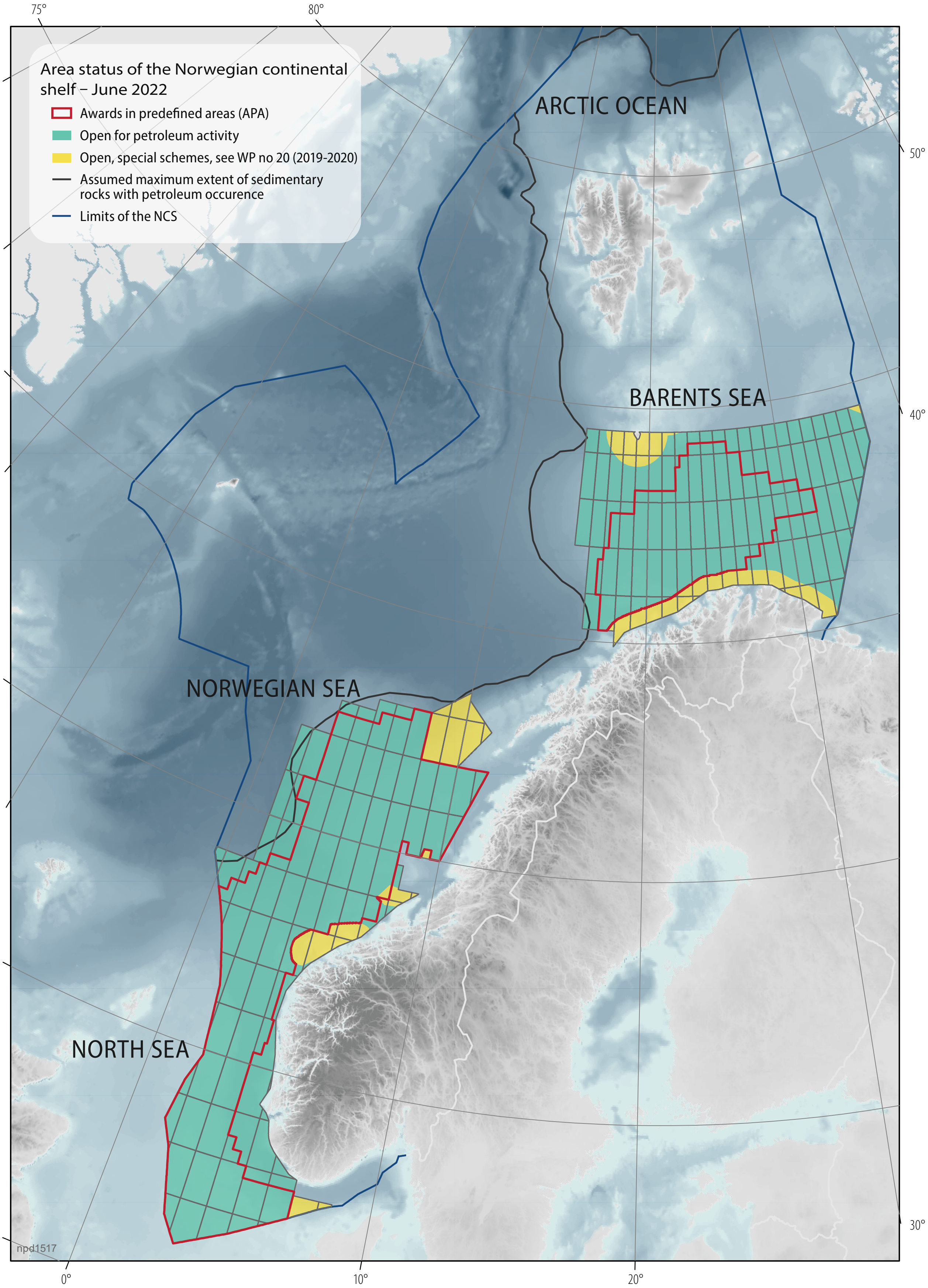


Figure 2.4 Opened and unopened areas on the NCS

2.1 Undiscovered resources

Undiscovered resources are the quantities of petroleum estimated to be recoverable from deposits which have yet to be proven by drilling. Estimates for undiscovered resources in open areas are updated every other year with assessments of exploration results in the recent past, new mapping and new documentation. These estimates were last updated in the autumn of 2021 and published in the resource accounts at 31 December 2021.

The method for estimating undiscovered resources is described in the resource report for 2016 [4]. Uncertainty in the estimates is discussed in the fact boxes on *Uncertainty in resource estimates* and on *Surprises*.

Estimates have not been updated for the areas off Lofoten, Vesterålen and Senja or for Barents Sea North and the waters around Jan Mayen.

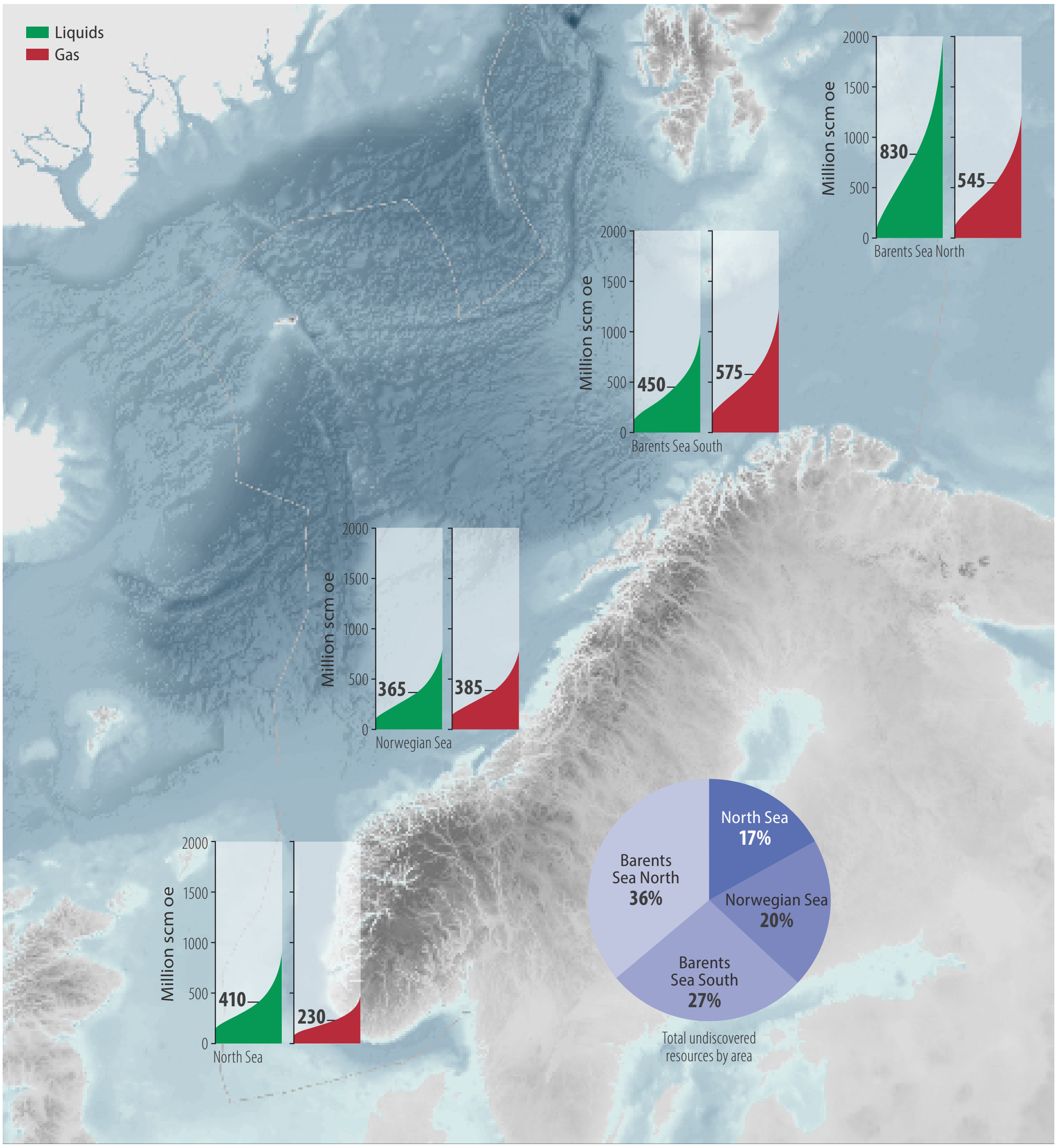


Figure 2.5 Distribution of undiscovered liquids and gas in the various NCS areas with the uncertainty range

Uncertainty in resource estimates

Uncertainty expresses the range of possible resource outcomes or results. It is most frequently described with the aid of low and high estimates.

The NPD estimates the undiscovered resources on the NCS to be 2 140-6 020 million scm oe. This uncertainty is calculated using a statistical method known as Monte Carlo simulations. The high and low estimates are described utilising statistical concepts.

Where undiscovered resources are concerned, the NPD uses P95 for the low estimate. This means that, given the assumptions applied in the analysis, the probability of a result equal to or larger than the P95 value is 95 per cent.

P05 is used for the high estimate, which means a five per cent probability that the result will be equal to or larger than the P05 value.

The expected value is the average value. This is generally defined as the arithmetic mean of all the outcomes in the statistical distribution. Widely used, it has the property that the expected value for various distributions can be summed to give a sum of distributions.

Surprises

Surprises will always occur in exploration. They are normally termed "serendipitous" by the industry, meaning a happy chance or "finding what you weren't looking for". Many people would argue that serendipity is not a matter of good luck, but reflects experience and insights acquired over a long time and combined with an open and curious mindset.Taking account of surprises when estimating undiscovered resources is difficult.

Unexpectedly large discoveries such as Johan Sverdrup can seldom or never be included in the uncertainty range for resource estimates in mature areas. New digital methods such as machine learning and deep learning may provide more surprises in coming years. Being aware that unexpected outcomes may occur is in itself a form of knowledge. However, taking account of such awareness in resource classification and estimating is demanding [5].

Being aware that unexpected outcomes may occur is in itself a form of knowledge

Substantial undiscovered resources remain on the NCS. The NPD expects them to comprise 24 per cent of total resources. Of this, 56 per cent are in opened areas, with the Barents Sea containing 26 per cent, the Norwegian Sea 13 per cent and the Norwegian Sea 17 per cent.

Substantial undiscovered resources remain on the NCS

Although the overall resource potential is somewhat larger in opened areas, the upside is greatest in the unopened part of the Barents Sea (Barents Sea North, Figure 2.6). Resources in the Lofoten, Vesterålen and Senja area are split in Figure 2.5 between the Norwegian Sea and Barents Sea South.

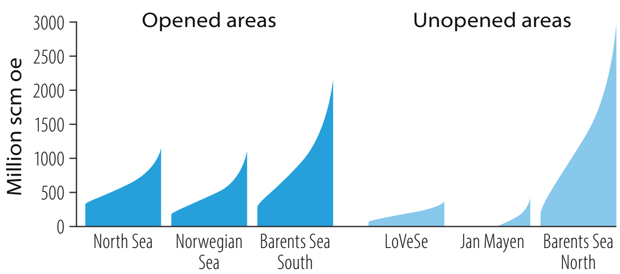


Figure 2.6 Undiscovered resources in opened and unopened areas with the uncertainty range *LoVeSe is an abbreviation for the areas off Lofoten, Vesterålen and Senja*

Historically, most of the resources have been discovered in the North Sea. Resource growth by NCS area demonstrates its uniqueness (fact box: *The North Sea is unique* and Figure 2.7). Undiscovered resources are expected to contain a preponderance of liquids in the North Sea, and to be equally divided between liquids and gas in the Norwegian Sea.

The potential for discovering gas is greatest in the Barents Sea

The potential for discovering more gas on the NCS is greatest in the Barents Sea, and divided fairly equally between south and north (Figure 2.5). Uncertainty is greatest in Barents Sea North, as reflected in the wide range between the high and low estimates.

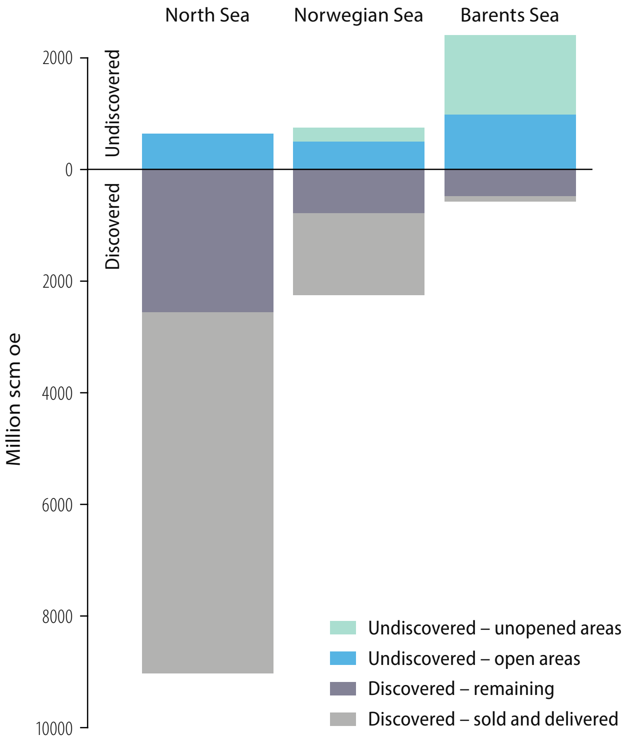


Figure 2.7 Total resources by NCS area

The North Sea is unique
The Norwegian sector of the North Sea is the most explored area of the NCS, and also where the largest quantities of oil and gas have been proven and produced. Norway's oil adventure began at its southern end, with the discovery of Ekofisk in 1969. Ranked then as the world's largest offshore field, it has been on stream for more than five decades and current plans expect production to continue for almost another 30 years.

Large quantities of oil and gas were subsequently proven in the northern North Sea with the Statfjord, Gullfaks, Snorre, Oseberg and Troll fields. Over 400 million scm of oil were proven in Johan Sverdrup in 2010. That made this the fifth largest oil discovery ever on the NCS. These giant discoveries demonstrate that the North Sea is one of the world's best petroleum basins.

The reasons why this area contains so much petroleum are complex, and depend on several geological factors which arose in the Jurassic (145-201 million years ago). These processes created a very favourable setting for all the key conditions in forming oil and gas fields, namely source, reservoir and cap rocks.

These included the deposition of Draupne shale, known as one of the world's best source rocks for oil and gas.

Conditions for forming oil and gas fields are also present in the Norwegian and Barents Seas, but the geological processes have been different from those in the North Sea and not as favourable.

Although substantial undiscovered resources remain on the NCS, 76 per cent are estimated to have already been proven. Resource growth for each NCS area, as illustrated in Figure 2.7, demonstrates the uniqueness of the North Sea. Even if expected undiscovered resources are proven in the Norwegian and Barents Sea, the quantities will nevertheless be far lower than the volume proven in the North Sea.

North Sea

Estimated undiscovered resources in the North Sea amount to 640 million scm oe, which breaks down as 410 million scm oil and condensate and 230 billion scm gas. That represents a four per cent decline from the year before for both liquids and gas. This reduction is smaller than the quantity of resources proven by exploration since the previous estimate.

The play with the biggest resources in the North Sea, both discovered and undiscovered, lies in the northern section of the Viking Graben and adjacent terraces. It extends from about 60°N to 62°N (Figure 2.9). Reservoirs in the play are sandstones ranging from Late Triassic to Middle Jurassic in the Hegre to Brent Groups.

Almost 240 wildcats have been targeted at this play, with a technical success rate of about 60 per cent. These wells have collectively proven about 3 500 million scm oe, about three-quarters being liquids. Some the biggest NCS discoveries are in this play, including Statfjord, Oseberg and Gullfaks (Figure 2.8).

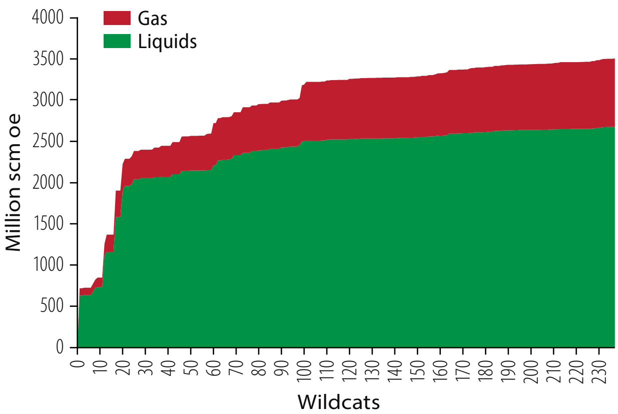


Figure 2.8 Creaming curve for the North Sea *Creaming curve for the Late Triassic-Middle Jurassic play (Hegre to Brent Groups) in the northern North Sea*

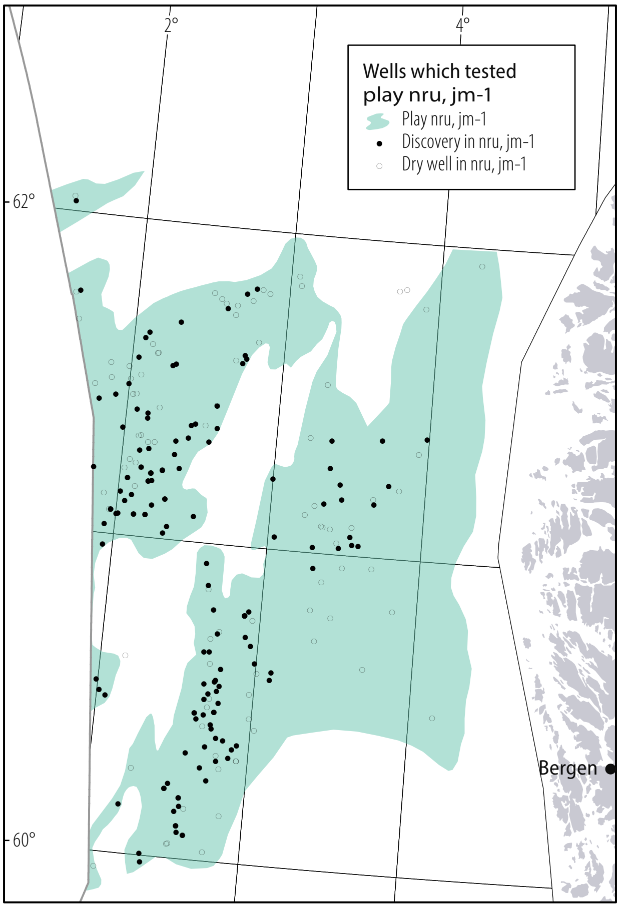


Figure 2.9 Play with the largest resources in the North Sea *The contour shows the extent of the play, circles indicate which wells have tested the play and which are discoveries*

Over the past 10 years, some 100 million scm oe has been proven in this play. Roughly 60 per cent are liquids (Figure 2.10). The average discovery size during the period was about 2.9 million scm oe and the technical success rate was 65 per cent. Estimated undiscovered resources in the play have an expected value of some 200 million scm oe. Although the possibility of larger ones cannot be excluded, most discoveries in the play are expected to be relatively small. The estimate for undiscovered resources includes an expectation of an average future discovery size of 2.5 million scm oe.

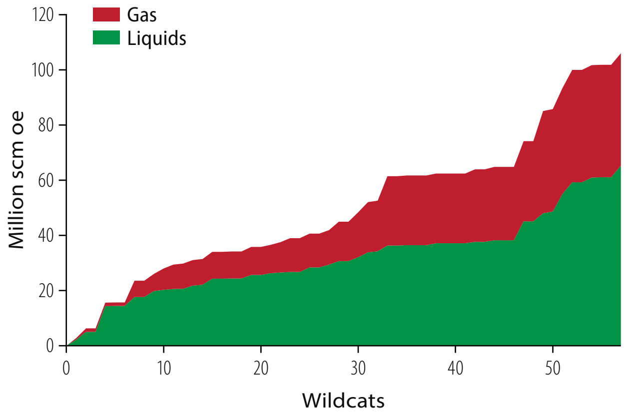


Figure 2.10 Creaming curve past 10 years *Creaming curve for the Late Triassic to Middle Jurassic play (Hegre to Brent Groups) in the northern North Sea*

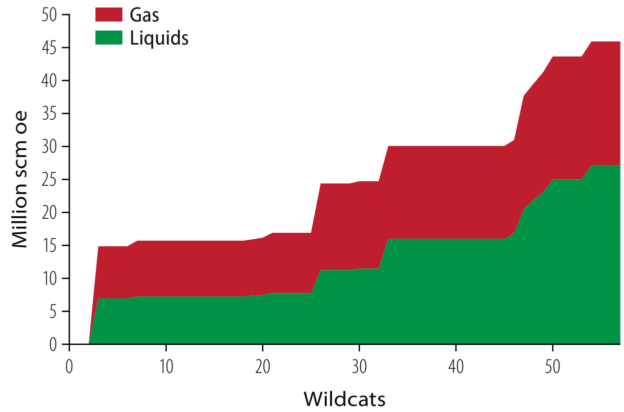


Figure 2.12 Creaming curve for the southern North Sea the past 10 years *Curve for Late Triassic-Jurassic plays (Hegre-, Statfjord-, Vestland- og Tyne Groups)*

Success rates for Jurassic plays in the Norwegian North Sea below 60°N are strikingly poorer than above that latitude (Figure 2.11). These plays have been the target for 58 wildcats drilled over the past 10 years, with only 15 discoveries made. That represents a success rate of 26 per cent, compared with 58 per cent in the northern part of the North Sea. The average discovery size is almost identical for the two areas, at 3.1 million scm oe. Figure 2.11 also shows a declining trend for both success rates and average discovery sizes compared with the previous decade. In all, Jurassic plays in the southern area have yielded about 45 million scm oe. Liquids account for roughly 60 per cent (Figure 2.12).

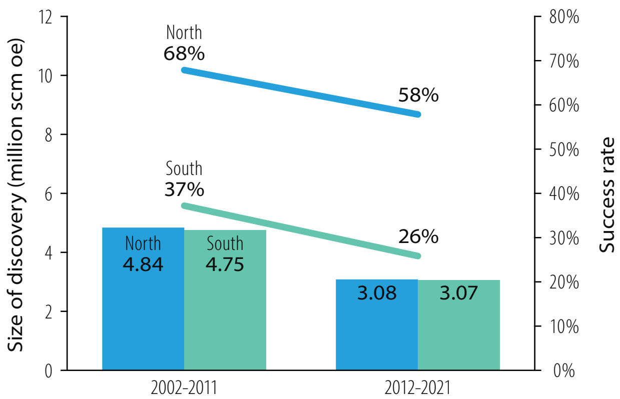


Figure 2.11 Success rates the past 10 years *Success rates for Jurassic plays in the North Sea. The north-south boundary is 60°N*

No resources have been proven in Cretaceous plays in the southern area, with the Hod, Tor and Ekofisk Formations as reservoirs, since the late 1990s. The last discovery of any size was Tommeliten Gamma in 1978, with about 15 million scm oe. Since then, the 36 wildcats drilled have proven less than five million scm oe in three small discoveries.

Norwegian Sea

Estimated undiscovered resources in the Norwegian Sea amount to 750 million scm oe, which breaks down as 365 million scm liquids and 385 billion scm gas. That represents a rise from previous years of 22 per cent for liquids and five per cent for gas, and 13 per cent overall. Involving Early Cretaceous and Late Triassic to Middle Jurassic plays in more mature parts of the Norwegian Sea, the increase reflects the exploration success of recent years in this area.

The average discovery size in the Norwegian Sea has risen over the past five years and is now 6.2 million scm oe. Resource estimates for this part of the NCS also include the unchanged volumes in the unopened areas off Lofoten and Vesterålen and in the waters around Jan Mayen, which account for about 33 per cent of the total.

As in the North Sea, the Norwegian Sea has one dominant play. This extends across the Halten and Dønna Terraces along with parts of the Nordland Ridge and the Revfallet Fault Complex. Reservoirs in the play are sandstones from the Late Triassic to the Middle Jurassic in the Båt and Fangst Groups (Figure 2.13).

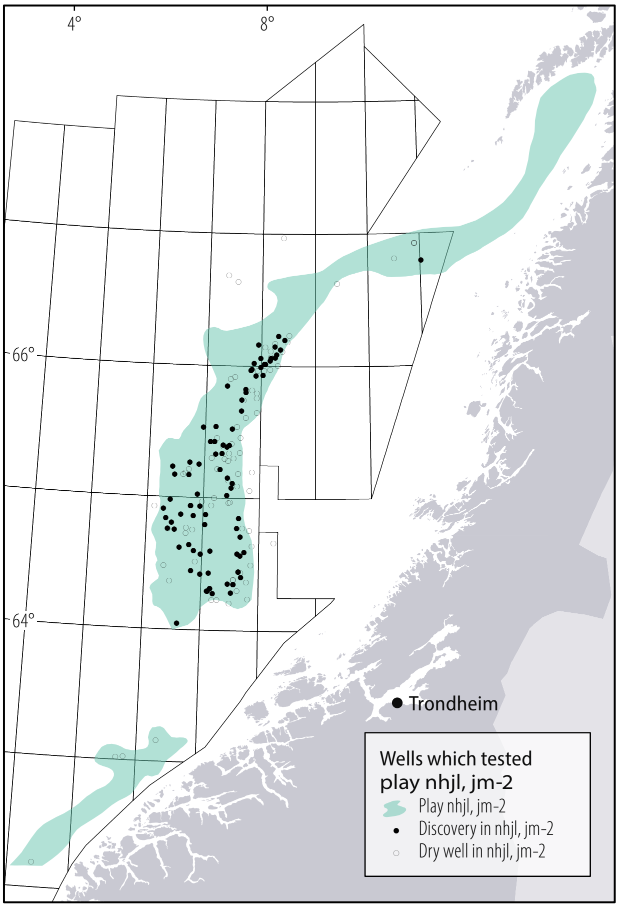


Figure 2.13 Play with the biggest potential in the Norwegian Sea *The contour shows the extent of the play, circles indicate which wells have tested the play and which are discoveries*

About 160 wildcats have tested the play and the technical success rate has been 52 per cent. These wells have proven about 1 500 million scm oe, with 57 per cent being liquids (Figure 2.14). More than 80 million scm oe have been proven in this play over the past 10 years, with some 56 per cent being liquids. The average discovery size has been 3.2 million scm oe, while the technical success rate is 63 per cent. Estimated undiscovered resources in this play amount to roughly 210 million scm oe, with 52 per cent being liquids. Although most of the future discoveries in the play are expected to be small, exploration in recent years shows that larger ones can be made – such as 6507/5-10 S (Slagugle).

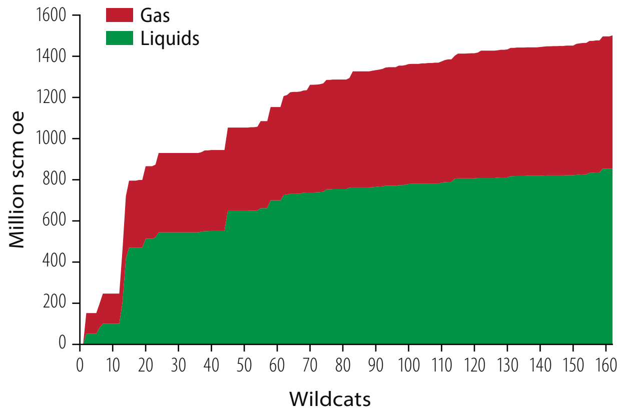


Figure 2.14 Creaming curve for Norwegian Sea *Creaming curve for Late Triassic to Middle Jurassic plays (Båt and Fangst Groups)*

Barents Sea

Estimated undiscovered resources in the Barents Sea amount to 2 400 million scm oe, which breaks down as 1 280 million scm liquids and 1 120 billion scm gas. That represents a decrease of four per cent for both liquids and gas from the year before. This reduction relates in its entirety to Barents Sea South, where it amounts to 11 per cent for liquids and eight per cent for gas. To a great extent, the decline concerns Triassic plays in the eastern part of the area.

Exploration results in the Barents Sea during recent years have been disappointing, with an average discovery size of 3.9 million scm oe. That is the main reason for the downward adjustment. The corresponding figure for the previous period was 10.6 million scm oe.

Unopened areas of the Barents Sea have the highest probability of large new discoveries

Fifty-nine per cent of resources in the Barents Sea lie in areas which have not been opened for petroleum activities, mostly in Barents Sea North. That area has the highest probability of making large new discoveries on the NCS.

The biggest play in terms of resources in Barents Sea South extends over much of the Barents Sea (Figure 2.15). The expected value for this play is about 220 million scm oe, with 60 per cent being liquids.

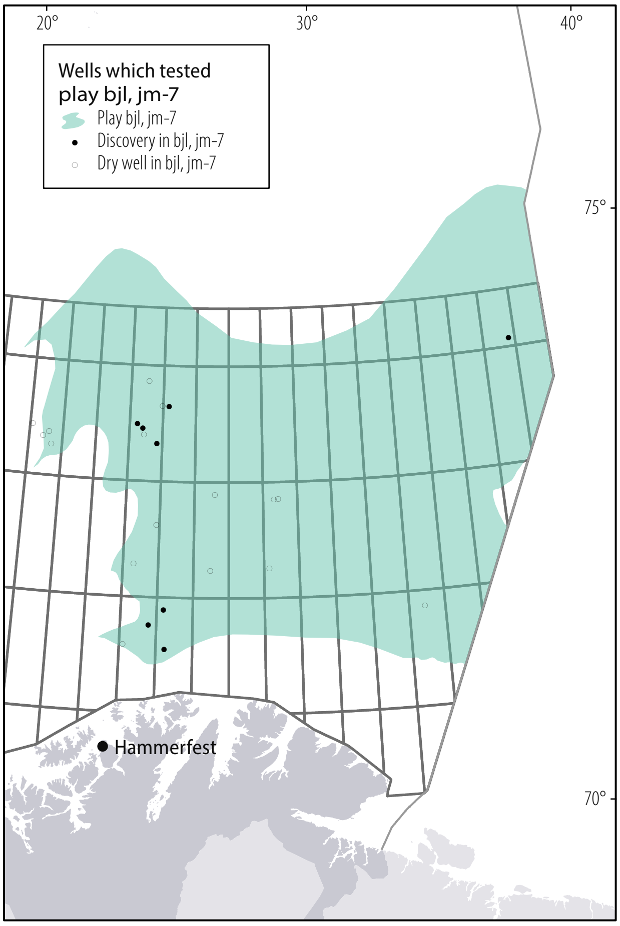


Figure 2.15 Extent of the Early to Middle Jurassic play *The contour shows the extent of the play, circles indicate which wells have tested the play and which are discoveries*

Reservoirs in the play are in the Early to Middle Jurassic and include the Kapp Toscana Group with the Tubåen, Nordmela, Stø and Fruholmen Formations. The most important source rock is Early-Middle Triassic (the Steinkobbe Formation). A critical factor in the play is the presence of cap rocks which provide sufficient sealing and retention. The whole area has been subject to tilting and reactivation of faulting. In addition, Cenozoic uplift and erosion create an increased risk of leakage, particularly for shallow and truncated structures.

Only 24 wildcats have been drilled in the play, with eight discoveries. That represents a technical success rate of about 33 per cent. The bulk of the undiscovered resources in the play are expected to be in its western part, where the probability of discovering liquids is also far higher. This is primarily because of a much lower probability of oil-generating source rocks to the east. Possible gas deposits in the latter part of the play lie at shallow depths and the recoverable quantities are therefore limited. By far the biggest discovery is 7324/8-1 (Wisting), with 78.2 million scm of oil and 3.9 billion scm of gas (Wisting including the 7324/8-1 and 7324/7-2 wells).

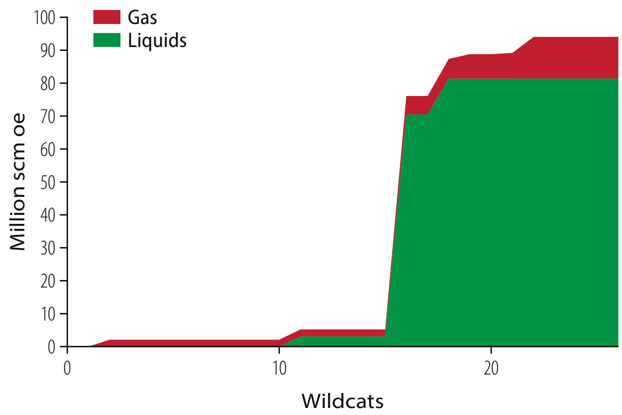


Figure 2.16 Creaming curve for Barents Sea *Creaming curve for the Early to Middle Jurassic play (Tubåen, Nordmela, Stø and Fruholmen Formations)*

Ninety-four million scm oe has been proven in the play (Figure 2.16). Liquids account for about 90 per cent. Discovery sizes have varied considerably, with the average of about 12 million scm oe strongly influenced by the Wisting discovery.

Figure 2.17 presents an overview of primary targets reported for wildcats in 1990-2021. Forty-five per cent of the wells were primarily targeted at Jurassic reservoirs, which include the Tubåen, Nordmela, Stø and Fruholmen Formations (mainly the Stø Formation). By comparison, only one well had the Early Triassic play (Havert Formation) as its primary target.

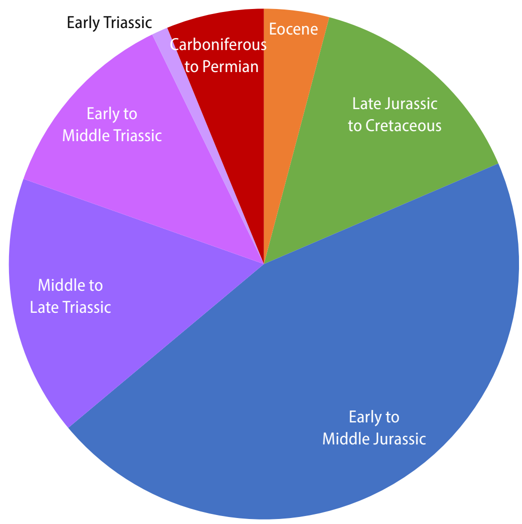


Figure 2.17 Exploration targets *Primary exploration targets during 1990-2021 in the Barents Sea*

Exploration activity and results over the past decade

The annual number of wildcats has varied between 22 and 43 over the past 10 years (Figure 2.18). A total of 31 were drilled in 2021 – 22 in the North Sea, five in the Norwegian Sea and four in the Barents Sea. The distribution of wildcats between these areas shows that most exploration is in mature parts of the NCS. The exception was 2017, when half the wildcats were drilled in the Barents Sea.

Since discovery size is declining in the mature parts of the NCS, a high success rate will be important for maintaining resource growth. Figure 2.19 presents the success rate since 1967. Technical and commercial rates average about 46 and 29 per cent respectively. All discoveries are included when calculating the technical success rate. The commercial rate does not include resource class 6 (RC6). A discretionary judgement is made for new discoveries in resource class 7 (RC7) – in other words, ones which have not been evaluated.

The main target for 70 per cent of the wildcats completed in 2021 was to test Jurassic reservoirs. So far, wildcats in plays with Jurassic reservoirs have proven the largest petroleum quantities on the NCS. Similar exploration is expected to make a substantial contribution to future resource growth. Testing less well-known plays is nevertheless important in order to acquire greater understanding of their resource potential.

Wells with several targets are usually not positioned optimally for testing secondary targets. Understanding this is important when comparing success rates and creaming curves in different plays, for example.

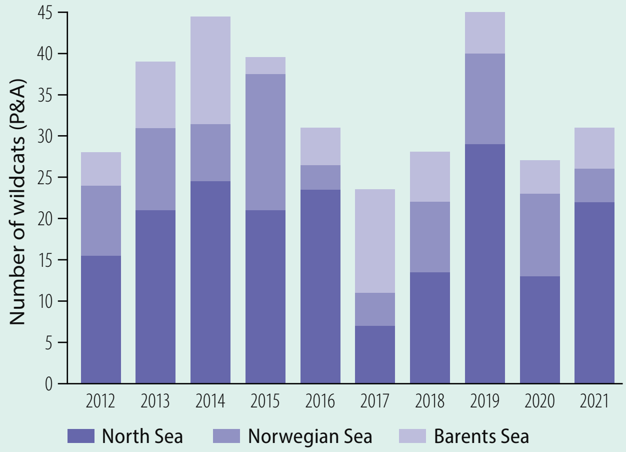


Figure 2.18 Wildcats in the various NCS areas over the past decade

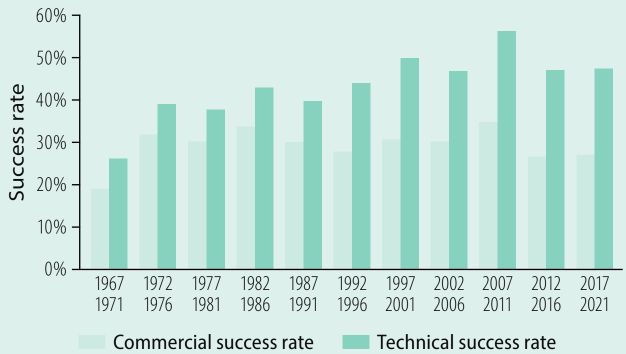


Figure 2.19 Technical and commercial success rates
Technical and commercial success rates at five-year intervals

2.2 Discoveries

At 31 December 2021, 88 discoveries (RC4F, RC5F and RC7F, Figure 1.4) on the NCS were under consideration by the licensees for development (Figure 2.20).

These amount to 666 million scm oe, which breaks down into 359 million scm liquids and 307 billion scm gas.

Of the 88 discoveries, 47 with a total of 299 million scm oe are located in the North Sea, 26 with a total of 211 million scm oe in the Norwegian Sea and 15 with a total of 157 million scm oe in the Barents Sea (Figure 2.20).

The discovery portfolio represents 16 per cent of the remaining proven resources. Twenty-nine discoveries are in the planning phase for production (RC4), and account for 60 per cent of resources in the portfolio. The NPD expects plans for development and operation (PDOs) of a number of these discoveries to be submitted in 2022.

Figure 2.20 presents the discovery portfolio in the resource accounts by size per NCS area. The largest discovery, 7324/8-1 (Wisting), is in the Barents Sea, with 6406/9-1 (Linnorm) and 30/11-8 S (Krafla) as the biggest in the Norwegian and North Seas respectively.

Plans call for 83 of the discoveries in the portfolio (Figure 2.21) to be tied back to established infrastructure. In some cases, new infrastructure is planned in coordination with other discoveries in an area. The five discoveries being considered for development with production facilities (featuring separation and process equipment) depend on relatively large resources or coordinated development with smaller discoveries to be profitable.

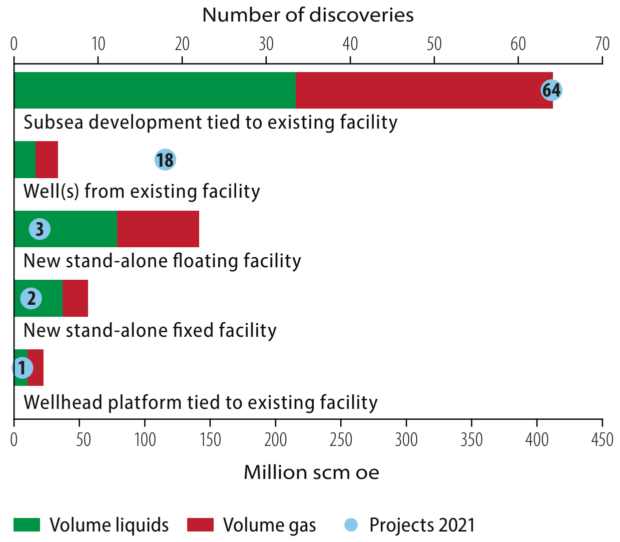


Figure 2.21 Probable development solutions for the discovery portfolio

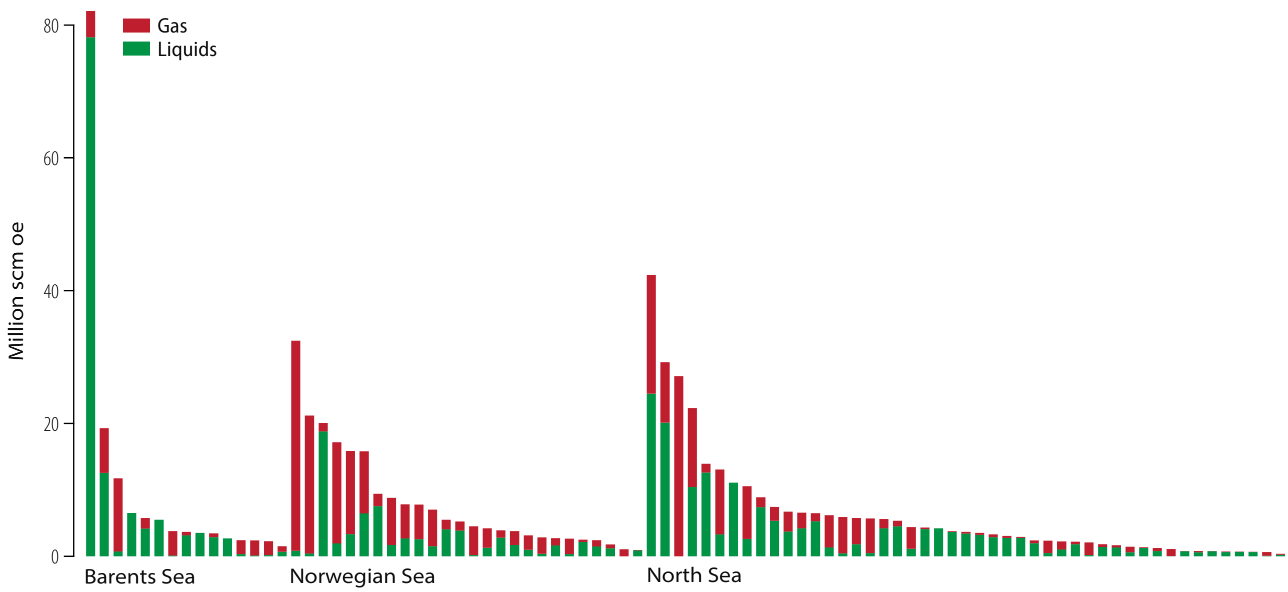


Figure 2.20 Discoveries by NCS area

Discoveries unlikely to be produced (RC6)
In the NPD's resource classification system, discoveries where production is unlikely are placed in resource class 6 (RC6, Figure 1.4). These are assessed as unprofitable today because they are too small, require the development of new technology or lack access to infrastructure.

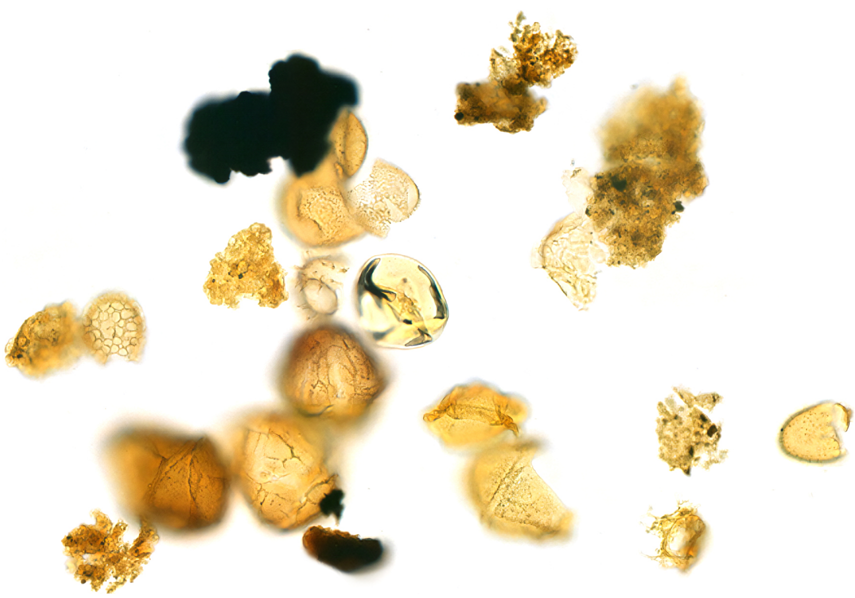
RC6 contains 168 discoveries, including 90 in the North Sea, 45 in the Norwegian Sea and 33 in the Barents Sea (Table 2.1). They are divided almost equally between oil and gas discoveries.

It is important that these are not written off, since technological advances, available infrastructure, coordination and changes in market conditions could make their development relevant. Certain of them might become commercial if new discoveries in the vicinity offer the possible basis for a coordinated development (chapter 3.2 Assets in the discovery portfolio). New technology or infrastructure could move discoveries out of RC6.

Almost 70 per cent of the discoveries are located in licensed acreage. Those in relinquished areas can be made available to the industry through licensing rounds.

Table 2.1 Discoveries in resource class 6 at 31 Dec 2021

	Number	Oil	Gas	Multiphase	In active production licences	Outside production licences
North Sea	90	52	19	19	69	21
Norwegian Sea	45	10	22	13	26	19
Barents Sea	33	4	24	5	6	27
Total	168	66	65	37	101	67



2.3 Fields

Since petroleum production began on the NCS more than 50 years ago and up to 31 December 2021, 5 218 million scm of liquids and 2 798 billion scm of gas have been sold and delivered (fact box *Gas production*). Figure 2.22 shows how this breaks down between the NCS areas.

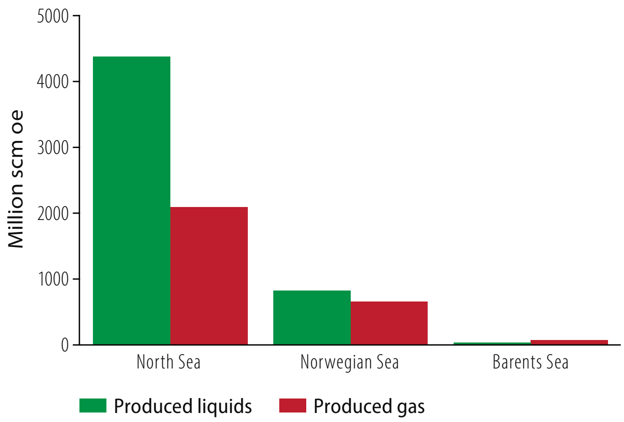


Figure 2.22 Gas and liquid volumes produced at 31 December 2021

Gas production

Gas produced from the NCS is primarily exported by pipeline to Europe, with a small proportion sold abroad as liquefied natural gas (LNG). A substantial share is injected to improve oil recovery or because no sales opportunities are available (Figure 2.23). Injected gas can be produced again and sold at a later time. A small proportion of the gas is used for power generation on facilities.

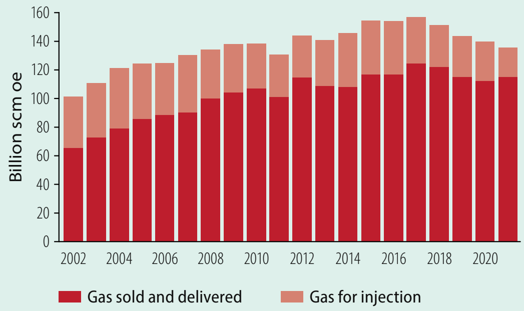


Figure 2.23 Gas produced by sale and injection

At 31 December 2021, 94 fields were producing on the NCS. Five came on stream in 2021 – Duva, Martin Linge, Solveig, Yme and Ærfugl North. Troll phase 3, a large project for improved recovery from a producing field, also came on stream.

Eight PDOs were submitted to the government. The biggest projects are Tommeliten A, Ormen Lange phase 3, Troll West electrification (TWEL) and the Oseberg gas capacity upgrade and power from shore project (OGP). No fields ceased production in 2021. The Knarr and Veslefrikk fields had ceased producing by 31 May 2022.

The North Sea is the area which has yielded the largest quantity, produced for longest, and possesses the largest remaining resources in fields and discoveries. Reserves total 1 885 million scm oe in the North Sea, while they amount to 466 million scm oe and 277 million scm oe in the Norwegian and Barents Seas respectively.

Goal of reserve growth

To encourage the companies to devote greater efforts to increasing reserves, the NPD launched a goal in 2014 of raising these by 1 200 million scm in 2014-23. Annual reserve growth is recorded for discoveries and fields, and the reserves are amended as knowledge about the reservoirs improves and new projects are sanctioned. Growth is the change from the resource accounts for the year before. Figure 2.24 presents the status at 31 December 2021. The coloured areas in the figure show total reserve growth since 31 December 2014, while the lines show the plans taken into account and the route towards meeting the target.

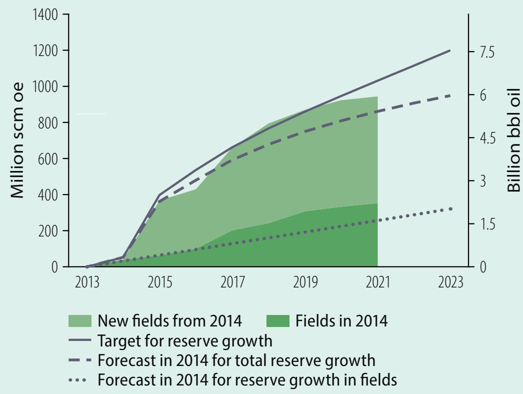


Figure 2.24 Reserve growth goal 2014-23

2.4 Improved recovery

A potential exists for improving recovery from fields. Figure 2.26 presents oil volumes produced and sold from the 25 largest oil fields (grey columns), the volume remaining to be produced under plans currently sanctioned (dark green columns), and the volume which will be left behind under current plans (light green columns).

The resource accounts for 2021 include 184 specific but unsanctioned projects for improved oil and gas recovery (IOR). Figure 2.25 presents these broken down by project type, with associated resources in oe.

IOR projects primarily involve production wells (*wells*), in terms of both number (75) and volume (about 130 million scm oe).

Other projects which could help improve recovery are *late life production* (24 with about 60 million scm oe) and *low pressure production* (28 with about 58 million scm oe).

Few measures have been identified where new *injection and advanced methods* (enhanced oil recovery – EOR) are adopted to improve recovery (13 totalling about 10 million scm oe). In addition, 27 projects are identified as *further development*. This could help to extend a field's producing life, particularly by phasing in new discoveries (almost 100 million scm oe).

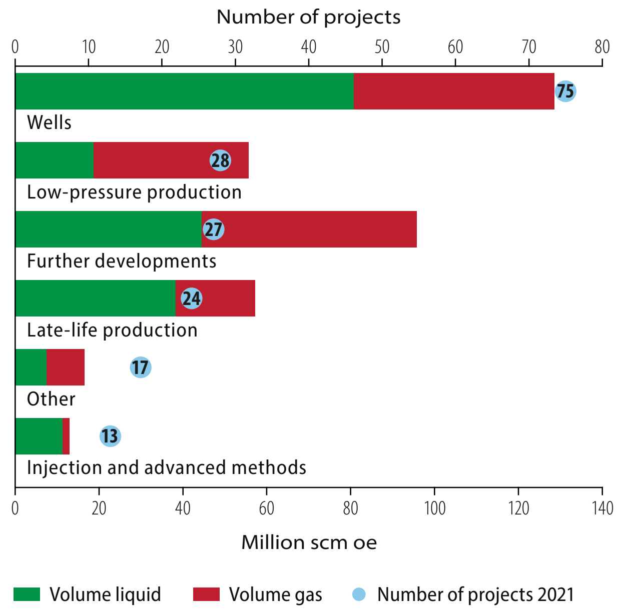


Figure 2.25 Specific projects for improved recovery from fields, number and resources

In addition to the projects reported by the companies, the NPD has identified a substantial resource potential related to adopting EOR methods (Figure 2.27). The figure presents the potential for specific EOR methods summed for 27 discoveries and fields (described in more detail in the resource report for 2019, [6]). Despite the big resource potential, few projects are being assessed by the companies – as Figure 2.25 shows.

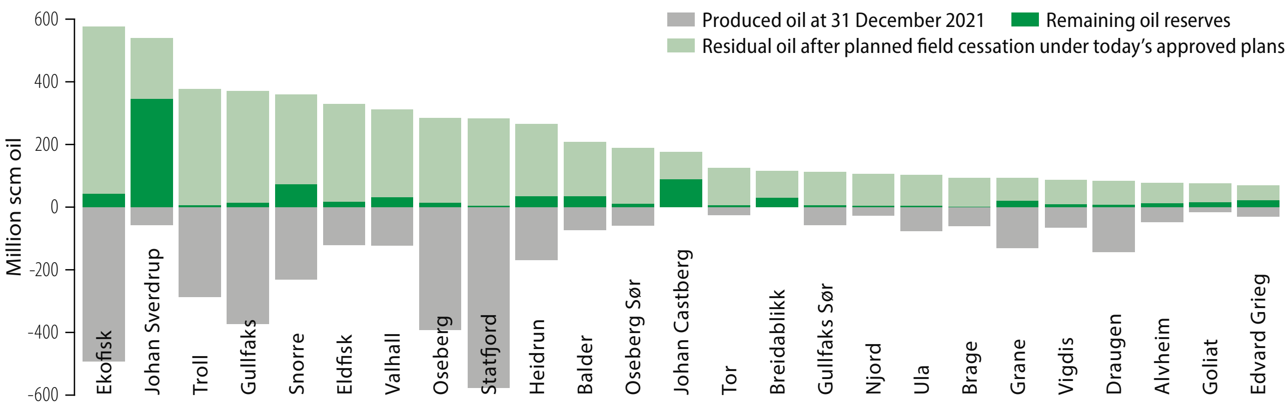


Figure 2.26 Oil reserves and resources for the biggest oil fields

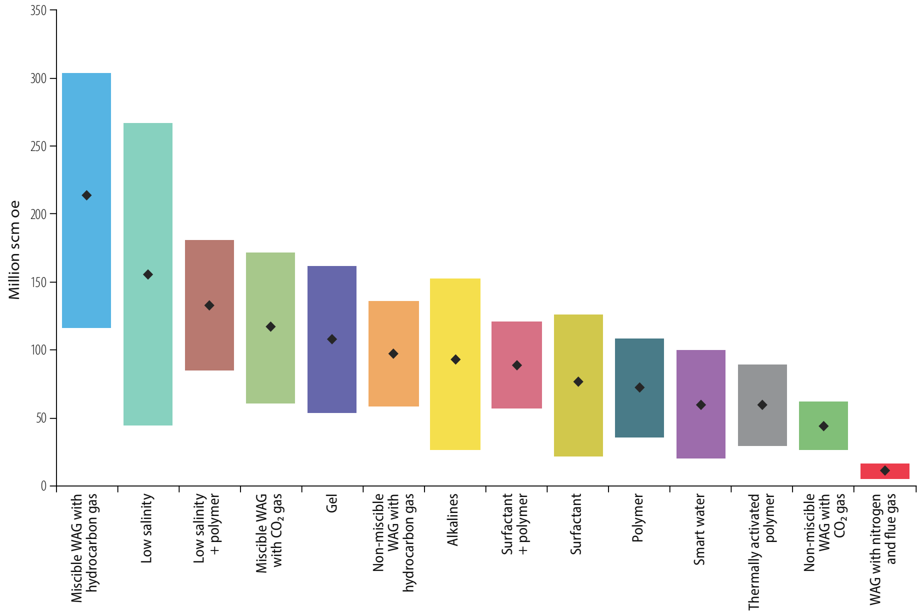


Figure 2.27 Increased potential for oil with EOR methods on the NCS

Measures to improve recovery from fields could also include starting production from reservoir zones which have not previously been considered producible in a profitable manner. These might be, for example, tight formations or injectites (fact box *Injectites*). Tight formations have poorer quality and require different types of wells and completions to achieve profitable production. Examples of such solutions include slim hole technology (chapter 3.5 Technology development and expertise) and hydraulic fracturing.

Reservoirs with injectites have long been difficult to understand because mapping their extent is challenging. That has thereby made it difficult to place the wells in a good way. Understanding has increased considerably in recent years, largely because of big advances with seismic imaging and geological modelling. Progress also made in drilling and completion technology makes it more attractive to develop injectite deposits.

Injectites

Injectites, or intrusive sand accumulations, are sand deposits which have been remobilised and squeezed through overlying strata. The sediments are redeposited there as either vertical/inclined dykes or intruded between layers as horizontal sills (Figure 2.28, [7]). On the NCS, injectites are particularly widespread in the central North Sea and are found primarily in the Heimdal and Hermod Formations. Several discoveries were made in injectites during 2021, with 25/8-20 B (King) as the largest. Various injectite discoveries are now in the planning phase towards development.

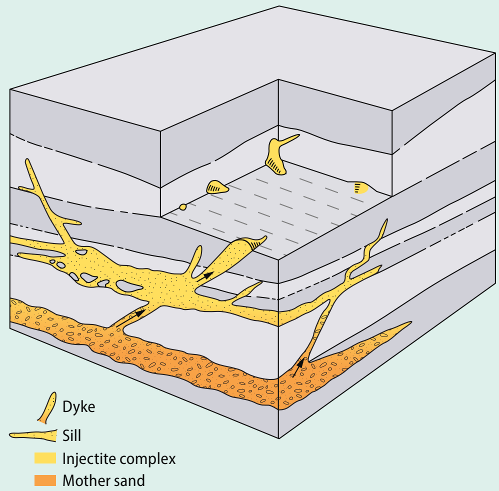


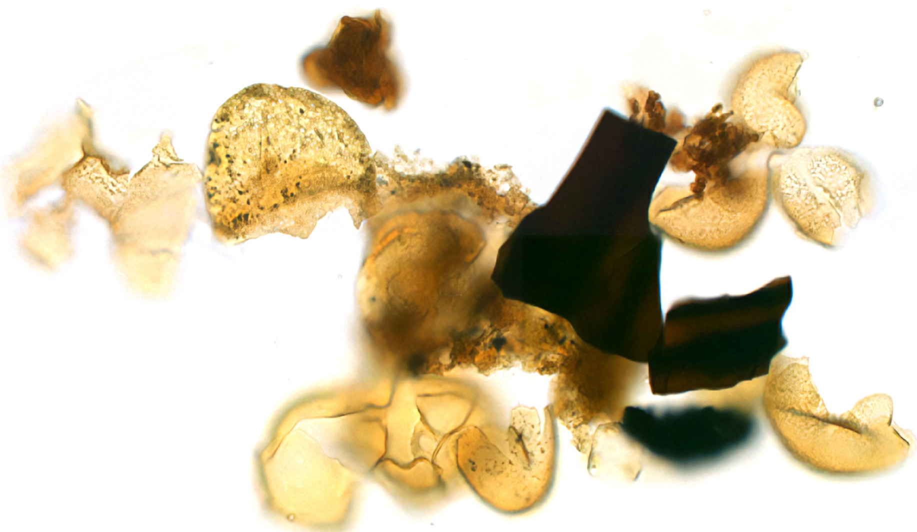
Figure 2.28 Geodiagram of injectites *modified after Hurst et al (2007)*

Improved understanding of aquifers has become increasingly important in mature areas (fact box *Aquifers*). A number of initiatives are under way on constructing aquifer models. With its unique access to NCS data, the NPD is well placed to produce holistic models. It is pursuing an internal modelling project of the aquifers around Frigg-Heimdal at the Palaeocene-Eocene level and around Troll at the Jurassic level. These aquifer models will be made as accessible as possible to the industry and academia, so that the players can combine them with detailed modelling of the individual field.

Aquifers

Sub-surface sedimentary strata have different properties. Some consist mostly of sand and are easily permeable by water, oil and gas. Strata dominated by clays or shales are more or less tight and impermeable to liquids. A great deal of seismic data have been acquired and many wells drilled in the mature parts of the NCS, and the extent of the strata is well known. Production data and downhole pressure metering reveal how the liquids flow. An aquifer is a volume of rock where water can flow without much hindrance. In the North Sea, aquifers can be present at many levels down through the rock column and may extend across several geological formations.

Improved understanding of aquifers is increasingly important in mature areas. If the aquifer in contact with a field is strong, water flows easily into the reservoir as the hydrocarbons are produced. The pressure drop is then neither as quick nor as large as when the aquifer is weak. This is significant for planning water injection and for understanding how producing fields influence each other. The aquifer is therefore included in the simulation models, but often only schematically modelled. If CO_2 is to be stored, the operator is required to construct simulation models which can predict pressure buildup and how the CO_2 will move in the aquifer.



Chapter 3

Competition and value creation

Exploration for and production of oil and gas have provided huge value for Norwegian society. The petroleum sector is Norway's largest industry by value creation, government revenues, investment and export value. Timely exploration and development are important for ensuring good resource management.

A competitive continental shelf is a precondition for maintaining value creation. Indicators such as unit costs and CO_2 intensity (emissions per unit produced) provide a good basis for assessing the competitiveness of the NCS.

The NCS is a capital-intensive petroleum province where exploration and development costs are higher in relative terms than operating expenses [8].

With relatively high exploration and development costs, the competitiveness of the NCS will come under pressure if resource growth slows even further. Falling production from a number of fields means that total operating expenses per unit produced rise and thereby weaken competitiveness. Measures to increase resource growth and exploit capacity in the infrastructure will be important in the future.

Measures to increase resource growth and exploit capacity in the infrastructure will be important in the future

Remaining resources on the NCS have a low CO_2 intensity compared with other petroleum provinces. Analyses also show that Norwegian gas sales to Europe have the lowest climate footprint per unit compared with other exporters [9]. Important reasons for the relatively low CO_2 intensity include the provision of power from shore to a number of facilities, as well as the government ban on production flaring and the introduction of a CO_2 tax as early as 1974 and 1991 respectively.

Although several measures are being initiated to cut emissions, CO_2 intensity may increase if transport and processing capacity is not matched to reduced production on the fields. This trend can be countered by phasing in new discoveries, by reducing the water cut through better drainage solutions, or by water separation downhole or on the seabed.

Norway's biggest industry

The petroleum sector is the biggest industry in Norway measured by value creation, government revenues, investment and export value. It is expected to account for 28 per cent of gross domestic product (GDP) and 58 per cent of Norwegian exports in 2022 (Figure 3.1, [1]).

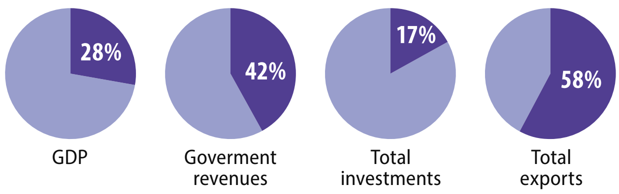


Figure 3.1 The petroleum sector's share of value creation, 2022 estimate *Source: Ministry of Finance, 2022*

According to Statistics Norway (SSB), the export value of crude oil in 2021 was NOK 349.6 billion, compared with NOK 207.8 billion the year before. The value of natural gas exports came to NOK 475.8 billion, more than four times the 2020 level [10].

About 200 000 people nationwide were employed by the petroleum industry in 2020. Almost 165 000 of these related to activities on the NCS. Some 35 000 people were employed in exports to the international petroleum industry [11].

Welfare for generations

The high level of earnings in 2021 yielded NOK 287.5 billion in government revenues, or about 20 per cent of the total. This figure is expected to reach NOK 960 billion in 2022, or more than 40 per cent [1] of the total.

Government revenues from petroleum make this sector a key contributor to financing the welfare state. The state's net cash flow from petroleum operations is transferred in its entirety to the government pension fund global (the oil fund), to ensure that these revenues benefit both present and future generations. The fund had a market value at 31 December 2021 of more than NOK 12 000 billion [12].

Important for Norway's economy

Investment in the petroleum sector accounted for 18 per cent of total capital spending in Norway for 2021 [1]. However, it has declined somewhat over the past two years after rising in 2019. Reporting by the companies indicates that investment will also fall in 2022 but increase thereafter. That is because many investment decisions have been and will be taken on profitable projects, in part thanks to the temporary changes to the petroleum tax regime. Overall investment in the petroleum sector over the next few years will be on a par with the period after 2015. Figure 3.2 presents investment in fields and discoveries as well in exploration, plus forecasts for the next five years.

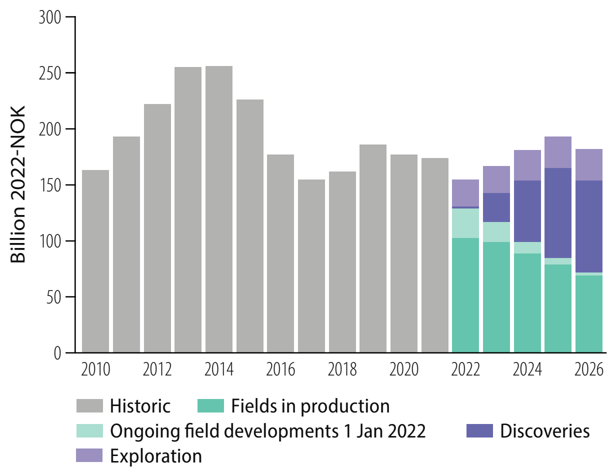


Figure 3.2 Investment on the NCS from 2010, with forecasts to 2026

3.1 Profitability of exploration

Successful exploration is a precondition for long-term production and export of petroleum. The NPD's analyses show that exploration for oil and gas over the past 20 years has been profitable in all NCS areas and has contributed great value to society.

Successful exploration is a precondition for long-term petroleum production and export

Methods and preconditions

The profitability of exploration is defined as calculated revenues from the discoveries made during the period, less all costs. The latter encompass exploration which has yielded discoveries or has failed to prove resources. Revenue and expense flows are discounted to the same year. Profitability calculations do not include indirect economic effects or spin-offs for the rest of the economy.

More than 80 per cent of the resources discovered over the past two decades have yet to be produced. Great uncertainty attaches to the profitability estimates, owing to uncertainties over future prices, production profiles, the resource estimates and costs. Assumptions about future oil and gas prices accord with those applied in the revised national budget (RNB) for 2022. Historical prices for oil and gas have been applied for the pre-2022 period [13].

Investment in exploration and resource growth

A total of 813 exploration wells (including 249 for appraisal) were spudded in 2002-21, with about NOK 550 billion (2022 value) invested in exploration (Figure 3.3).

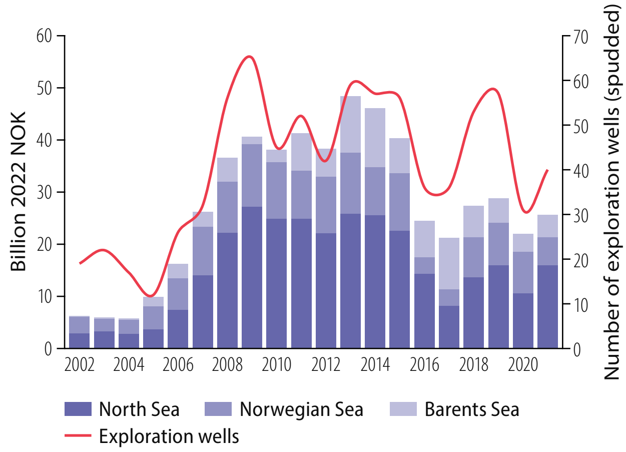


Figure 3.3 Exploration costs and wells, 2002-21

Exploration activity during this period resulted in almost 300 discoveries and a total growth of about 1 900 million scm oe in resources (Figure 3.4). Of these, 190 discoveries totalling 1 600 million scm oe are included in the profitability calculations. Discoveries not included are mainly categorised as RC6 (chapter 2.2 Discoveries).

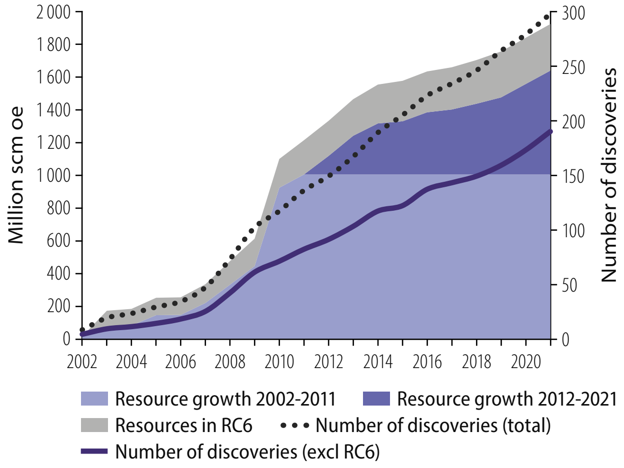


Figure 3.4 Discoveries and resource growth, 2002-21

Figure 3.4 shows that resource growth was greatest in the first half of the period. About 60 per cent of the growth took place from 2002 to 2011, and 40 per cent from 2012 to 2021. The period was characterised by few and large discoveries in its first half and many small ones in the second decade.

Eight of the 10 largest discoveries in the period were made in the first decade. These include 16/1-8 Edvard Grieg (2007), 16/1-9 Ivar Aasen (2008) and 16/2-6 Johan Sverdrup (2010). The last of these was by far the biggest discovery in the analysis period and accounts alone for about 25 per cent of the resources covered by the analysis.

Value creation from exploration in the past 20 years

The overall NPV of exploration over the past 20 years is estimated to be about NOK 1 500 billion and NOK 2 100 billion with discount rates of seven and four per cent respectively. Overall net cash flow is estimated at more than NOK 3 000 billion (Figure 3.5).

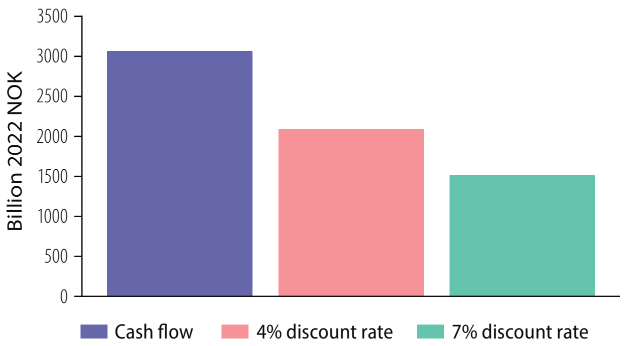


Figure 3.5 Profitability of exploration in the past 20 years

High resource growth and a number of big discoveries in the first 10 years of the analysis period contributed higher value creation than in the second decade. Exploration costs were high during 2012-21, while resource growth was relatively low.

A number of small discoveries in this period led to many profitable developments. Although these provide considerably lower present value than the big discoveries in the previous period, they contribute to a positive return from exploration over the past 10 years.

Exploring for oil and gas over the past 20 years has provided enormous value for society

Figure 3.6 shows that each krone invested in exploration on the NCS in the past two decades yielded a return of roughly NOK 2.40. Each krone invested in exploration over the past 10 years gave a return of about NOK 1.10. The good exploration results over the past five years yielded a return of roughly NOK 1.60. These results exceed a seven per cent return.

The NPD's calculations show that exploration activity has been profitable in all NCS areas. Some two-thirds of the overall revenues from discoveries made over the past 20 years come from the North Sea, while roughly a third is split more or less equally between the Norwegian and Barents Seas.

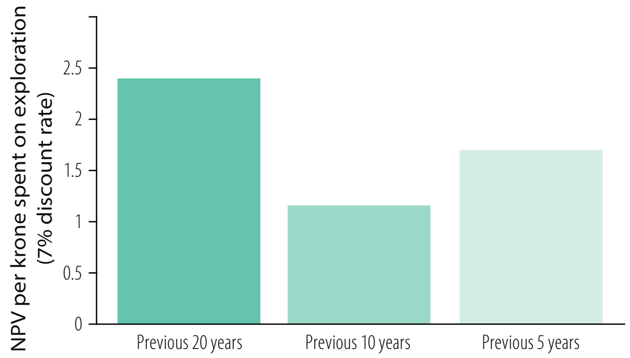


Figure 3.6 Profitability per exploration krone

Unit costs

Unit costs are undiscounted and defined as total costs per unit of oe produced from the period. They differ between projects and depend on such factors as discovery size, type of phasing-in, reservoir quality and distance to infrastructure. Unit costs for discoveries over the past 20 years average about USD 25 per barrel (Figure 3.7). They are lowest in

North Sea, at some USD 23 per barrel, and highest in the Barents Sea at around USD 31 per barrel. Unit costs in the Norwegian Sea average roughly USD 28 per barrel.

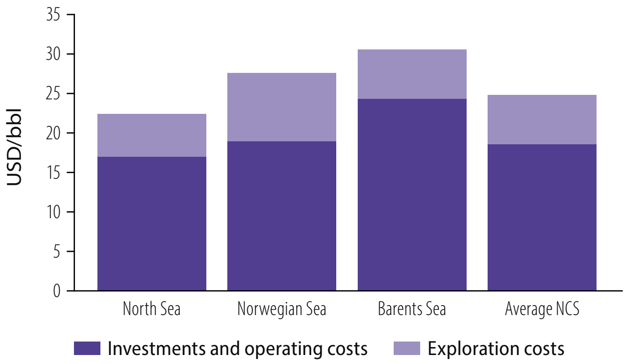


Figure 3.7 Unit costs for discoveries in 2002-21 by NCS area

Figure 3.7 shows that investment and operating costs per unit produced are lower in the North and Norwegian Seas than in the Barents Sea. With big capital spending in the North and Norwegian Seas already fully recouped, new discoveries can be phased in with good profitability. At the same time, declining production from a number of fields in these areas could mean that unit costs rise. To maintain good profitability on the NCS in the future, it is extremely important that new resources are tied back to cost-effective infrastructure (chapter 3.2 Assets in the discovery portfolio).

Good profitability requires that new resources are tied back to cost-effective infrastructure

New infrastructure investment represents a large proportion of unit costs in the Barents Sea. That is as expected in a petroleum province being matured and in the development phase. At the same time, calculations show that exploration costs per unit produced do not exceed the average for the NCS (about USD 6 per barrel). To continue maturing the Barents Sea as a petroleum province, it will be important that the companies persist in exploring in frontier areas as well as close to existing discoveries.

Value creation from discoveries of different sizes

The profitability calculations show that both small and large discoveries have been important for overall value creation from exploration over the past 20 years (Figure 3.8). About half the value creation has derived from discoveries larger than 25 million scm oe.

These are Johan Sverdrup, which alone accounts for 35 per cent of the value created, and eight discoveries in the 25-100 million scm oe range which collectively contribute 14 per cent. These discoveries are important for developing infrastructure and other discoveries in the areas around new or existing field centres.

The other half of the value creation comes from discoveries smaller than 25 million scm oe. More than 60 of these are in the five to 25 million scm oe range and account collectively for 37 per cent of the value created. The smallest discoveries have also contributed a substantial proportion of total value creation, since even very small deposits can provide good profitability when developed in a cost-effective way towards existing infrastructure. In addition, it is important to exploit capacity already developed and enhance the profitability of fields approaching cessation. Over the past 20 years, about 120 discoveries of less than five million scm oe have accounted for roughly 14 per cent of total value creation on the NCS.

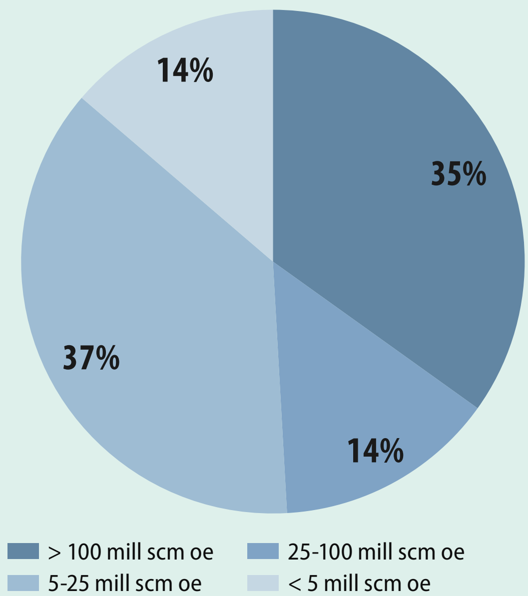


Figure 3.8 Present value contribution from various discovery sizes (7% discount rate)

Significance of exploration for future production
Production and energy deliveries from the NCS are expected to decline rapidly over the next few years unless supplemented by new resources. Figure 3.9 shows that a large proportion of production over the next 10 years will derive from discoveries made in the past two decades. Almost 25 per cent of overall production from the NCS in 2022 comes from discoveries made after 2002. This will rise to about 40 per cent by 2030.

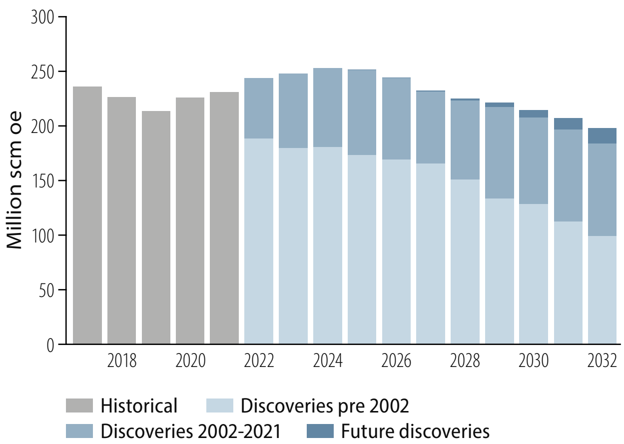


Figure 3.9 Historical and future oil and gas production

Significantly more oil than gas was discovered on the NCS over the past 20 years. About 75 per cent of total revenues from discoveries made in 2002-21 derived from oil production, and the remainder from producing gas. Oil prices were significantly higher than for gas during the same period.

Figure 3.10 shows that more than half the oil produced on the NCS over the next 10 years will derive from discoveries made in the past two decades. Production from Johan Sverdrup accounts for a large proportion of this.

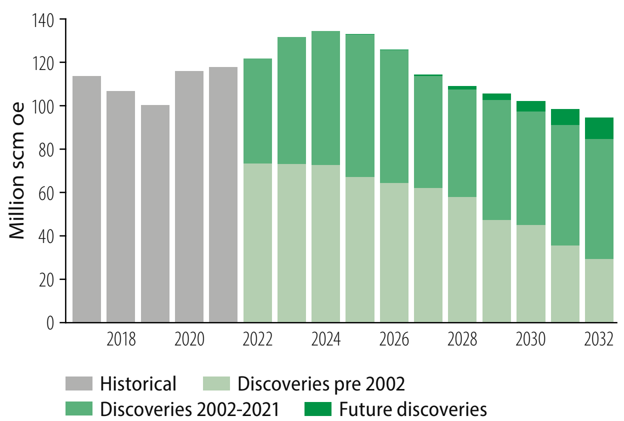


Figure 3.10 Historical and future oil production

Figure 3.11 shows that less than 20 per cent of gas produced over the next 10 years will derive from discoveries made in the past two decades. In other words, future gas production will be based to a great extent on discoveries made more than 20 years ago. Troll accounts for a large proportion of this.

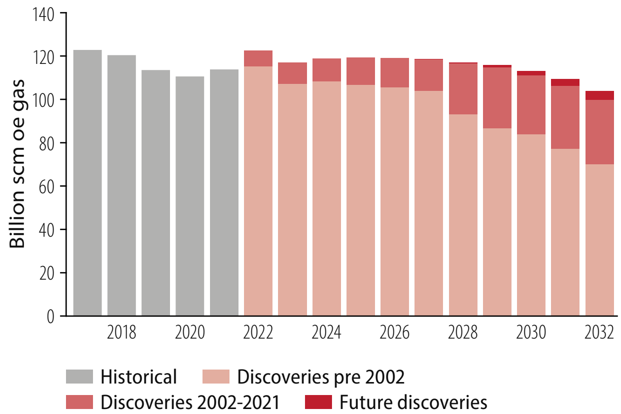


Figure 3.11 Historical and future gas production

After 2030, production will fall substantially. Forecasts for fields and discoveries reported by the companies show overall output in 2040 down by a third from today's level without the addition of new resources (Figure 1.1). That would weaken the economics of fields on stream. Exploration will therefore be very important for the development of production and value creation after 2030.

3.2 Assets in the discovery portfolio

Timely exploration and development
Phasing into existing or future infrastructure can make even small discoveries profitable. That can help to extend the producing life of existing fields and infrastructure, which in turn incentivises more exploration close to fields. Opportunities for improved recovery and increased value creation from host fields are thereby enhanced.

Phasing discoveries in before unit costs become too high is important. That means further development of discoveries does not depend on spare capacity alone, but on this being combined with low unit costs (Figure 3.12).

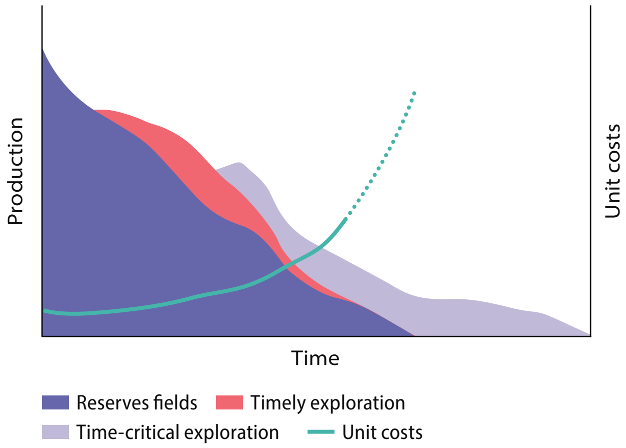


Figure 3.12 Timely and time-critical phasing-in

Timely exploration and development are important for profitability

Figure 3.12 distinguishes between timely and time-critical resources. The first are resources phased in while unit costs on the host field are low. Time-critical resources are those phased in when unit costs on the host field are rising rapidly. In that case, resources are either lost or produced with low profitability.

Coordinated development
Exploiting economies of scale through coordinated development across production licences will become increasingly important as the NCS matures. Such area solutions can contribute to lower unit costs and effective exploration, so that as much as possible of the socioeconomically profitable resources can be recovered.

Coordination is crucial for profitable development of small discoveries

The Petroleum Act (fact box *The Petroleum Act*) requires licensees to collaborate across production licences in order to ensure the maximum possible value creation.

The Petroleum Act
Pursuant to section 4-7 of the Petroleum Act, licensees must make efforts to reach agreement on the most efficient coordination if a petroleum deposit extends over more than one block with different licensees or when joint petroleum activities would obviously be more efficient in the case of several deposits.

Furthermore, section 4-8 empowers the government to determine that facilities can also be used by others if required for rational operation or the benefit of society, and provided that such use is not to the unreasonable detriment of the licensee's own requirements or of someone who already has a right of use.

Examples of possible coordinated developments are provided by the Halten East Unit in the area south of Åsgard and phasing-in the 25/5-9 (Trell) and 25/4-2 (Trine) discoveries in the Alvheim area (fact boxes *Halten East Unit* and *Trell and Trine*).

Halten East Unit

Several discoveries and prospects on the eastern side of the Halten Terrace in the Norwegian Sea could be tied back to Åsgard B (Figure 3.13). Coordinating the development of small fields can increase value creation and, in this case, investigating small prospects is possible by drilling sidetracks from discovery or production wells. Coordination in this project offers synergies through joint use of infrastructure and more cost-effective project execution, as well as helping to extend tail production on Åsgard.

The government gave the green light in 2019 for extending the deadline to reach a decision on continuation (DoC) for 6407/6-6 (Mikkel South (Gamma)) and 6407/6-7 S (Mikkel South (Harepus)), and 6407/2-6 S (Flyndretind) in order to achieve a coordination. The extension was conditional on the licensees undertaking to drill a new exploration well, which resulted in a discovery. Conditions were specified for assessing possible coordination gains with other discoveries and prospects in the whole Halten East area.

The licensees and the government reached agreement in 2020 on unitising four production licences, and the unitisation agreement was approved by the MPE on 15 December 2020. This has secured the necessary progress, and the preconditions underlying the DoC extensions will be realised. The PDO for Halten East was submitted to the government for approval in May 2022.

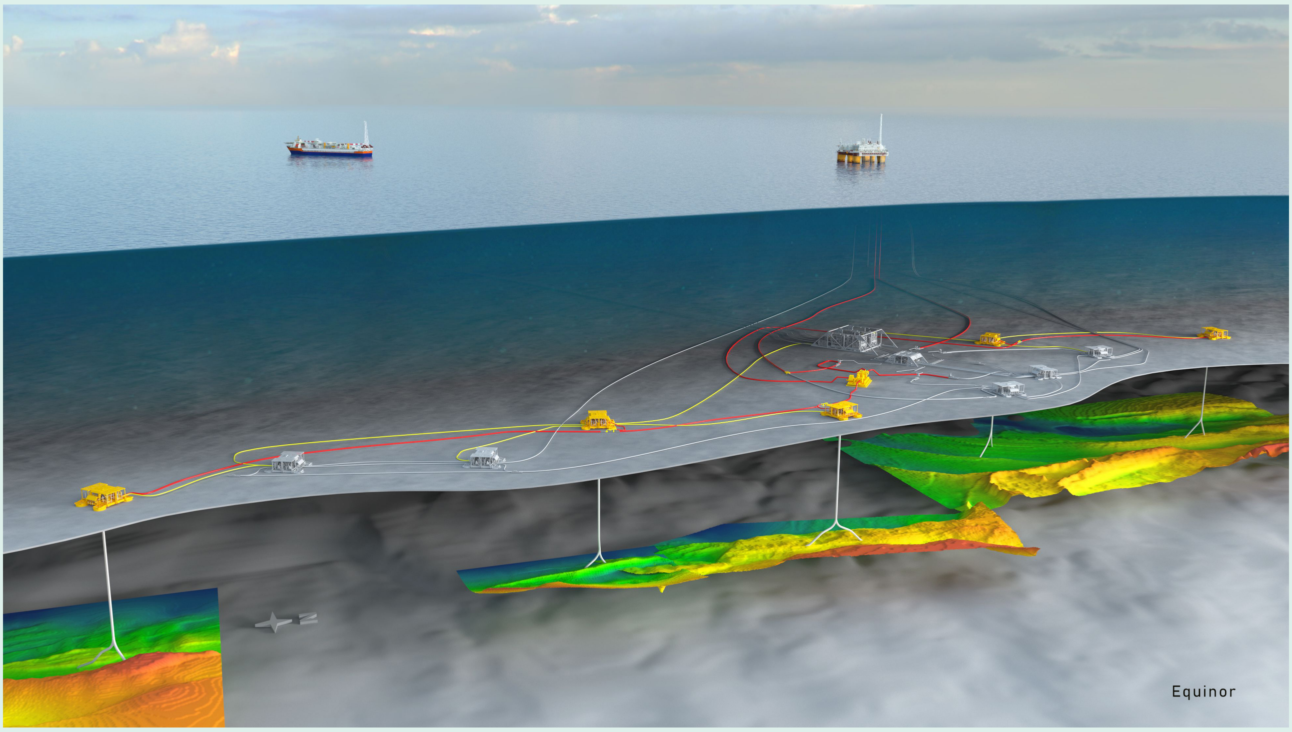


Figure 3.13 The Halten East Unit

Trell and Trine

25/5-9 (Trell) and 25/4-2 (Trine) are two small discoveries in the central part of the Norwegian North Sea. They lie 10 and five kilometres respectively east of the Heimdal field. Small oil discoveries like these are normally developed with subsea installations tied back to an existing field.

In this part of the North Sea, the Alvheim FPSO is the nearest production facility suitable for handling liquids from new discoveries. In addition to the third-party access (TPA) agreement which 25/5-9 (Trell) and 25/4-2 (Trine) have secured with host field Alvheim pursuant to the regulations relating to the use of facilities by others, a coordinated development of the two discoveries is planned pursuant to section 4-7 of the Petroleum Act. Overall resources are estimated at 3.8 million scm oe. This approach helps to reduce total development costs compared with developing each discovery separately.

Discovered in 2014 (Trell) and 1973 (Trine), the two are dependent on cost-effective recovery solutions for achieving acceptable profitability. The licensees in the area have therefore implemented a number of measures which make it possible to coordinate their development, and have submitted a PDO in 2022. Production licence 036 E covering 25/4-2 (Trine) was carved out from production licence 036 BS (Heimdal), and changes in participant interests have occurred. Aker BP took over the operatorship in both production licences in 2018, and the licensees concerned established a unitisation agreement in 2021. This means that their share of production will be the same for the two discoveries.

3.3 Assets in fields and improved recovery

Operating costs have declined substantially since oil prices fell in 2014 (Figure 3.14). The NPD does not expect overall operating costs to rise significantly towards 2026, even if more fields come on stream.

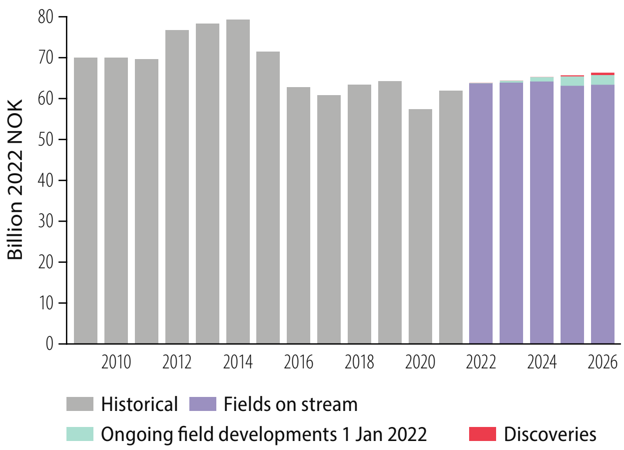


Figure 3.14 Historical operating costs and forecasts
Updated at 13 January 2022

That can help to keep unit costs down to a competitive level. In today's circumstances, continuing production is profitable even with very low oil and gas prices (Figure 3.15).

Profitable production even with low oil and gas prices

However, unit costs will rise unless measures are adopted to prevent production declining quickly.

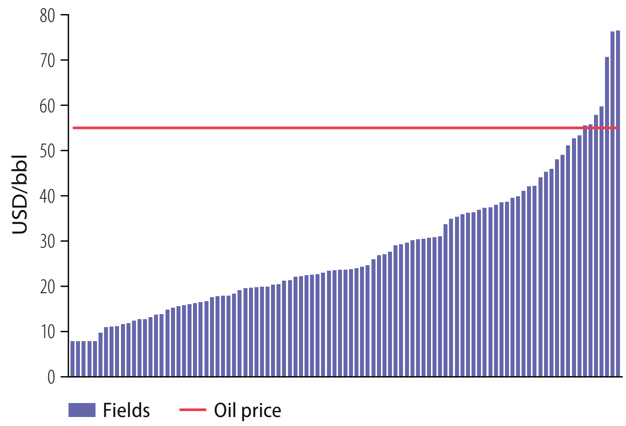


Figure 3.15 Competitive unit costs *Unit costs (undiscounted) are based on forecasts for production and costs from 2023. They include operating costs (incl area fee, green taxes and transport costs) and investment in fields on stream*

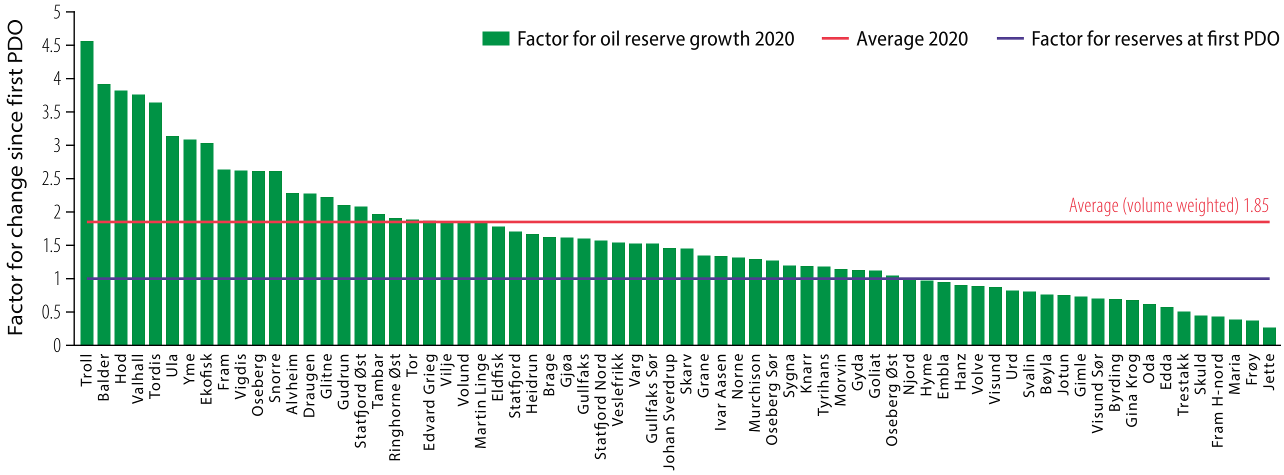


Figure 3.16 Present versus PDO resources

History shows that most of the big fields on the NCS have produced more and for longer than was assumed when they were developed. Figure 3.16 compares current oil reserves in fields with the figure given in the original PDO. A field with the bar extending above the blue line has had its estimated reserves upgraded – in several cases, by more than double. Those below the line have seen their estimate reduced, and are by and large small fields.

Understanding of a reservoir's properties improves throughout the production phase. That may contribute to big differences between the original PDO production forecast and actual output.

Flexible development solutions increase future value creation

This emphasises the importance of planning early for flexibility and upsides – such as providing sufficient well slots to permit future measures involving improved recovery or additional resources.

The oil companies submit annual reports of planned improved recovery projects in connection with the RNB, (chapter 2.4 Improved recovery). Company reporting has identified relatively few EOR measures. Such projects are therefore expected to make a small value contribution. This confirms that a big gap exists between the industry's plans and the resource potential offered by the EOR methods identified by NPD studies.

A number of reasons exist for this gap. An important one is that the required rate of return set by the companies is higher than that applied in socioeconomic analyses (fact box *Required rate of return*). More socioeconomically profitable EOR projects could thereby be available than the companies wish to implement.

CO_2 captured for storage (CCS) can be used to improve oil recovery (carbon capture, utilisation and storage – CCUS). This represents a competitive method for storing CO_2, which might have a big potential when CCS value chains are established on the NCS (chapter 5 Energy transition opens new opportunities).

Required rate of return
Economic theory stipulates that a project should be implemented if its NPV is positive, and rejected when the NPV is equal to zero or negative. Even were all projects with a positive NPV to be sanctioned, this does not describe what actually happens. That is because company behaviour includes rationing capital. That means projects with a positive NPV are not necessarily realised because their profitability is insufficient to come high enough up a company's internal ranking.

In 2015, **the Auditor General's offic**e investigated required returns and investment behaviour on the NCS. It reported that the companies generally required a higher real rate of return than the state, and that the requirement was often higher than that prescribed by the capital asset pricing model. In addition, the office described a trend whereby investment on the NCS must compete more strongly with projects abroad and where only the most profitable projects in commercial terms are realised [14].

A study by **Wood Mackenzie** in 2018 [15] indicated that oil companies required a return of 13-14 per cent for projects typical of the NCS.

The climate risk commission concluded that the requirement for higher returns by the companies pointed towards lower investment on the NCS than would be socioeconomically profitable [16].

This report is referred to by the **MPE** in its *energy White Paper* [17]: "The [commission] notes that the oil companies probably require a higher return than the state when assessing projects. This points towards lower investment on the NCS than is socioeconomically profitable". In its *supplementary White Paper* [18], the ministry adds: "Experience from the NCS is that the companies require a high expected return and great economic robustness before sanctioning new investments. The companies typically apply a higher return than the state for investment decisions and require that projects are also financially robust with significantly lower oil and gas prices than expected."

3.4 Managing gas for increased value creation

Russia's invasion of Ukraine has affected the European gas market. The completed gas export pipeline from Russia to Germany remains unopened, Russia has made big cuts in spot sales to Europe, and the long-term gas sales contracts are partly being cancelled and partly under heavy pressure. Norway is in a unique position here, thanks to an extensive pipeline network for natural gas to the EU with low transport costs. That makes it competitive with LNG transport from other regions.

A joint declaration on energy collaboration from an EU-Norway meeting emphasises the special Norwegian position and the need for deliveries of both oil and gas, including after 2030. "The EU supports Norway's continued exploration and investments to bring oil and gas to the European market." [19]

Norwegian gas has acquired more value
Given substantial remaining gas resources, an efficient and reliable gas transport system to Europe, the expected trend for gas demand and declining gas production in the EU, the basis exists for maintaining Norwegian gas exports at a high level for a long time to come (Figure 3.17). At 31 December 2021, five fields accounted for almost 70 per cent of Norway's gas reserves – with Troll alone providing about 45 per cent.

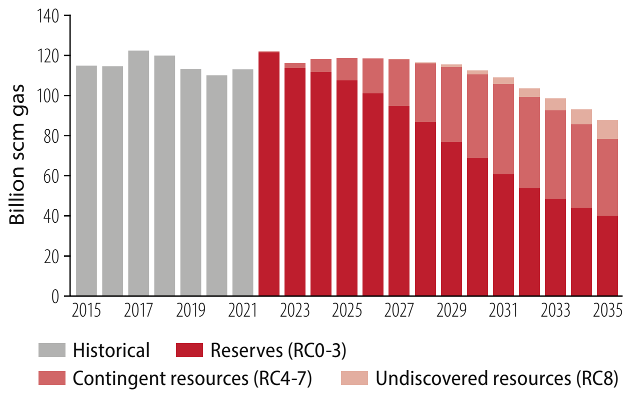


Figure 3.17 Gas sales from the NCS by resource class

Gas exports have increased from several fields in recent years. An important reason is accelerated gas output from fields in a mature phase with small remaining oil resources. High gas prices in 2021-22 meant that exports from the larger fields have risen even more. Such acceleration yields substantial revenues but could also lead to the loss of oil resources (fact box *Dilemma: gas injection to improve oil recovery – or accelerating the gas?*).

Dilemma: gas injection to improve oil recovery – or accelerating the gas?
Gas has been injected in many North Sea oil fields to provide full pressure support, either in the whole field or in some segments. That has contributed to a substantial increase in oil production. Once the profitable oil has been recovered, gas injection ceases and oil production declines before eventually halting. If infrastructure is available, the gas can be exported and thereby contribute to increased value creation. A transition to gas export alone is being planned on Troll, Oseberg, Skarv and other fields with gas infrastructure.

Some fields require additional investment if injection gas is to be produced and exported. Johan Castberg and Ula are examples. The Ula licensees currently have no plans to export injected gas. Where Johan Castberg is concerned, a joint gas pipeline is under consideration from the planned Wisting field to Snøhvit. With high gas prices, the transition from gas injection to export could be accelerated. During the winter of 2022, the government has given temporary permission to increase gas exports from some fields. These include Gina Krog [20], where Equinor has secured a temporary permit to halt injection in order to export the gas.

Gas is exported from the Barents Sea today via the gas liquefaction plant at Melkøya off Hammerfest. Production from Snøhvit will occupy all capacity in this facility for a long time to come. Based on exploration activity so far in the opened areas of the Barents Sea, no individual field is able to support the establishment of new export capacity. The latter therefore depends to a great extent on coordinating resources. At the same time, a failure by the companies to explore for gas will make it harder to find enough resources to justify new infrastructure – either stand-alone or coordinated.

Studies conducted by the NPD and Gassco in 2020 showed that it will be socioeconomically profitable to increase gas export capacity from this part of the NCS. Later studies have confirmed this [2].

To secure sales opportunities for gas fields and for oil fields with associated gas, various companies are looking at the possibility of developing joint infrastructure for managing gas between Snøhvit, Johan Castberg og 7324/8-1 (Wisting). These fields and discoveries would thereby acquire sales opportunities. But revenues from the gas would come far in the future, once the Snøhvit resources have been produced. The solution outlined does not increase gas export capacity from the Barents Sea.

With support from Enova, industrial players are exploring opportunities to produce "blue" ammonia from natural gas combined with CO_2 storage beneath the seabed. Plans for this Barents Blue project call for the ammonia to be transported to market by sea. Other gas export options include increased LNG capacity and new pipelines. It will be important to develop solutions which take account of area and NCS perspectives and which incentivise increased exploration for and development of oil and gas.

3.5 Technology development and expertise

Technological advances have made big resources originally considered non-commercial available on the NCS. As the NCS matures, continued development of technology, expertise and knowledge will be no less important.

Within exploration, more and better data and greater understanding of the geology have made it possible to identify new plays. That has contributed to further discoveries. Figure 3.18 shows an increase in the technical success rate on the NCS over the past five years. It was on a par with the international average in 2021 [21]. The figure is based on 995 wildcats in 80 countries completed in 2017-21. The commercial success rate on the NCS has also increased in recent years, but is somewhat below the international average. Technological progress, improved surveying, more and better use of data, and greater understanding of the geology could contribute to reduced exploration risk and more discoveries.

Where development and operation are concerned, coming up with and implementing new and more cost-effective technology permit oil and gas to be produced from ever more technologically demanding fields. Slim hole drilling on Åsgard and Edvard Grieg is a good example (Figure 3.19).

Technologies for faster drilling speeds, optimising recovery strategies with the aid of new digital tools (fact box *Digital solutions on Johan Sverdrup*), EOR methods and next-generation developments with remotely controlled and low-manned operation will also play key roles in the future.

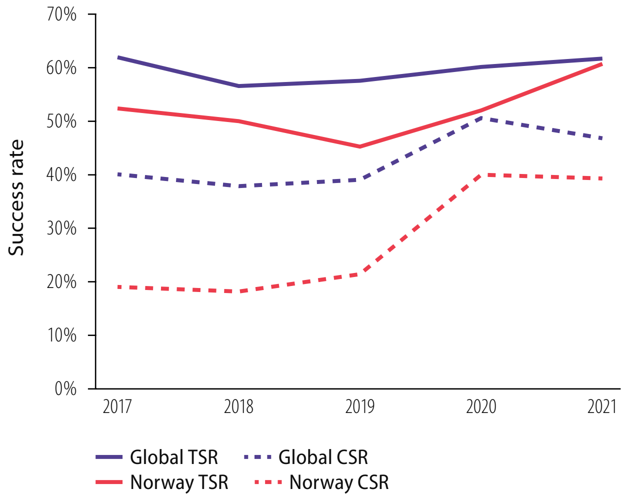


Figure 3.18 Development of technical (TSR) and commercial (CSR) success rates over the past five years *Based on data from Westwood (2022)*

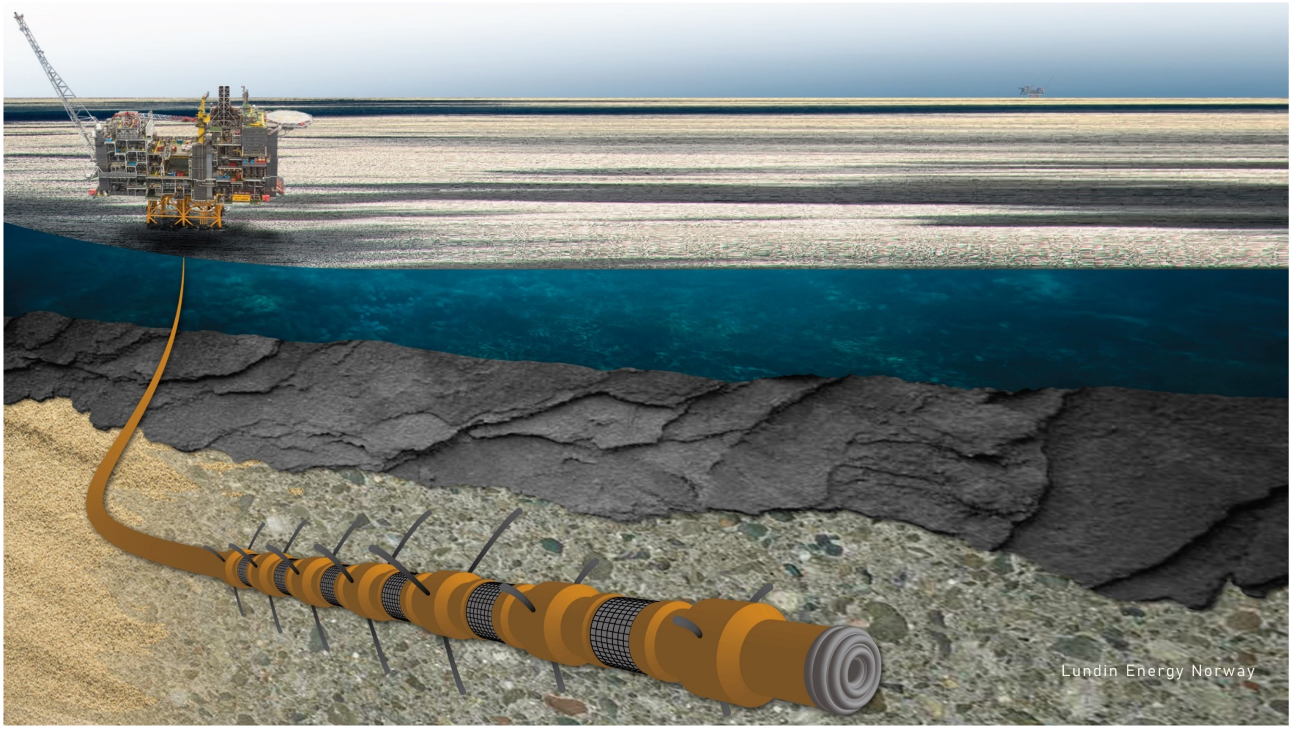


Figure 3.19 Slim hole drilling

Early technology adoption and improvement are important for maintaining production and value creation on the NCS. Studies show that the industry devotes insufficient resources to research, technological progress and innovation in relation to what might be socioeconomically profitable [22]. In particular, the global petroleum industry is known for taking a conservative approach to adopting new technology [23]. The Norwegian authorities have therefore played an active role in this area. The NPD wants to ensure the players investigate and adopt new technology to an even greater extent in order to increase discoveries and development, and to reduce emissions.

Technology and expertise must be viewed in relation to each other. Innovative technology, particularly advanced digital solutions, calls for new expertise and skills. Making a commitment to technology yields results far beyond new technical solutions. A continuous concentration on building up and maintaining technology and expertise is therefore a key precondition for efficient and sustainable activity.

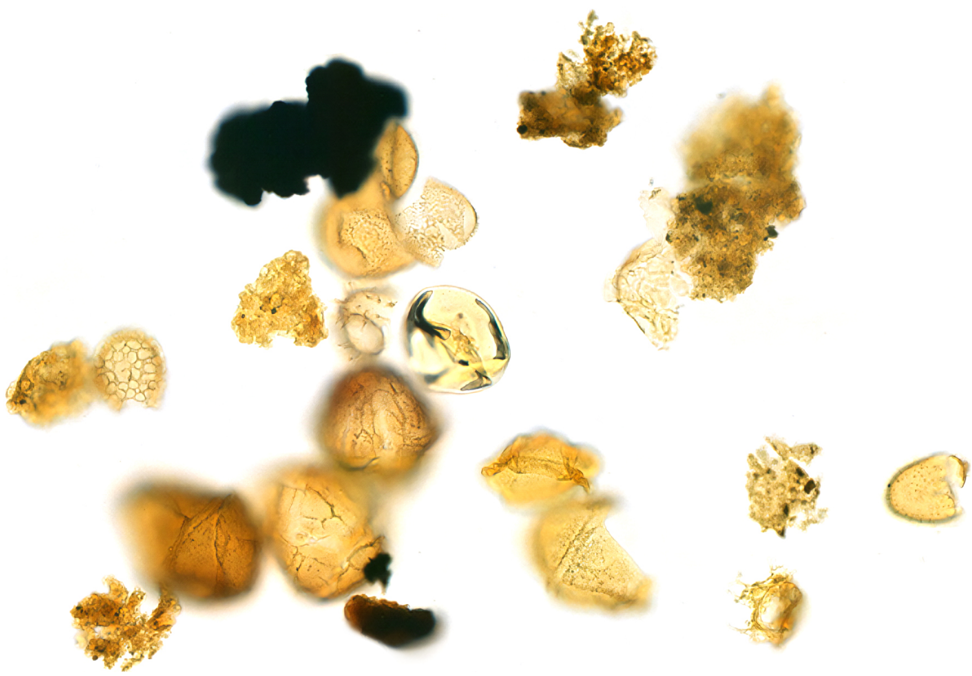
Norway's petroleum industry is approaching the big "changing of the guard". A large proportion of its employees are set to retire during the coming decade, with the risk of losing experience and technical knowledge [24]. In order to maintain value creation, therefore, it will be important that the sector manages to attract new graduates. Another success factor is that the existing workforce adopts new technology and working methods.

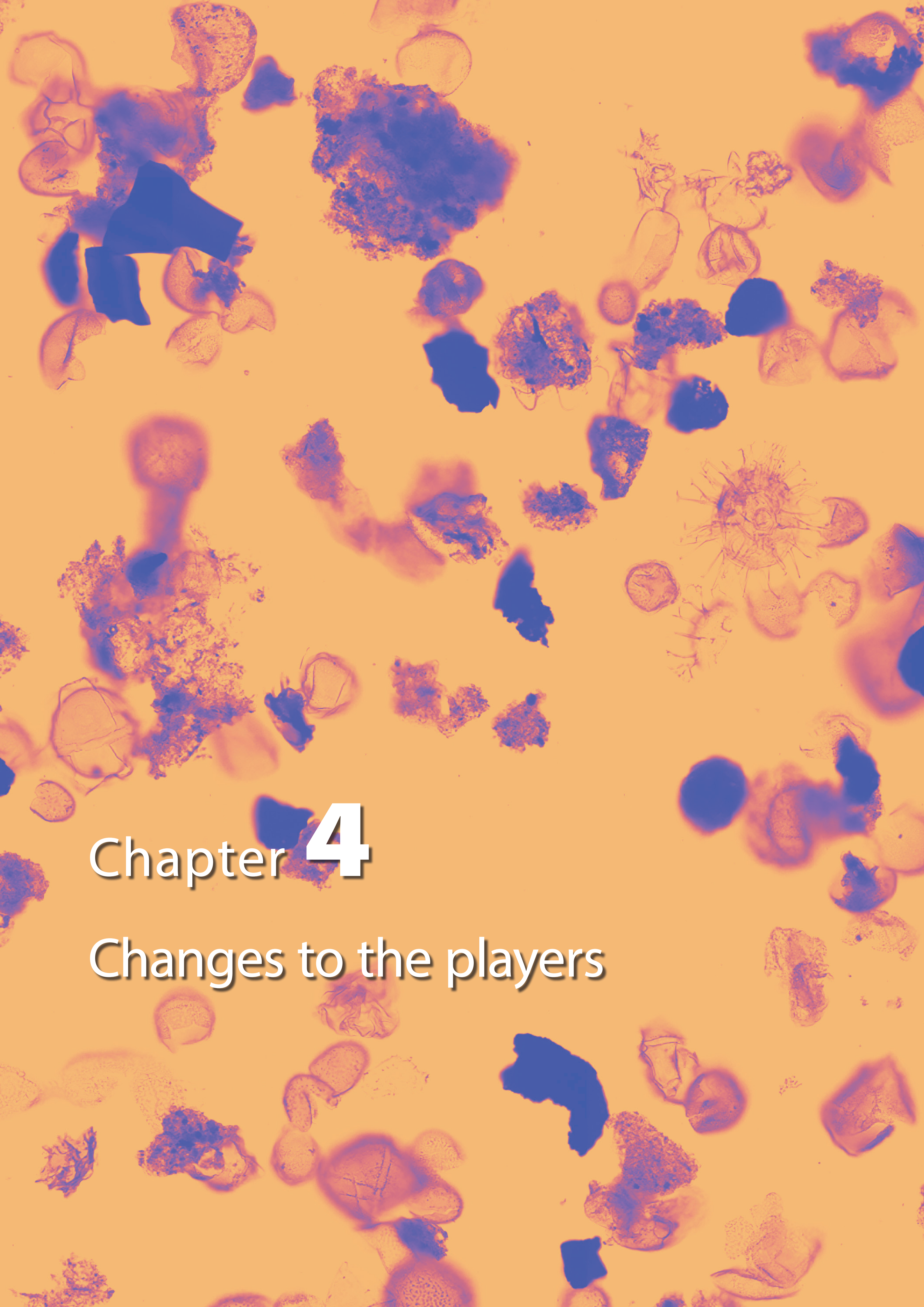
Digital solutions on Johan Sverdrup
Equinor estimates that more than NOK 2 billion has been saved during Johan Sverdrup's first year on stream by adopting digital solutions. The gains derive primarily from the following:

- Higher stable production as a result of automated production optimisation and more effective start-up of wells. Collaborating with integrated operation centres on land to optimise production and remove restrictions.

- Improved subsurface understanding as a result of better and more complex data sets, which provide more information on the reservoir.

- Improved operation and maintenance because of stable production and implementation of "digital fieldwork". This means that operators on the facilities use tablets and digital twins of the installation in their day-to-day work [25].





Chapter 4

Changes to the players

The number of players on the NCS has declined considerably in recent years. Nevertheless, the level of activity remains high. Many small and medium-sized companies have merged and strengthened their position. The medium-sized companies have become an increasingly important force in the continued development of the NCS.

4.1 Development of the player picture

Developing oil and gas operations on the NCS depends on the size of the resource base and the industry's ability and willingness to find and recover as much of these resources as possible in an efficient and sustainable manner.The oil and gas resources provide differing commercial opportunities for the oil companies. So it is important that the player composition is sufficiently varied and represents a diversity of knowledge and approaches.

Most of the big discoveries on the NCS were made in the first decades of exploration. This represented commercial opportunities for the oil majors, and the NCS was consequently dominated by these together with Statoil, Norsk Hydro and Saga Petroleum.

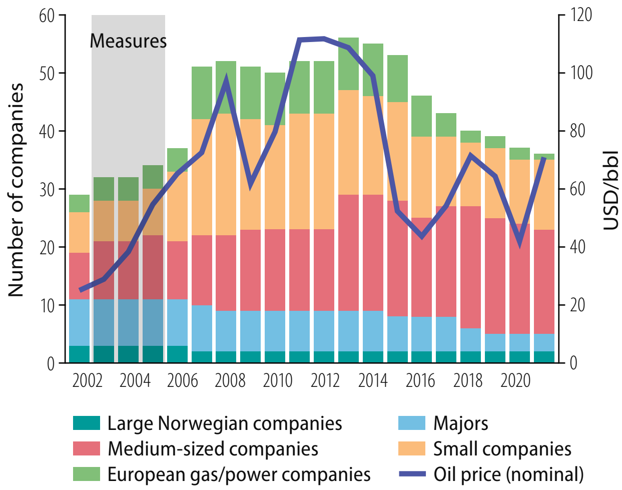


Figure 4.1 Development of oil prices and number of companies by type

As the NCS became better explored and a number of majors merged, a broader player composition became necessary. The big participants who could undertake demanding and capital-intensive projects were still needed. At the same time, it was important to attract companies whose attention was focused on the smaller projects. The government took a number of steps to make it attractive and easier for new players to enter the NCS. Examples included a new arrangement for prequalifying companies, awards in predefined areas (APA rounds) and a reimbursement system for exploration costs.

Table 4.1 Licensees at 31 December 2021 by various company types

Large Norwegian companies	Equinor, Petoro
Majors	ConocoPhillips, Shell, TotalEnergies
Medium-sized companies	Aker BP, Chrysaor, DNO, Idemitsu, INPEX, KUFPEC, LOTOS, LUKOIL, Lundin, MOL, Neptune, OMV, ONE-Dyas, Repsol, Spirit, Suncor, Vår Energi, Wintershall Dea
Small companies	CapeOmega, Concedo, Lime, Longboat, M Vest, Mime, OKEA, Pandion, Petrolia, Source, Sval Energi, Wellesley
European gas/power companies	PGNiG

Combined with rising oil prices, these measures led to a marked increase in both number and breadth of companies. Their number rose from 29 in 2002 to 56 by 2013 (Figure 4.1 and Table 4.1). The new entrants contributed to increased competition over acreage, and have secured a large proportion of the production licences awarded over the past 20 years (Figure 4.2).

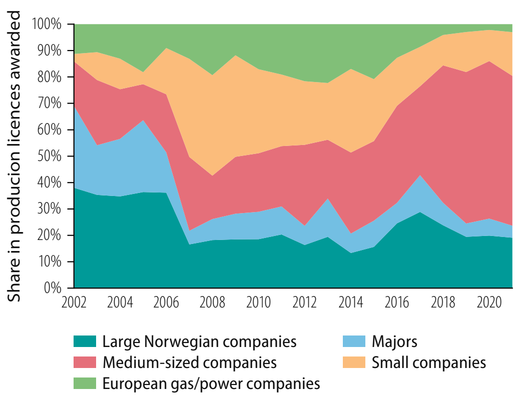


Figure 4.2 Share of awards by company type (licensees)

Figure 4.3 presents the development in exploration wells by company type. In line with the rise in the number of players, exploration activity rose markedly from 2007. Over the first decade, large Norwegian companies and majors accounted collectively for more than half the wells drilled. During the second 10 years, these players reduced their share of exploration wells while medium-sized and small companies substantially increased their proportion.

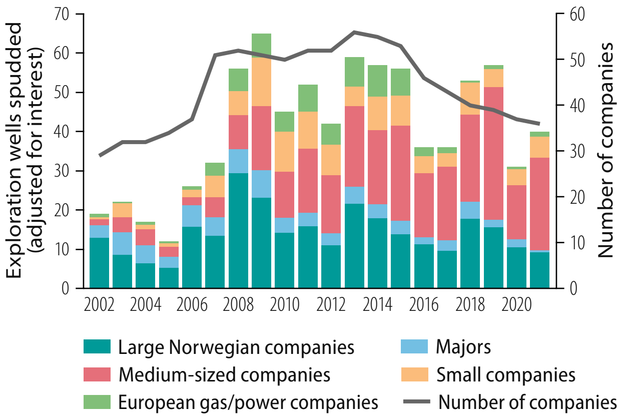


Figure 4.3 Development in number of exploration wells by company type (licensees)

More players and rising oil prices have contributed to increased exploration, many new discoveries and greater resource growth (Figure 4.4). The new players have contributed to a number of discoveries and field developments on the NCS.

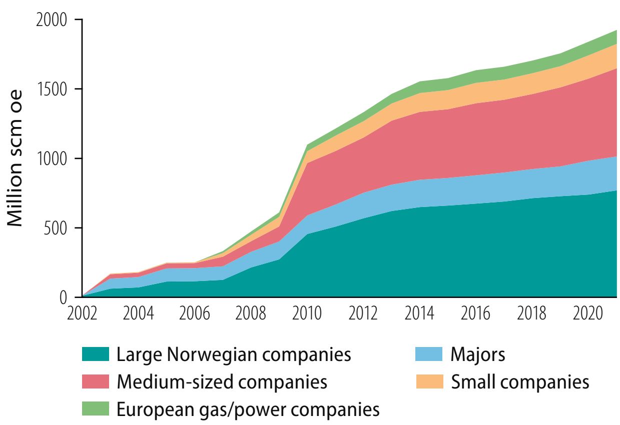


Figure 4.4 Accumulated resource growth from discoveries by company type

At 31 December 2021, 36 companies were active on the NCS – a reduction of 20 from the 2013 peak (Figure 4.5). During the first six months of 2022, two companies have been taken over. Aker BP is acquiring the oil and gas business of Lundin Energy, and Sval Energy has bought up Spirit Energy. In addition, Suncor Energy has announced that it is withdrawing from the NCS.

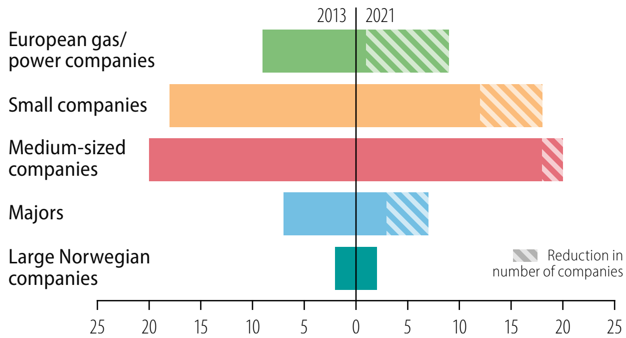


Figure 4.5 Changes to player composition since 2013

The decline in player numbers is partly a result of majors and European gas/power companies selling out of the NCS in recent years. Following the oil price slump in 2014 and an increased emphasis on the rate of return among majors, the international oil industry has seen a consolidation of activity. Combined with a more mature NCS and a lack of big projects, this contributed to several majors departing. Some have committed to petroleum provinces where big discoveries can be made, while others are concentrating on such business opportunities as shale oil, LNG and renewable energy. European gas/power companies have increasingly committed to renewables and withdrawn from petroleum activities.

Medium-sized companies have strengthened their position

A number of mergers and acquisitions, largely involving companies with exploration as their main activity, have further reduced the number of players. One result of this process is that several companies have strengthened their position on the NCS.

Diversity has increased among field operators. Figure 4.6 presents the number of approved PDOs by company type in 2002-21. During recent years, several medium-sized companies and one small company have become field development operators. The proposed restructuring of the petroleum tax regime [26] could facilitate greater operator diversity in bringing discoveries on stream, since it will be easier for companies without taxable earnings to finance the development phase.

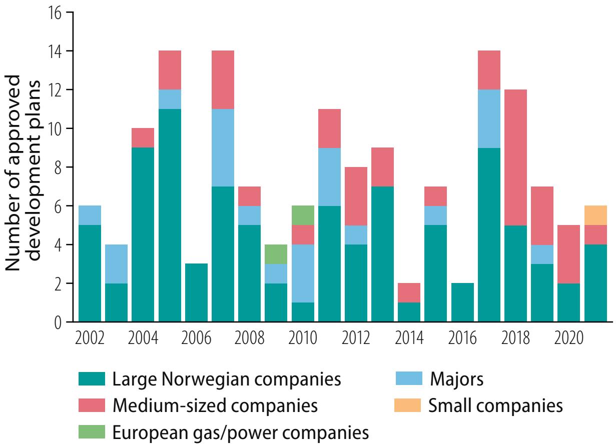


Figure 4.6 Approved development plans (PDO and PDO-exempt) by company type (operators)

Figure 4.7 presents the trend for the share of production by company type over the past 20 years. Majors and European gas/power companies have substantially reduced their proportion of total production, while medium-sized companies have increased theirs correspondingly.

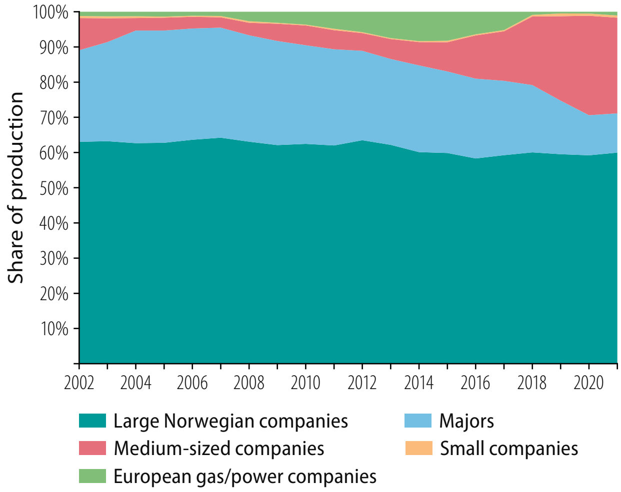


Figure 4.7 Development in production by company type (licensees)

4.2 Ability and willingness

A precondition for value creation is that the licensees not only possess expertise but are also willing to apply this along with investment funds to their Norwegian portfolio of production licences, discoveries and fields. Exploration results depend on a number of factors, including the prospectivity of the acreage awarded, where exploration takes place, and its scope and quality. Figure 4.8 and Figure 4.9 present the correlation between the number of wildcats and resource growth for the past five years.

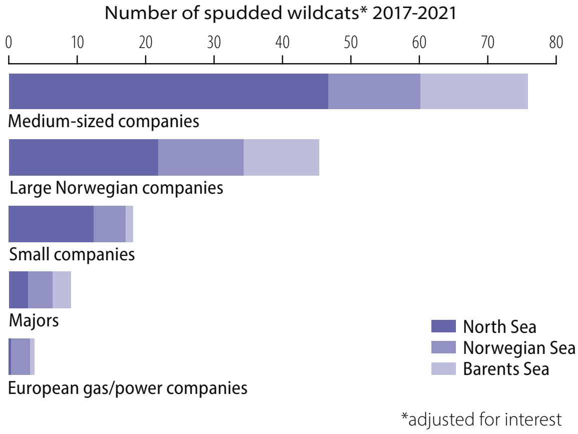


Figure 4.8 Wildcats in 2017-21 by company type (licensees)

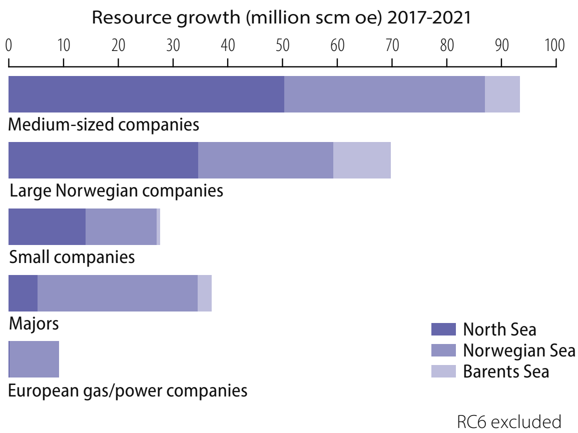


Figure 4.9 Resource growth in 2017-21 by company type (licensees)

Medium-sized companies participated in the greatest number of wildcats in 2017-21, and had the largest resource growth. However, resource growth per wildcat has been relatively low. Large Norwegian companies also drilled many wildcats and these have yielded higher resource growth per well than for medium-sized companies. Majors drilled relatively few wildcats, but achieved relatively high resource growth.

A total of 57 wildcats were drilled on the NCS in 2020-21. Thirteen were not close to infrastructure, with medium-sized companies as the operator for almost half of these (Figure 4.10).

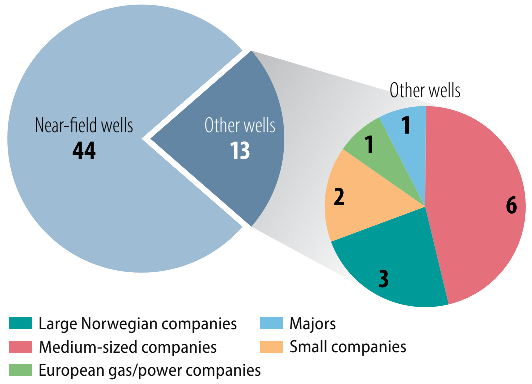


Figure 4.10 Wildcats spudded in 2020-21 by company type (operators)

At 31 December 2021, large Norwegian and medium-sized companies held the largest remaining resources on the NCS (Figure 4.11). They account collectively for more than 85 per cent of remaining resources, with large Norwegian companies alone accounting for 63 per cent. Medium-sized companies have strengthened their position, and are the category with the largest increase in production licences and the highest level of exploration activity in recent years. That has yielded a number of discoveries and increased both reserves and resources in discoveries yet to be sanctioned for development.

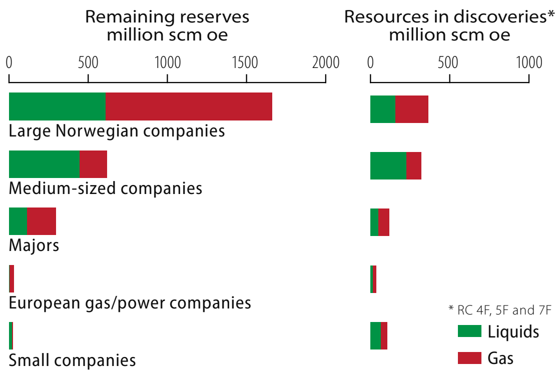


Figure 4.11 Remaining reserves and resources in discoveries at 31 December 2021

4.3 Player adaptation to the energy transition

The energy landscape is changing, which could have major consequences for players in the petroleum sector. A key question for oil and gas companies is how they can position themselves to develop their core business in the best way while being part of the energy transition.

A strategy directed at a heavy commitment outside the core business may pose a big risk for players, but a "wait-and-see" attitude could also be risky. As a result, a number of companies are widening their business model and trying to build an integrated and balanced portfolio which includes not only oil and gas but increasingly also renewable energy, hydrogen and CCS (fact box *Large integrated European oil firms defining themselves as energy companies*).

Underinvestment in oil and gas
After a sharp growth spurt related to the US "shale revolution", global investment in upstream oil and gas operations has declined substantially since 2014 [27]. According to the IMF [27], this decline is greater than one produced by price fluctuations in a cyclical industry. Although this development could have several causes, the IMF notes that expectations of a rapid energy transition have led to insufficient investment in oil and gas. It calls for greater coordination of climate efforts which balance the growth of renewable energy and new enterprises with the need to maintain oil and gas production into the future.

The energy transition may lead to underinvestment in oil and gas

The energy transition and company adaptations have been identified by several key players, such as the International Monetary Fund (IMF) [27], as one reason for underinvestment in oil and gas (fact box *Underinvestment in oil and gas*).

Large integrated European oil firms defining themselves as energy companies
"In line with developments in the energy markets, large integrated oil companies are defining themselves to a greater extent as energy companies and developing a broader business base to meet changes in these markets. Both the European and American integrated companies have therefore altered their strategies in recent years and are now placing growing emphasis on goals to decarbonise their upstream business. The European integrated companies are also moving into wind and solar" [17].

In the longer term, such an adjustment by players, where they "develop a broader commercial base", could pose challenges for resource management on the NCS. "In order to reallocate equity investment towards renewables, the required return for upstream oil and gas activities has been adjusted up in a number of companies to around 20 per cent, so that these companies ensure through capital rationing that only the investment opportunities with the highest return are realised" [17].

When the oil companies increase their required return, a number of socioeconomically viable projects will not be realised on the NCS. This reinforces a known issue (fact box *Required rate of return*). Resource management will be challenged if players reap from the petroleum sector without reinvesting adequately in profitable measures on the NCS.

Chapter 5

Energy transition opens new opportunities

The NCS is well positioned to meet the energy transition. At the same time, opportunities are being opened to strengthen the value chains in the oil and gas industry as well as in new business activities such as carbon storage, hydrogen production and recovery of seabed minerals.

Energy-market conditions and Russia's invasion of Ukraine have created a new position for production, import and use of energy in Europe. The EU countries have an express goal of making themselves independent of a large proportion of Russian gas exports by the end of 2022. At the same time, Europe faces a challenging energy transition where the EU, like Norway, has ambitious climate targets for 2030 and a goal of climate neutrality by 2050.

At a meeting between Norway and the EU in June 2022, it was emphasised that the NCS will remain a stable and long-term supplier of oil and gas to Europe. The joint declaration on energy collaboration emphasised Norway's special position and the need for both oil and gas deliveries also after 2030: "Recognising that Norway has significant remaining oil and gas resources and can, through continued exploration, new discoveries and field developments, continue to be a large supplier to Europe also in the longer term beyond 2030. The EU supports Norway's continued exploration and investments to bring oil and gas to the European market" [19].

The joint declaration also made mention of a long-term collaboration over hydrogen and CCS: "Noting (…) future potential for cooperation on offshore renewable energy and hydrogen, driven by ambitious EU objectives under RePowerEU Plan, and on carbon capture and storage (CCS)" [19].

Norwegian gas

In order to meet its climate goals, the EU has made a big commitment to such renewable sources as wind and solar power. That contributes to cutting CO_2 emissions, but poses some challenges because this type of energy production is variable. The growth in renewable power calls for energy sources and storage which can interact with variable power supplies. Norwegian gas and regulatable hydropower are highly efficient for balancing variable energy (fact box *Energy production from different sources*).

Energy production from different sources

Norway is the world's seventh largest generator of hydropower and one of the few countries with almost wholly renewable electricity. In most years, it has a surplus of renewable power which is exported to other European countries. Norway and Iceland have the highest proportion of renewable energy in Europe measured by end use.

Gas and oil exports from the NCS totalled about 2300 terawatt-hours (TWh) in 2021 [28] (Figure 5.1). An installed hydropower capacity of 33 gigawatts (GW) generates an annual average of 138 TWh [29] (Figure 5.1). The corresponding figures for wind power are 4.7 GW and 15.4 TWh. In May 2022, the government announced that some 30 GW of offshore wind power is to be developed by 2040, which corresponds to a conservative estimate of 120 TWh per annum.

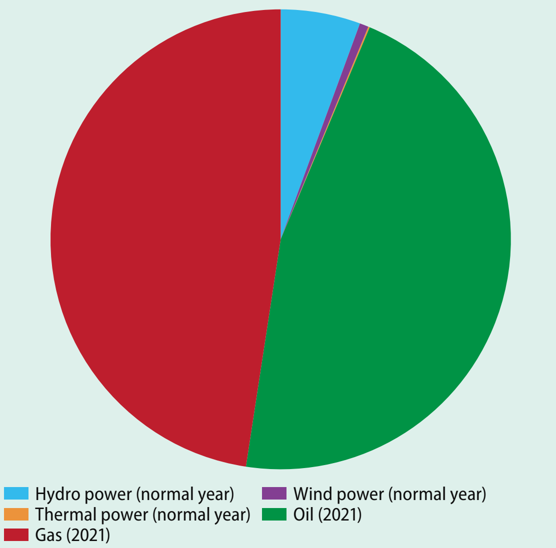


Figure 5.1 Annual production (TWh per annum) for various energy forms* *Based on data from the Norwegian Water Resources and Energy Directorate (NVE) and Statistics Norway. *The energy content of the energy forms is not directly comparable. Using electricity from hydro and wind power is more efficient than from oil and gas.*

A combination of gas and wind power, a high CO_2 price and energy-efficiency enhancements in the UK has led to a substantial drop in coal-fired power generation and cuts in CO_2 emissions. Gas from Norway, Britain's most important supplier of this commodity, has made a big contribution here. Generally speaking, replacing coal with gas and renewable energy represents an efficient way of achieving large, rapid and reasonably priced emission cuts, since gas releases 50 per cent less CO_2 than coal when burnt.

Norwegian gas could play a key role in Europe's energy transition. Investment in gas, under certain conditions, has been defined by the European Commission as sustainable pursuant to the EU taxonomy, a position supported by the European Parliament in July 2022. The taxonomy is a comprehensive scheme for channelling investment in a sustainable direction so that the EU can reach its zero emission target by 2050. Its rules apply from 2023.

From natural gas to hydrogen
Both the UN intergovernmental panel on climate change (IPCC) and the International Energy Agency (IEA) have included hydrogen in their most ambitious scenarios for cutting GHG emissions. In the longer term, gas from the NCS could also be used in combination with CCS for commercial production of virtually emission-free blue hydrogen.

An existing natural gas value chain and a low-carbon value chain based on blue hydrogen have many similarities.

The most important differences are:

- converting natural gas to hydrogen will in many cases require supplies of electricity
- hydrogen plants must have a solution for capture, transport and permanent storage of CO_2
- converting the natural gas transport system to hydrogen will eliminate the risk of methane emissions.

Studies are being conducted by the Norwegian government to determine whether the gas infrastructure on the NCS can, with some adaptations, carry both hydrogen and CO_2 [30]. Reusing the gas infrastructure could help to make the transition to new energy forms cheaper. A coordinated development permits synergies between the various value chains to be exploited. The goal is to ensure that solutions contribute to creating the highest possible value and do not have unfortunate consequences for resource management.

The industry is an active driver in achieving low-emission solutions involving gas, CCS and hydrogen. If these initiatives help to develop a value chain for virtually emission-free hydrogen, demand for gas as feedstock could increase. The government wants to contribute to building a continuous value chain for hydrogen produced with low or no emissions, where production, distribution and utilisation are developed in parallel [18].

Norway has injected CO_2 for storage on the NCS for more than 25 years

CCS
In most of their scenarios, the IPCC and the IEA have included the need for many CCS facilities to meet the Paris goals. CCS involves capturing CO_2 from electricity generation and industry in order to transport and store it securely in deep geological formations. Where Norway is concerned, that means in the NCS subsurface.

Norwegian players have long experience with and good expertise on secure storage of CO_2. This has been done on the NCS in connection with petroleum production since 1996. The intention has been to meet European specifications on CO_2 content in export gas. CO_2 is removed from the gas stream on Sleipner in the North Sea and injected into the Utsira Formation. Similarly, CO_2 from the Snøhvit gas is separated at the Melkøya gas liquefaction plant and returned to the field by pipeline. Figure 5.2 presents historical volumes of CO_2 injected from 1996 to 2020 and forecasts for such injection in 2021-50.

The Norwegian government aims to facilitate socioeconomically profitable CO_2 storage on the NCS. Investigation, utilisation and transport activities for this purpose are governed by the storage regulations [31].

Areas suitable for storage have been mapped by the NPD, resulting in a CO_2 storage atlas for the NCS [32]. The NPD's mapping shows that large quantities of CO_2 can be stored in the subsurface.

CCS on the NCS could contribute to considerably reduced GHG emissions in both Norway and the rest of Europe. CO_2 storage is a precondition for developing a value chain for hydrogen-based gas, which will strengthen the competitiveness of Norwegian gas.

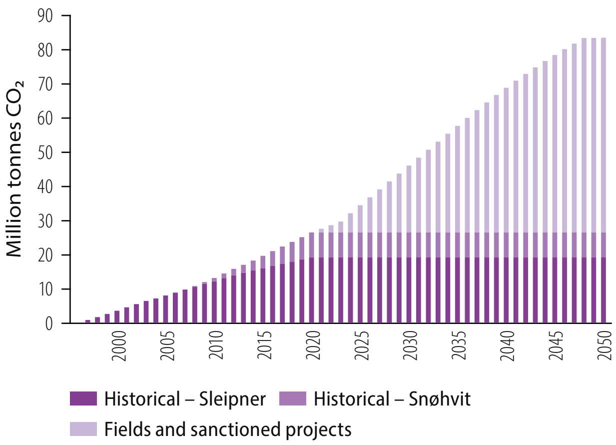


Figure 5.2 Cumulative CO2 storage, based on historical figures to 2020 and forecasts from 2021 *Includes Sleipner, Snøhvit and sanctioned projects at June 2022*

Further development and demonstration of cost-effective technology for capture, transport, injection and monitoring of CO_2 will be required. The main challenge is to develop profitable business models which can contribute to the necessary volume of CO_2 being stored for continued operation of industry and the development of new industrial sectors. This will be demonstrated by Longship, one of the world's first CCS projects developing a complete value chain for capture, transport and storage of CO_2.

Offshore wind power

Developing offshore wind power could become an important market for the supplier industry and yards in Norway. Implementing a long-term Norwegian commitment to offshore wind depends on the availability of large areas at sea. That could involve conflicts of interest between offshore wind developers and the further development of other industries over utilising the ocean space.

The MPE has asked the Norwegian Water Resources and Energy Directorate (NVE) to identify new areas for renewable energy production offshore, and the NPD is participating in this work together with several other directorates. Assessments by this group will underpin proposals for areas which permit good coexistence with other industries, take care of important environmental values, and provide the basis for profitable development. This work is to be submitted to the MPE on 30 April 2023.

Seabed minerals

Globally, the energy transition requires further electrification of society [33]. That could lead to increased demand for minerals required to manufacture such products as electric vehicles, wind turbines, batteries and electrical components. In coming years, greater interest is expected to be shown in exploring for and recovering minerals on the NCS. The NPD is responsible for mapping such seabed deposits.

The government has initiated an opening process for mineral activities on the NCS [34]. As part of this work, an impact assessment will be carried out to identify which effects such an opening could have on the environment and on industry-related, economic and social conditions. This assessment is being implemented in accordance with an established programme. The NPD is supporting work on the impact assessment and coordinating the technical studies.

Over several seasons, the NPD and its partners have acquired data from the deep sea (Figure 5.4), and a map application which shows where these expeditions have been conducted is available on its website. Digital data acquired by the NPD alone or with other institutions were made available in 2022. The published information has attracted great interest.

Figure 5.3 Sulphide sample from the Mohn Ridge *The green mineral is atacamite, which is rich in copper*

Preliminary results show that interesting deposits of manganese crusts and sulphides are to be found on the seabed. Findings from chemical analyses conducted by the NPD include a high content of copper, zinc, cobalt and rare earths (Figure 5.3). During 2022, the NPD is involved in four Norwegian Sea expeditions to investigate the potential further, and work is under way on a resource estimate for seabed minerals. This could open very interesting future prospects for the NCS.

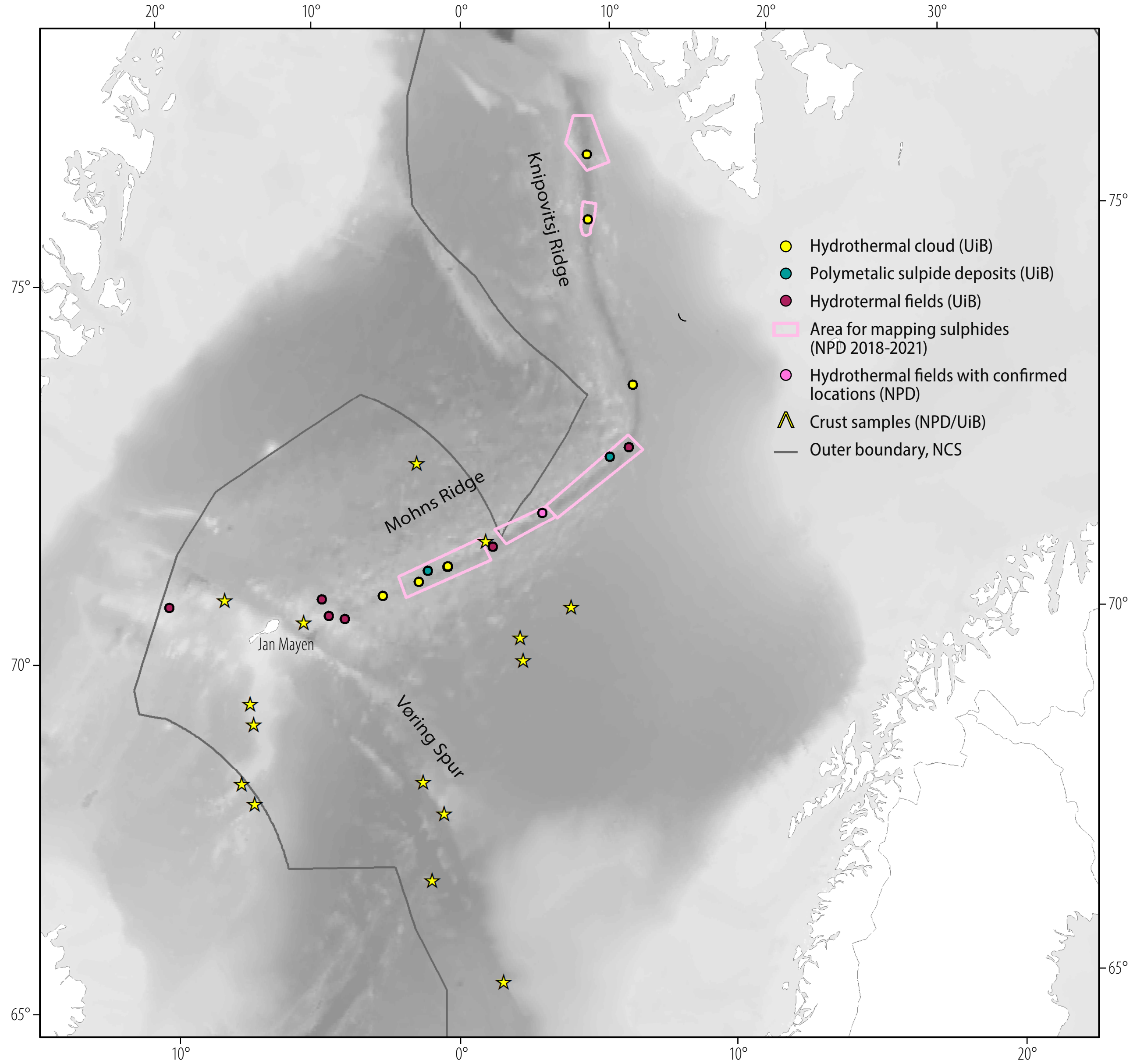
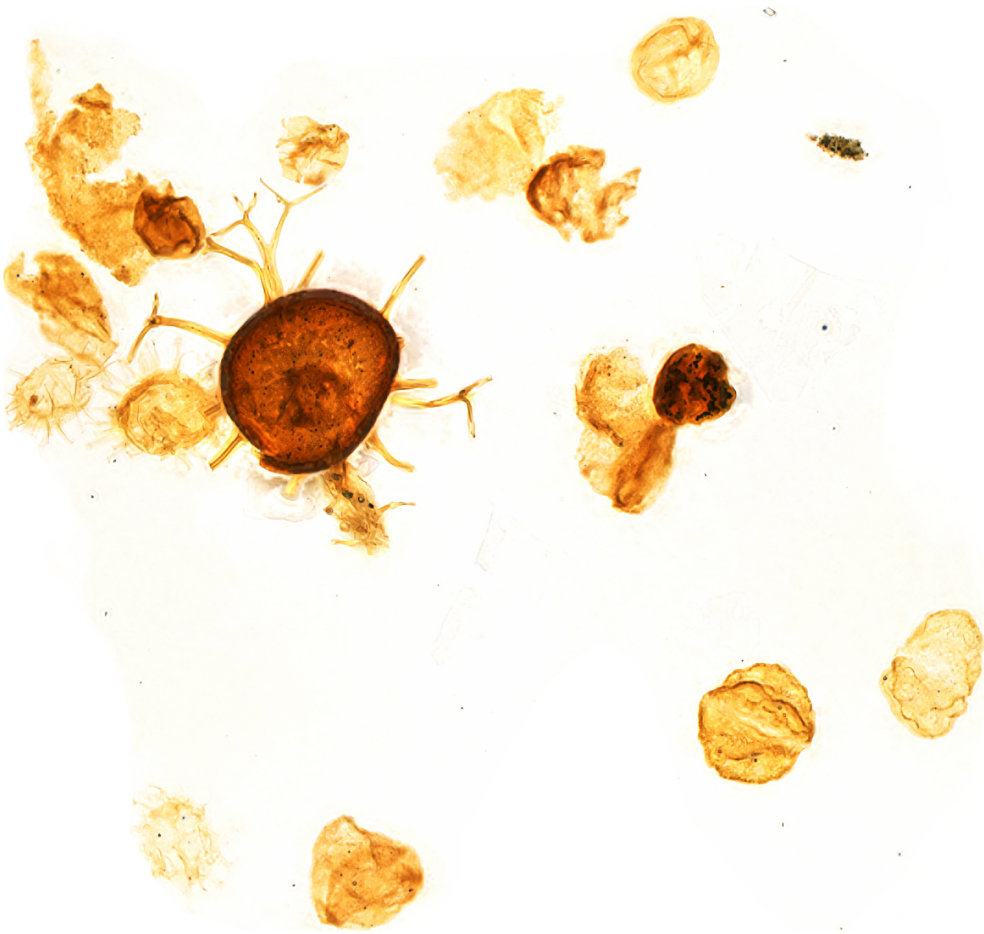


Figure 5.4 Areas investigated for seabed minerals



Chapter 6

Future production and revenues

Uncertainty prevails over the future of both production on the NCS and revenues from the industry. Three scenarios show a substantial uncertainty range for both production and revenues. Purposeful technology development, players willing to invest and successful exploration can increase opportunities for maintaining both production volumes and revenues at high levels.

Background

An important precondition for continued development of the petroleum sector is that Norway has a resource base which can be exploited. The NPD's analysis (chapter 2 Remaining petroleum resources) shows that large resources still exist in all NCS areas. Half the total expected resources have been recovered since production began in 1971. This means that the remaining half can provide the basis for production over several decades. Proportionately more of the oil than the gas has been produced.

Limiting the expected decline in output will be important for maintaining production on the NCS at a high level, contributing large assets to society and providing stable, long-term and secure oil and gas deliveries to Europe. This can be achieved by improving recovery from existing fields, developing commercial discoveries and continuing active exploration of prospective acreage in both mature and frontier regions.

Large resources remain in fields on stream, with a substantial potential for improved recovery which can help to counteract the decline. That calls for investing more than the present level in improving recovery, maturing discoveries already made for development, and keeping down unit costs.

Current forecasts show that a steadily rising share of production in 2030 and beyond must come from undiscovered resources. Much of this growth will be provided by small discoveries. Larger discoveries than those being made today are also needed to slow the production decline. The potential for making large discoveries is greatest in frontier areas and those still not opened for petroleum activities.

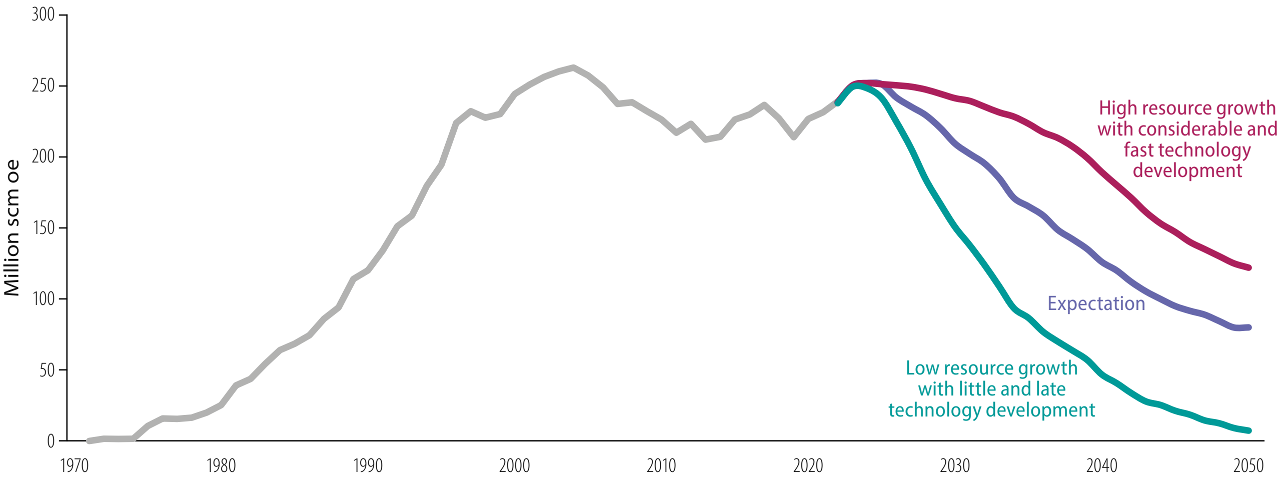


Figure 6.1 Three scenarios for production development on the NCS 2022-50

Three scenarios

Given the challenges and opportunities on the NCS described above and elaborated in chapters 1-5, three scenarios have been developed for oil and gas production off Norway up to 2050 (Figure 6.1).

The starting point is the production trajectory illustrated in Figure 1.1, which represents the government's expectation if today's policies are maintained. In purely methodological terms, this trajectory is determined using data reported by the companies (for the *RNB*) to establish production curves for fields, discoveries and improved recovery. The NPD's estimate for undiscovered resources forms the basis for forecasting production from new discoveries. Random drawing is used to determine the order of discoveries, with a bias for larger discoveries to be drawn before smaller ones.

Each scenario incorporates assumptions for exploration activity, success rates and lead times. All three pictures assume the same market development. For technical calculatory reasons, future real oil and gas prices of USD 55 per barrel and USD 5.85 per metric million British thermal units (MMbtu) respectively are assumed for 2030-50. An NPV (seven per cent before tax) is calculated for discoveries, and only projects with a positive NPV are included.

Corresponding profitability assessments are made for discoveries, fields and improved recovery to provide a production trajectory up to 2050 for each scenario. The pictures will vary with regard to the properties of the resource base, exploration activity, and the strength and speed of technology development.

Expectation

The *Expectation* scenario envisages exploration at its present level for the early years, followed by a decline over time. Such activity will largely occur in known areas close to infrastructure. Production on the NCS more than halves from 2025 to 2050. Development of new discoveries and projects for improved recovery are not on a scale which succeeds in countering the production decline from fields on stream. Most new discoveries brought on stream are developed as satellites to existing infrastructure. The fall in production, combined with investment in low-emission solutions, mean that the sector reaches its goal of net zero emissions by 2050.

Gas as a proportion of total production has been rising over time, and will continue to do so. Since the industry is efficiently run, new production capacity on the NCS will be almost entirely competitive on a global basis.

More than a halving of production from 2025 to 2050 will reduce the industry's significance in the Norwegian economy, both as a growth engine and as a source of government revenue.

Low resource growth with little and late technology development (Low)

The *Low* production trajectory illustrated in Figure 6.1, is below the government's *Expectation*, with the resource potential in fields, discoveries and undiscovered resources failing to be realised.

More dry wells are drilled, with few new discoveries, during the early years, and exploration activity stagnates over the coming 10-20 years. The industry downgrades its expectations of the resource potential on the NCS and declares itself satisfied with what has been achieved, and reaps from the investment made. Exploration declines sharply and eventually ceases, few new discoveries are developed and very few improved recovery projects are initiated.

Investment on the NCS virtually ceases, leading to sharply reduced production and lower value creation in relation to the potential for revenue and value creation offered by the resource base. The decline in exploration, development and production has major negative effects, both direct and indirect, for several mainland industries delivering to the petroleum sector. That means a substantial increase in the need for restructuring over coming decades.

High resource growth with considerable and fast technology development (High)
The *High* production trajectory illustrated in Figure 6.1 exceeds the government's *Expectation*. This is because it incorporates additional opportunities offered by fields, discoveries and exploration. The forecast falls well within the uncertainty range in the NPD's estimate of remaining resources on the NCS.

New discoveries are made rapidly along *High*, with several large ones in frontier areas. Gas discoveries are made in the Barents Sea and quickly developed. The logic is based on the McKelvey box [35] (Figure 6.2). which illustrates how market conditions, technology development and exploration activity contribute to converting undiscovered and non-commercial resources into proven and commercially recoverable assets. Unforeseen resources are also included in the figure, reflecting the way drilling can lead to surprises in both mature and frontier areas as a result of encountering unexpected resources. See fact box *Surprises* in chapter 2 Remaining petroleum resources and the *Resource report exploration 2020* [5].

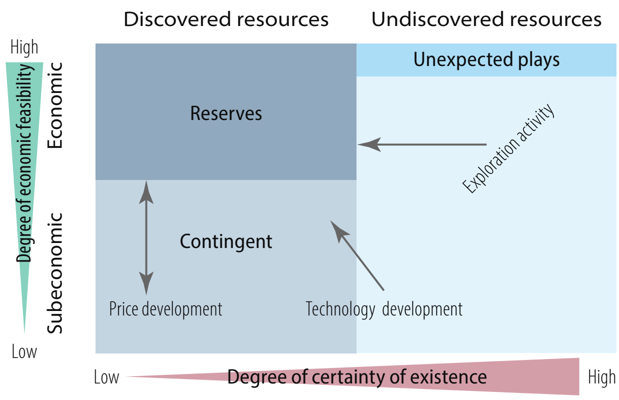


Figure 6.2 Modified McKelvey box

Historically, a tendency has been seen to underestimate how increased knowledge of the subsurface, technological progress, amendments to operating parameters and changes to market conditions, as well as surprises, contribute to resource growth and higher production. This is shown for the development of reserves and production forecasts in Figure 3.16 and Figure 6.3 respectively. The forecasts have been conservative and adjusted in line with developments on the NCS [36].

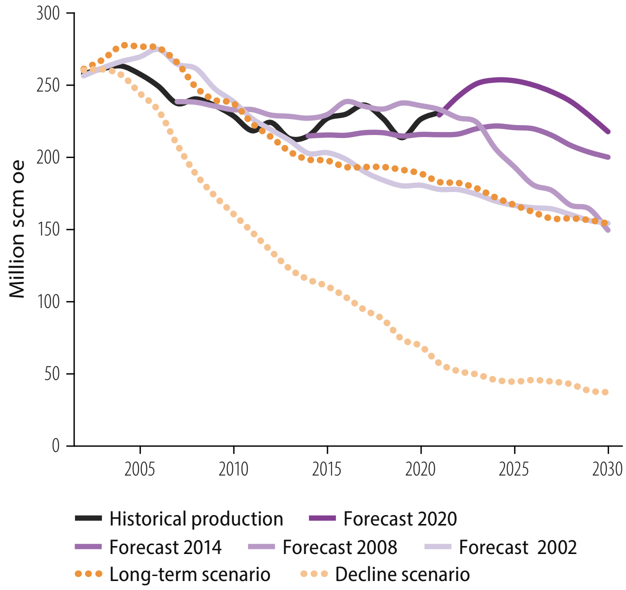


Figure 6.3 Forecasts for future production *The long-term development and depletion trajectories from Report no 38 (2001-2002) to the Storting on oil and gas activities. NPD forecasts from the RNB.*

In this scenario, the NCS sustains its position as an attractive petroleum province, and the government and the industry contribute to maintaining exploration activity, technology development and profitable production for a long period (Figure 6.1). Increased production helps to secure long-term oil and gas deliveries to Europe.

The industry will also be expanded gradually to include the new value chains such as CCS and hydrogen. In addition, commitments are made to seabed minerals and floating wind farms. Technological development is pursued and investment made in low-emission solutions, so that the sector's transition goal of net zero emissions in 2050 is reached.

Coordinated development makes it possible to exploit synergies between the various value chains. Reusing gas infrastructure and establishing large-scale solutions for CO_2 transport and storage simplifies developing petroleum value chains to also incorporate blue hydrogen. Further development of petroleum value chains by integrating hydrogen and CCS represent important technological advances which will benefit the rest of the world. At the same time, this helps to maintain the value of Norwegian gas as Europe and the rest of the world switch their attention from natural gas to hydrogen.

Price sensitivities

To address the uncertainty range for future revenues, a sensitivity analysis has been carried out with prices equal to +/- 50 per cent. Low prices have been used with *Low* and high prices with *High*. The effect of the various price sensitivities on future revenues is illustrated in Figure 6.4. This shows that developments in prices, exploration activity, resource growth and technological progress can contribute to a considerable uncertainty range for future net revenues from activities on the NCS.

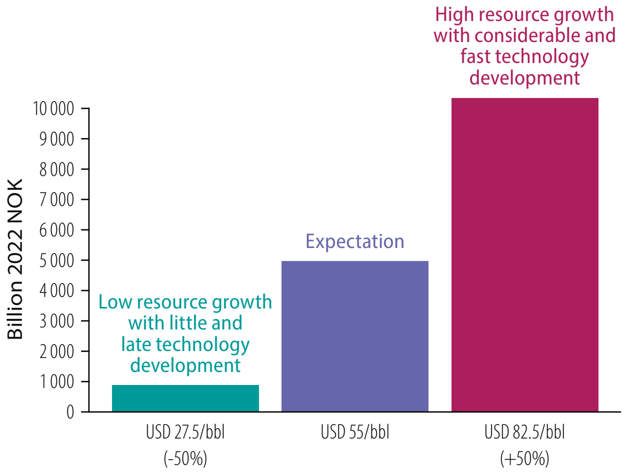


Figure 6.4 Net revenues from 2023 to 2050 in the three scenarios combined with low (-50%) and high (+50%) prices

Different scenarios – different leeways

All three scenarios show a fall in production over time, but the pace of this decline will differ. In 2050, production in *High* is at the same level as the early 1990s and near zero for *Low*.

The production decline will depend on developments in the world at large, the resource base and exploration activity as well as the strength of technological progress. How these factors develop may produce substantial differences in future production and in Norway's role as a long-term exporter of oil and gas to Europe. That could lead to substantial differences in future government revenues from petroleum operations.

Measures for increasing resource growth and keeping unit costs low could be crucial to future production and revenues for society. At the same time, existing petroleum value chains must be further developed to also embrace CCS and hydrogen as well as seabed minerals. A high level of exploration, purposeful technology development and active players can enhance the chances of success.

Conversion tables

	1 scm of oil	=	1 scm oe
	1 scm of condensate	=	1 scm oe
	1 000 scm of gas	=	1 scm oe
	1 tonne of NGL	=	1.9 scm of NGL = 1.9 scm oe

Gas	1 cubic foot	1 000 British thermal unit (Btu)
	1 cubic metre	9 000 kcal
	1 cubic metre	35.3 cubic feet

Crude oil	1 scm	6.29 barrels
	1 scm	0.84 tonnes oe (toe)
	1 tonne	7.49 barrels
	1 barrel	159 litres
	1 barrel/day	48.8 tonnes/year
	1 barrel/day	58 scm/year

	MJ	**kWh**	**TCE**	**TOE**	**Scm natural gas**	**Barrel crude oil**
1 MJ, megajoule	1	0.278	0.0000341	0.0000236	0.0281	0.000176
1 kWh, kilowatt hour	3.60	1	0.000123	0.000085	0.0927	0.000635
1 TCE, tonne coal equivalent	29 300	8 140	1	0.69	825	5.18
1 TOE, tonne oil equivalent	42 300	11 788	1.44	1	1 190	7.49
1 scm natural gas	40.00	9.87	0.00121	0.00084	1	0.00629
1 barrel crude oil (159 litres)	5 650	1 569	0.193	0.134	159	1

1 Ministry of Finance, 2022: *Macroeconomic indicators for the petroleum sector, 2022.* Source: https://www.norskpetroleum.no/en/economy/governments-revenues/ (Downloaded: 01.06.2022)

2 Gassco, 2020: *Evaluation of gas transport alternatives in the Barents Sea South*

3 Norwegian Petroleum Directorate, 2020: *Resource report exploration 2020*. Fact box 1.1 Resource classification

4 Norwegian Petroleum Directorate, 2016: *Resource report exploration 2016*

5 Norwegian Petroleum Directorate, 2020: *Resource report exploration 2020*

6 Norwegian Petroleum Directorate, 2019: *Resource report 2019 – discoveries and fields*

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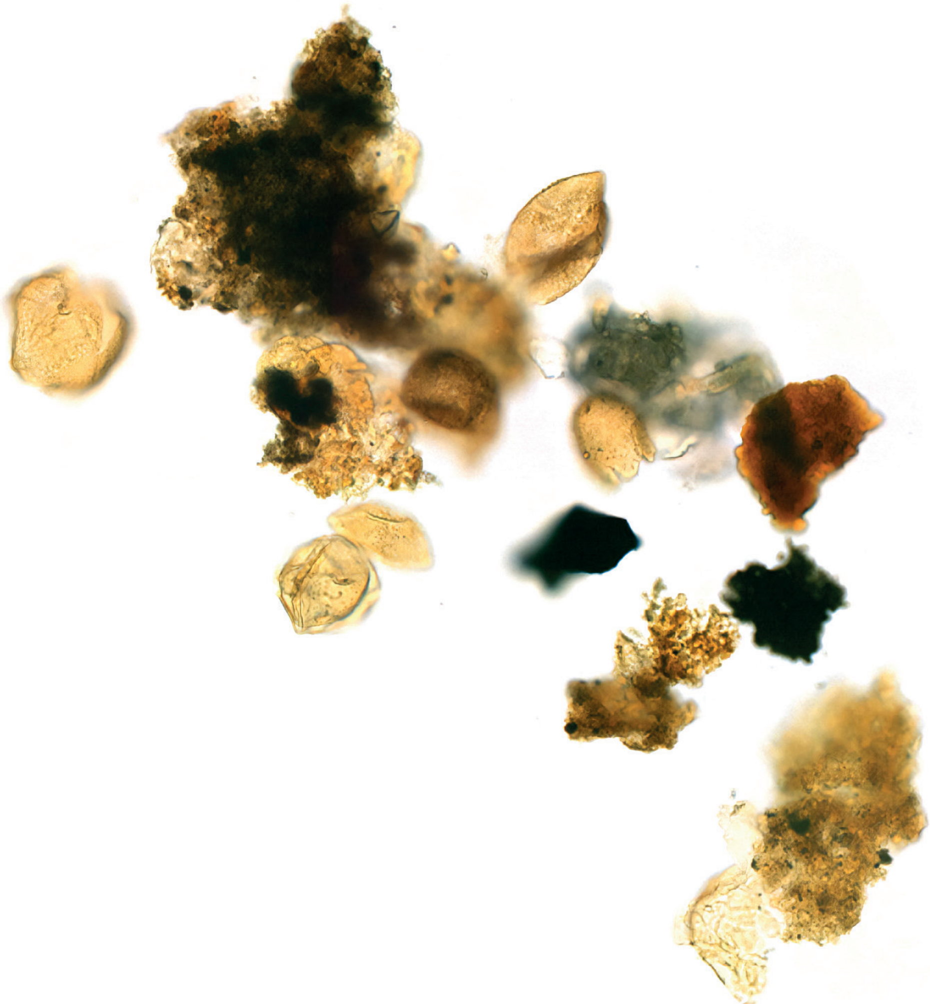

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